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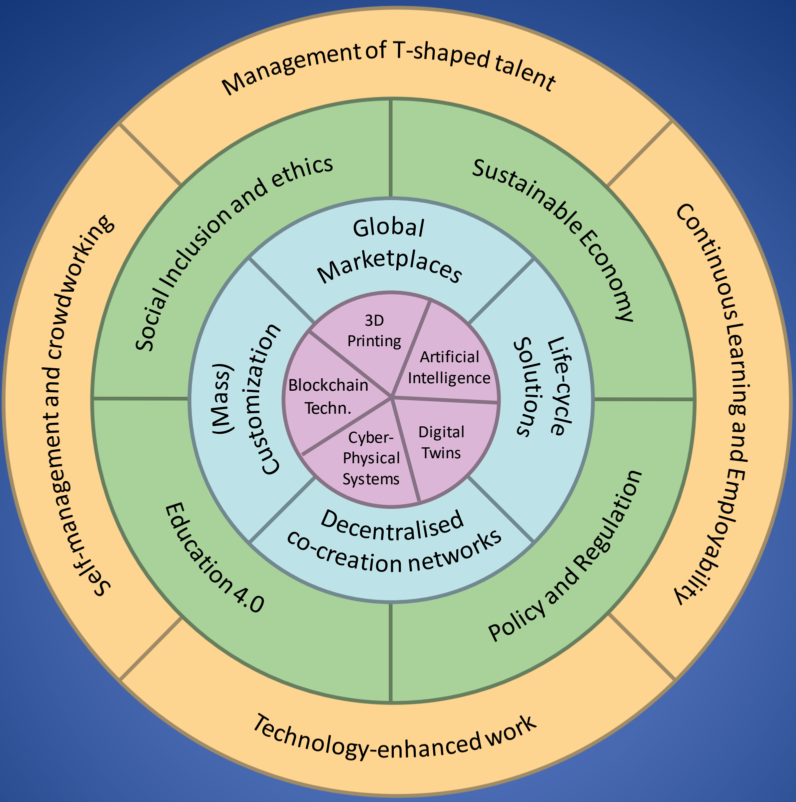

BMS Smart Industry Research Roadmap

BY THE INDUSTRY WORKING GROUP OF

UNIVERSITEIT TWENTE.

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HRM (Human Resource Management) 76
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NIKOS (Department of Entrepreneurship, Strategy & Innovation Management) 78
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The main tasks of the IWG are: to define the research strategy and agenda for the coming 10-15 years for the theme INDUSTRY, and to conduct community forming activities.

Next to the IWG, a smaller Consultative Group has been formed with experts from the faculty which have been consulted and informed about the IWG activities.

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LIST OF ABBREVIATIONS AND TERMS

AI - Artificial Intelligence
BMS – Behavioural, management and social sciences
I4.0 – Industry 4.0
IoT - Internet of things
IWG – Industry Working Group
SIRM - Smart Industry Roadmap Model
SME – Small and Medium Enterprises
UT – University of Twente

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EXECUTIVE SUMMARY

Domain challenges

The fourth industrial revolution, also known as Smart Industry (the Netherlands), Industry 4.0 (Germany) and Advanced Manufacturing (United States), is in full swing. The vision of decentralized business processes consisting of autonomous yet interconnected units along global value chains is about to become reality. The use of cyber-physical production systems holds the potential of raising customer satisfaction through individualized products, while increasing productivity and resource efficiency. Currently, industry and research are working closely in field labs and smart factories to develop these cyber-physical production systems through digital applications, smart machinery, sensor technology, intelligent robots, and manufacturing concepts for globally interconnected value chains.

Along with the new digital technologies and the bright vision regarding their potential business and sustainability benefits outlined above, many concerns and worries also arise about their implications for individuals and society as a whole. Will we be having a production without humans and how will our society handle the risk of increasing job losses? Are large IT companies controlling our data? Will we deplete our natural resources even more as result of an increased and more efficient production? Will companies ever mange implement circular business models in a structural way? How do we avoid increasing the technology gap between the global north and the global south? These questions reveal that the 4th industrial revolution is not only a technological but also a societal challenge that requires a responsible "human touch" approach for understanding and controlling the driving forces behind the "high-tech". Furthermore, since most I4.0 technologies are still in the phase of innovation triggers or have just reached the peak of inflated expectations, their societal and environmental benefits need not just to be declared but also to be proven in the years to come.

Scientific contribution

As part of a university that carries the motto 'High Tech, Human Touch', the Faculty of BMS in the University of Twente is uniquely positioned to engage in research on the origins, developments and consequences of this digital transformation of the economy and society. The Faculty consists of various departments that focus on business processes, human resources, information systems, communication sciences, policy studies, sociology, economics and the philosophy of science. Through the combination of these sub-disciplines and its connection to the engineering-oriented faculties of the University of Twente, the faculty of BMS can proactively anticipate and explore different possible scenarios (revolving around critical societal challenges), explain and predict (and teach about) the consequences of smart industry for systems of production, management, and governance.

As result of several workshops, numerous exchanges of ideas, and literature research, three major focal areas have been identified as target of BMS strategic research for the coming years: Business, Society, and People (see the figure below). We refined each of the focal areas into several sub-areas that reflect both the research interests of BMS researchers, and the information we collected on I4.0-related industry needs. Next, the most important research questions to be addressed per area are mentioned.

Business:

- How to govern platform markets such that both platform leaders as well as complementary organisations/individuals can capture value?
- What are the organisational implications of servitization? What cultural changes are needed?
- What is optimal balance between economies of scale (e.g., costs of production line reconfiguration) and customisable features?
- How does the configuration of value chains change due to new technology and how can collaboration be improved?

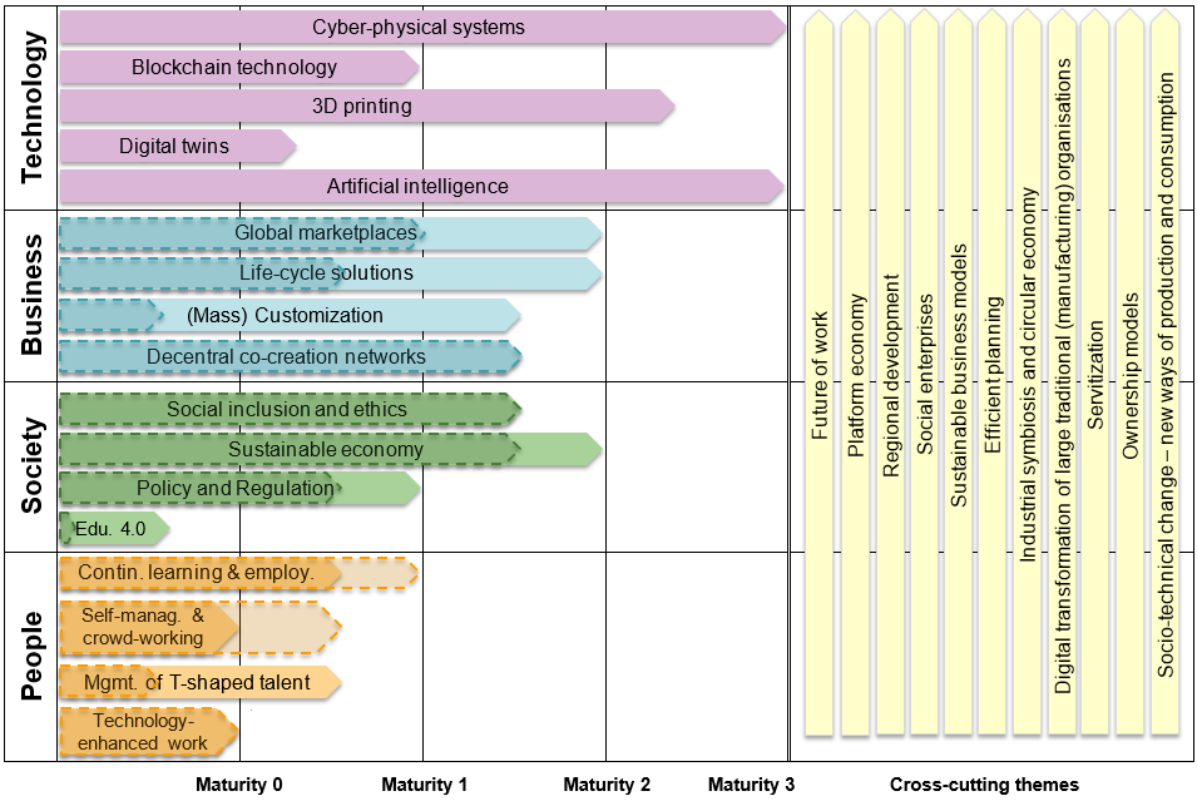
- How to maximize the localization (i.e., decentralisation) of production, through sustainable planning, e.g. by selling designs instead of products (and use 3d printing to organize the production locally)?

Society:

- How to develop new education plans and programmes tailored to I4.0?
- How can we avoid the expansion even further of the digital divide between the people with and without technology-driven education?
- To what extent the current regulatory and legal frameworks have to be changed and extended to cope with the transformations imposed by I4.0, in the areas of data ownership, protection and privacy, liability, work?
- How to design marketplaces and closed loop supply chains to foster industrial symbiosis and to support the exchange of waste into fuel, by reusing products, components or materials in the manufacturing sector?

People:

- In what way does the nature of work change jobs in I4.0 and what does it imply for the employer-employee relationship?
- In what way do jobs need to be designed to structure work to allow for decentralized decision-making and self-management among workers?
- In what ways can workers take responsibility for their own retraining and employability?
- In what way can organizations develop HRM systems to attract, develop and retain T-shaped talents?



Societal impact

The societal impact of BMS' strategic research in the area of smart industry is explicitly incorporated in the roadmap model we put forward by design. Society is, next to Business and People, one of the core focal areas of the roadmap. In particular, we expect that smart industry research will also have a great impact on multiple aspects of society ranging from the way organizations and individuals behave in relation to waste, to the education of a future generation of workers, to considering societal needs when developing new technology, and in general, to new policies and regulations. With our research we aim at having an impact on:

- **Sustainable economy**: through our research aimed at novel ways the manage the production, distribution, trade and consumption of goods in a manner which promotes reduction of waste and efficient use of resources, we address important sustainability concerns. Our vision is that organizations can make use of sustainability-driven management systems, sensor technology and big data analytics in order to ensure the achievement of such efficiency objectives and industrial symbiosis, and the development of a circular economy.

- **Policy and regulation**: We argue that one critical aspect for all the smart industry technologies is that they deal with large amounts of data of organizations and individuals which need to be shared and handled in a responsible, and secure way. Therefore, our research will address the development of new policies and regulations, together with standardization in areas, such as sustainable production and consumption, data sharing & management, and interoperability of systems and organizations within the global value chain.
- **Education 4.0**: With the introduction of new technologies, processes and practices, the workforce of the future needs to be educated within a fundamentally new type of education system adequately tailored to smart industry needs. Understanding how to create the institutional context to support the development of and migration to this new type of education, while focusing on how to shape professionals that master 21st century skills, is part of our research program.
- **Social inclusion and ethics**: In this respect we intend to explore the ways in which we can steer this technological transformation in an inclusive manner, in order to anticipate and avoid at an early stage the risks, and challenges of excluding (large) groups of people from the gains of the socio-technical transformation (e.g. due to the digital divide).

Infrastructure

- ***Funding schemes***: in the next 5 years, several national and EU programmes are providing funding for Smart industry projects relevant to the research interests of the BMS faculty. A few examples are: Erasmus+ Strategic Partnerships, Smart Anything Everywhere, INNOSUP programmes, Duurzame Living Labs, Commit2data, Perspectief programma, Interreg spatial and regional development programmes.
- ***Relevant disciplines***: Operations Research, Management Science, Artificial Intelligence, Behavioural science, Production and Logistics Management, Data Science, Entrepreneurship, Supply Chain Management, Predictive maintenance, e-Commerce, Business and Data Analytics, Human Resource Management, Policy and Regulation, Education Sciences, etc.
- ***BMS groups working together:*** the BMS groups are working together in both developing new educational programmes and also on research projects. As an example, IEBIS and NIKOS are collaborating on a research project on the servitization of SMEs which is closely related to Smart Industry since it requires integrated processes, networks and a high level of digitalization
- ***External alliances:*** The BMS groups have close collaborations with the Fraunhofer institute and other research groups from other faculties such as EWI (e.g., Pervasive systems), and ET.
- ***Research methods***: interviews, case studies, survey questionnaires, systematic literature reviews, quantitative bibliographic landscaping.
- ***Technologies***: Portable audio recording and processing setup, Work stress and mindfulness measurement devices, Audio transcribing software, Collaboration and brainstorming software, Big Data and Smart Sensor Technology, Artificial Intelligence, Multi agent systems, Cloud Infrastructure, IoT platforms, System Integration technologies/platforms, Advanced man-machine interfacing, User profiling, Machine learning, etc.
- ***Data management issues***: All collected data which includes personal or sensitive information about people and organisations is/will be stored on the servers of the BMS lab which are compliant with the current EU and Dutch data policies and regulations.
- ***Relation to education programmes***: Many of the existing BIT, IBA and IEM courses can be extended with knowledge, research results and case studies relating to I4.0 and its impact on business innovation, society and people. Several steps in this direction have already been taken. As an example, BMS is involved in the development of an Industry 4.0 minor programme, together with other faculties, and there are also first ideas for a dedicated master. Moreover, several BSc, MSc and PhD assignments have already been formulated based on research questions relating to Smart industry.

1 INTRODUCTION

1.1 Smart industry vision and expectations

The fourth industrial revolution, also known as Smart Industry (the Netherlands), Industry 4.0 (Germany) and Advanced Manufacturing (United States), is in full swing. The first industrial revolution used water and steam power to mechanize production, and craft production was in many cases replaced by central factory production. The second industrial revolution was made possible due to the electrical motor, enabling industry to enter a period of standardised mass production. In the third industrial revolution, digitalisation and robotization enabled the automation of repetitive activities and led to completely new products and markets.

Now a fourth industrial revolution, building on the third, is taking place. Smart Industry is pushing digitisation beyond information flows by focusing on the digitisation of physical assets and systems by creating a digital identity for them (e.g., through “digital twins”), and subsequently by integrating them into complex digital ecosystems that span over infrastructures, systems, processes, people, organisations, and value chain partners and have impact on society as a whole. Thus, generating, analysing, and communicating data seamlessly (through a network of a wide range of new technologies, see Figure 1) underpins the potential benefits promised by Industry 4.0 (I4.0) to create value.

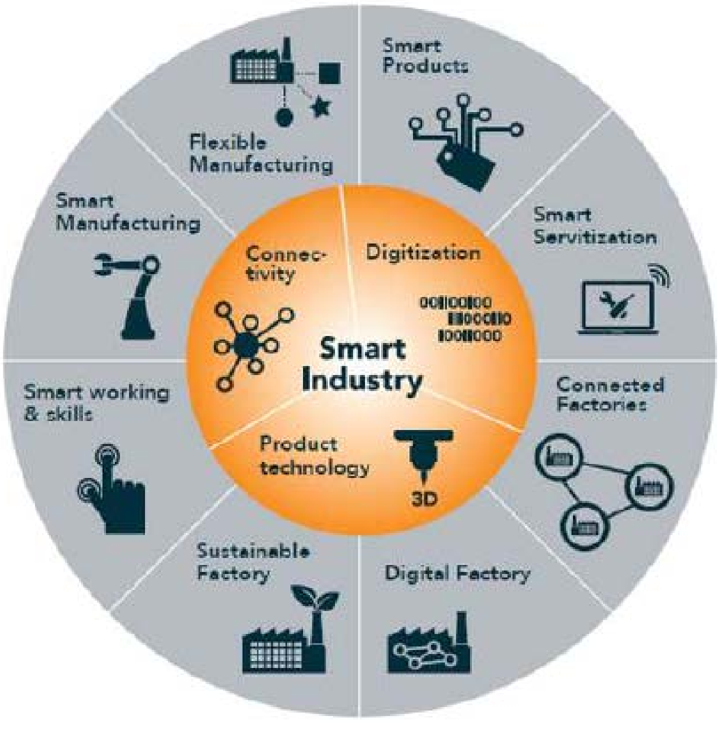


Figure 1: Smart industry wheel, according to the Research agenda for HTSM and ICT

The vision of decentralized business processes consisting of autonomous yet interconnected units along global value chains is about to become reality. The use of cyber-physical production systems holds the potential of raising customer satisfaction through individualized products, while increasing productivity and resource efficiency. Currently, industry and research are working closely in field labs and smart factories to develop these cyber-physical production systems through software applications, smart machinery, sensor technology, and manufacturing concepts for globally interconnected value chains.

New technologies from fields such as artificial intelligence (AI), robotics, the Internet of things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing will fundamentally alter how we do business, the way we live, work, and how we relate to one another. The digital manufacturing processes and the smart industry built on these technologies hold the promise of yielding faster, cheaper and more sustainable production. Smart industry will enable on-demand production (mass customization) and wholly new products. It will have far-reaching consequences for productivity, employment, skills, working environments, income distribution, trade, well-being and the environment. In its publication "The Next Production Revolution. Implications for governments and business", the OECD states: "Indeed, it is difficult to mention a major area of policy that will be unaffected"[1].

The implications of connecting global value chains go far beyond 'simple' technical links. Applying and implementing digital technologies will erode established industry structures and traditional supply chains, which will be gradually replaced by business ecosystems, (global) marketplaces and platforms. We can already observe that new actors and actor constellations emerge. Some years ago, it was not imaginable that companies like Amazon would take over a crucial role in industry as provider of the largest platform for company data around the world. This also holds for other IT companies, extending their value proposition with specific applications and infrastructure for traditional industry sectors. I4.0 is also interesting from a customer and client's perspective since co-creation of highly individualised products will be the driving force for smart manufacturing. Because of its demand driven focus, of the wide availability of data, and technology (Figure 1), and of robotization / automation (robots and software agents will take over more routine and repetitive work) the planning and execution of business processes will become more efficient and production will become increasingly sustainable (e.g., due to reduction of waste, better resource (re-)utilisation, localisation of production and thus less logistics, etc.).

Along with the new digital technologies and the bright vision regarding their potential business and sustainability benefits outlined above, many concerns and worries also arise about their implications for individuals and society as a whole. The 4th industrial revolution is not so much a technological but rather a societal challenge that requires a responsible "human touch" approach for understanding and controlling the driving forces behind the "high-tech". Furthermore, since most I4.0 technologies are still in the phase of innovation triggers or have just reached the peak of inflated expectations (see Gartner's hype cycle - Figure 3), their societal and environmental benefits need not just to be declared but also to be proven in the years to come.

As part of a university that carries the motto 'High Tech, Human Touch', the Faculty of BMS in the University of Twente is uniquely positioned to engage in research on the origins, developments and consequences of this digital transformation of the economy and society. The Faculty consists of various departments that focus on business processes, human resources, information systems, communication sciences, policy studies, sociology, economics and the philosophy of science. Through the combination of these sub-disciplines and through its connections to the technology-oriented faculties of the University of Twente, the faculty of BMS can proactively anticipate and explore different possible scenarios (revolving around critical societal challenges), explain and predict (and teach about) the consequences of smart industry for systems of production, management, and governance.

We do not know yet how the transformations driven by the fourth industrial revolution will eventually unfold, as they are interconnected across sectors and involve multiple stakeholders at various levels. Nevertheless, some of the questions that can be studied in the coming years by the colleagues in our faculty are identified in this roadmap. They are about production systems and businesses processes, about the role and place of workers and about the wider societal consequences in terms of income and wealth distribution, as well as the potential sustainability benefits that I4.0 may induce. All in all, we believe that, building on its unique position and strengths, the faculty of BMS should seize the opportunity to work on a better understanding of the origins, nature and impact of the fourth Industrial revolution. More precisely, the BMS should address, on the one hand the challenge of finding solutions

[1] OECD (2017), The Next Production Revolution.

for critical societal challenges (such as sustainable production, smart and green transport, or increased resource efficiency), and on the other hand seize research opportunities for transformative business innovations enabled by smart technologies. These have also become priorities of the EU, of many national and local governments, and also of the region of Twente, where our university is located.

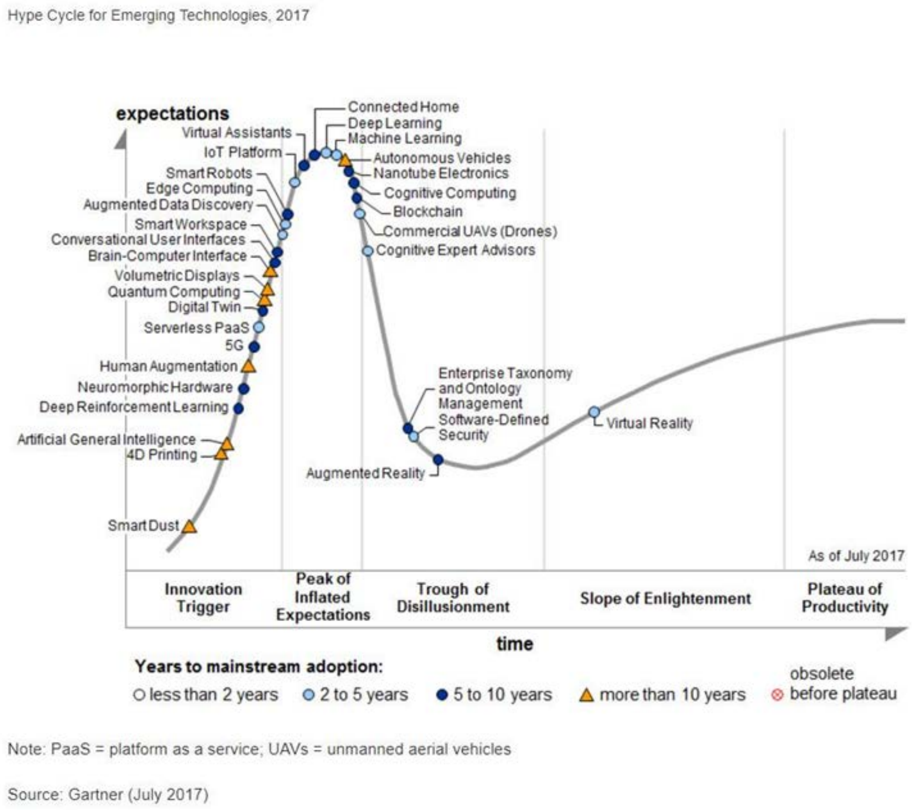


Figure 2 - Gartner's hype cycle for emerging technologies

1.2 Goal and principles

The goal of this document is to develop a BMS-specific strategic research agenda for the coming ten to fifteen years for the theme Industry 4.0.

It should be noted that since I4.0 is a rather broad (and to certain extent overhyped) new topic, it is far from being an established field with clear research directions, well defined theoretical foundations, and paradigms. Therefore, our main focus at this time (perhaps in contrast with the other BMS themes) was rather to identify, motivate and clarify focal areas with potential for BMS research, than to devise a very precise timeline, and specific activities (e.g., concrete research projects / programs) for the coming years. Later versions of this document may include those as well, if we will succeed in establishing a community around the IWG, consisting not only of researchers, but most importantly of industry, policy makers and other societal actors.

Similar to the approach of the other working groups (e.g., Learning), the following four principles have been followed throughout the creation of this roadmap.

- ***Inclusiveness*****:** We have encouraged the participation of all interested BMS colleagues in both the working group and the activities organised by the group. As such, the Industry working group is probably the largest one within BMS, with 11 active members and seven additional consultative members.

- ***Strategic alignment*:** Through the vision defined in this roadmap we aim to complement and align with other smart industry initiatives in the wider University of Twente community (UT). Following this line of thinking we have established strong ties with UT's Industry 4.0 Consortium and participate in their events and program development efforts. Also, it should be noted that while research within the other UT's engineering faculties is focusing primarily on technology development, the research program implied by our roadmap is primarily concerned with the social and societal implications of the adoption and implementation of technological innovations.
- ***Innovativeness*:** Our roadmap will stimulate ground-breaking research. Unlike the other BMS research themes (Learning, Health, Resilience and Emerging Technologies & Society), which to some extent rest on a consolidated and established body of research, our working group is starting from more of a green field situation, as the very concept of smart industry/I4.0 has been introduced about four- to five-years ago. On the basis of the bibliographic research we have carried out, we conclude that only a relatively small number of scientific publications that focus explicitly on I4.0 can be found in both the academic literature (4.834 documents), and in the BMS scientific output (7 documents). One of our most important findings after conducting this roadmapping activity is that the I4.0 research is currently dominated by research focusing on technology development and innovation, while social science research regarding the implications of I4.0 for people and society is very much lagging behind. This situation offers a great opportunity for us to engage in novel and ground-breaking research in the above-mentioned field, but also points at the strong time dependency between such research and the existence of an actual technology transfer processes. A reason for this dependency is the fact that an important part of social science research measures, explains and proposes interventions concerning the effects of innovation adoption and its implementation in organisations and society. In the case of I4.0 such research is to a large extent still just starting, as I4.0 technologies are in an emergent phase and have not yet reached the maturity needed for adoption and implementation.
- ***SEP-enabling*:** The strategic research areas identified in this roadmap have the potential of scoring high on the Standard Evaluation Protocol (SEP) criteria (e.g.: research quality, relevance to society, viability. Thus, topics such as the future workspaces in the smart industry era, education 4.0, efficient planning and execution of cyber-physical business processes, organisational digital transformation, and technology driven/digital business model innovations, etc.). They are not only unexplored territory but are also addressing important societal challenges, such as social inclusion, sustainability and natural resource depletion, etc.

1.3 Focal areas

From our bibliographic analysis one conclusion comes very strongly forward: at this time most of the academic community is focusing on the high-tech, i.e., the development of I4.0 technology, in particular IoT, artificial intelligence, cyber-physical systems, smart factories and on pushing its adoption by the industry. Far less attention has been paid to the exploration of the impact such technologies have individuals, organisations, society and environment. BMS is uniquely positioned to contribute to the human-touch aspects of I4.0 by focusing on three areas on expertise, namely business, society and people. With this in mind, we organised several workshops, and brainstorm sessions, in order to refine and validate our research scope. The results of these workshops have led us to create the Smart industry roadmap model, as detailed in Section 3, which contains the following three layers:

- *Business*: From integrated supply chains to global supply market
- *Society*: Impact of Smart industry on sustainability, policy and regulation, education, and social inclusion
- *People*: The future of learning and work

In the remainder of this document we refine and analyse the three above-mentioned themes from several perspectives, and finally to project them onto a rough timeline, while showing some interdependencies and relationships between them.

1.4 Structure of the document

This document is organised as follows: the introduction is providing some background information concerning the I4.0 theme and the goal of this document. Chapter 2 provides an overview of the methods used to collect and analyse the data that lead to the definition of this roadmap. Chapter 3 describes the smart industry roadmap model forming the very core of this document. The goal of each of the following chapters (4, 5, and 6) is to analyse in detail each of the layers of the proposed model (i.e., people, business and society) from the perspective of the current state of the art, and the main research topics and core problems to be addressed in future research. The role of Chapter 7 is to provide an integrative and systemic view on the whole roadmap, by identifying major cross cutting concerns, interdisciplinary research areas, and eventually by concretely defining an integrated roadmap based on a so-called "heat-map" analysis of the different parts of the roadmap. Additionally, overviews of current/past I4.0 flagship projects of the BMS, links to our education programs and of most important outlets (conferences and journals) publishing I4.0 research are provided. Chapter 8 is surveying other I4.0 UT initiatives, while Chapter 9 is giving an overview of other national and EU programs and agendas. We conclude this chapter with an overview of funding opportunities, organisations, and schemes and some conclusions regarding the type of research that is likely to be funded in the near future (two to five-year horizon). The document ends with conclusions, and some pointers to future work of the IWG.

2 APPROACH FOR DEVELOOPING A SMART INDUSTRY ROADMAP FOR BMS

2.1 Methods used

In order to define the BMS Smart industry roadmap, we have used a series of methods aimed at generating a converging BMS-specific I4.0 vision in a structured manner. These methods have been used for generating ideas from within the working group and the BMS faculty (inside-out), as well as from other faculties and industry (outside-in). The results were combined in order to create a balanced roadmap that is specific to the BMS faculty, but also reflects the needs and opinions of external actors. Additionally, we have performed a quantitative analysis of the state-of-the-art[2] for both international and BMS publications, on the topic of smart industry. By comparing these two results, we could discover which research areas would give us a competitive edge, i.e. they are a good match to the research profile of our faculty and/or they are either currently not extensively researched, or in which we are already at the forefront of scientific research.

2.1.1 World Café

The World Café is a very interactive method of research, which has a simple, effective and flexible format for organising large group discussions. This method is characterised by participants being divided into several groups which are seated around a table, with several brainstorming aids, such as flipcharts, sticky notes, markers, etc. Each of the tables has a specific topic/theme that is covered, with groups moving from one table to another after each round. When changing tables, the groups can either move together to a new table, or participants can change group while making sure that they visit a table they have not visited before. Both versions have been used during the World café's we organised. The main benefit of ad-hoc groups is that you interact with new people during each round, which can generate new ideas easier. However, the main benefit of staying together as a group is that you do not hear the same ideas or arguments multiple times from different people, since the whole group knows everything that has been said before.

The total number of rounds is determined by the number of tables, in order to ensure that every participant is able to experience a round discussing about each topic. In our case, the tables reflected the three themes, and in some cases, Smart industry technologies. Typically, a round takes 30 minutes, as it is considered a sufficient amount of time to discuss a topic without losing the interest of the participants. However, there are also variations to this which involve the first round being allotted a larger amount of time, with the following ones being given less time. The main reason for choosing such a setup is that each group would have generated a lot of ideas during the first round, and therefore, a second group would only need to complement these ideas and not start from scratch. During our World Café's we have chosen for the second option with uneven amounts of time. The feedback received from our participants confirms that this is the preferred option.

It is also customary to have a moderator at each table which ensures that the discussion is kept on track and that notes are being taken of the most interesting ideas. Additionally, the moderator can also have a set of questions prepared for the participants in order to kick-start the discussion. After the last round,

[2] Pease note that since we used the Scopus database and English terminology as source of keywords for formulation of queries, our bibliographic analysis is primarily focusing on literature published in English, while we are aware that a significant number of publications have been published in German. Despite the language barrier, BMS' future I4.0 analyses and research should also take this literature into account, as Germany is the place where I4.0 has recently emerged, and the chance is high that I4.0 research in Germany still is a step ahead of international research.

the results of the group discussions are gathered and integrated by the moderators of the tables in a way that can facilitate a plenary discussion. For our World Café's we chose to have a moderator for each table, which also documented the most interesting ideas with the help of sticky notes.

The plenary discussion can have several different objectives. For example, it can be used as an opportunity for reflection on the discussions which have taken place at the tables. This can help with identifying relationships between the topics that were not possible when discussing them in isolation at the different tables and can even inspire new ideas from the participants. Another objective of the plenary discussion can be to prioritize the different ideas which have resulted from the tables, with the help of a voting system. This can help gain a better understanding of the potential of the ideas which have been generated and discussed during the rounds. On separate occasions, we have used both approaches for the plenary discussion since we had different objectives in mind. In one instance, we wanted to determine which are the most important topics relating to the three themes and Smart industry technology. In a second instance, we used these prioritised ideas to determine if there are any connections between them, and what these connections might be. An overview of the different instances in which we have used the World Café method can be found in Table 1.

2.1.2 Quantitative bibliographic landscaping

A systematic literature review helps provide an overview of topics that have already been covered, and it can also highlight potential areas for research. It is a method that is based on a replicable, scientific and transparent protocol. Therefore, all the choices made need to be detailed in a manner that can be easily reproduced by another researcher, and often includes information, such as which queries have been made, which databases have been used, what filters have been applied, and how the final selection has been made.

For our purposes, we have created several queries which have been used to search the Scopus database. We have chosen to use Scopus above other databases since it quite comprehensive in its coverage of journals and conference publications, and because it allows the export of results in a CSV (Comma separated values) format, which include additional details about the publications, such as keywords, references, etc. We have chosen not to add restriction to language, year, type of publication, in order to get an as complete overview of publications as possible. However, it should be noted that since we used the Scopus database and English terminology as source of keywords for formulation of queries, our bibliographic analysis is primarily focusing on literature published in English, while we are aware that a significant number of publications have been published in German. Despite the language barrier, BMS' future I4.0 analyses and research should also take this literature into account, as Germany is the place where I4.0 has recently emerged (4-5 years ago), and the chance is high that I4.0 research in Germany still is a step ahead of international research.

For our roadmap, we have selected to create four large queries, as follows:

- For the overarching theme of Smart industry, we have used three keywords which are used interchangeably ("smart industry" OR "industry 4.0" OR "smart manufacturing"); This has resulted in 4.834 documents;
- For the three chosen themes we have used keywords which have been mentioned during the workshops and world café's, in combination with the three aforementioned keywords for Smart industry, to ensure that we include only results which are relevant for our roadmap; More details about these queries and their results can be found in Section 4 (business), Section 5 (society), and Section 6 (people).

To further reduce the reviewer basis, which is often a concern when refining the results of such queries, a bibliometric analysis can be performed that does not depend on the knowledge or preferences of the reviewer. There are several bibliographic analyses which can be used, such as Co-occurrence, Citation analysis, Bibliographic coupling, and Co-citation, each with their own purpose. Co-occurrence ca be used to identify the clusters of topics which are researched and their relationships, with the help of author keywords and indexed keywords. Citation analysis reveals the most influential publications/journals and conferences in a disciplinary area defined by query terms. Bibliographic coupling clusters recent papers but fewer old papers, which makes it useful for identifying research trends, while Co-citation does the exact opposite, by being unable to cluster recent papers that have not yet been cited.

There are several approaches which can be used to identify and visualise these results. We have chosen to use the Visualization of Similarities (VOS) approach since it also includes a free and well-documented software application (http://www.vosviewer.com). The software combines optimization and clustering algorithms to visualize the relative distance between items, which reflect the level of the similarity between reference lists. Furthermore, it generates a network of lines which represent the connections between keywords/articles, with possibilities to adjust the size of clusters, the importance of items, to group items which are synonyms under one label, etc.

We use the results of the aforementioned four queries in VOS viewer to generate several network maps which illustrate aspects, such as number of occurrences for a specific keyword, which other keywords it is linked to and how strong are these links. With the help of these network maps, we could identify current research areas, represented by clusters of research, in relation to our three themes, in the context of Smart industry. Thus, we could compare the results we obtained from the workshops and world café's conducted internally with the research that has already been published internationally in order to validate our roadmap and also to identify potential gaps. The results of these analyses can be seen in Sections 4, 5, 6, 7 in which we discuss in more detail the three themes and their integration.

However, these results reflect the state-of-the-art on a global level. In order to obtain the publications which have been produced by the BMS faculty, we have created an extended query. This query includes the last name of all the academic staff within BMS, combined with all the keywords from the three themes. This has resulted in 10098 documents. Similarly, we have used VOS viewer to visualise the results and have used them to make a comparison between the state-of-the-art generated by the BMS faculty and the publications at a global level. Additionally, we could identify if there are under-researched areas, which the BMS faculty would be uniquely qualified to address. Section 7.3 contains the results of this comparison.

2.1.3 Survey questionnaire

A survey is a method which can be used to collect opinions and ideas from respondents in a structured manner. The main advantage of using a survey questionnaire, compared to the aforementioned methods, is that it takes a rather little effort to set up, it can be easily distributed online, and can reach a broader audience in a short amount of time. It is especially useful when contacting respondents which do not have time to take part in a workshop/World Café or to be interviewed, but which can spend 5-10 minutes to provide their opinions on a specific topic.

We have chosen to create and distribute a small survey in order to gather more insight into the kind of priorities organisations have relating Smart industry, and also to understand what types of issues they are expecting to experience or currently experiencing regarding Smart industry. This kind of information ensures that our envisioned roadmap considers the reality of the industry. We have chosen to distribute our questionnaire to several groups including: the list of participants which were invited to the second workshop, the list of contacts and customers of PNO, and several LinkedIn groups on the topic of Smart industry. The results of the questionnaire are detailed in Chapter 7.

2.2 Conclusion: inside-out and outside-in

We conclude this section by providing an overview of all methods employed during the roadmap development process and of the artefacts in which they resulted.

Table 1: Inside-out and outside-in approaches for the definition of the BMS Smart industry roadmap

Inside-out		
What?	**How?**	**Results**
First workshop and World Café	World Café and Brainstorming	The selection of the three themes: New business models, Sustainability, The future of work
Round table discussions following the BMS conference	Brainstorming	Further refinement of core research questions falling under the three themes
Second World Café together with Industry 4.0 consortium	World Café	Identification and prioritization of topics related to the three themes and of main technologies for Smart industry
Retreat	Brainstorming	The definition of “THE SMART INDUSTRY ROADMAP MODEL” v1.0
Analysis of BMS research on Smart industry	Bibliographic analysis	Conceptual maps (in the form of a network visualisation) of the key terms used within the BMS publications
Second retreat	Brainstorming, Writing	Integrating all the results so far. The consolidation, improvement and final drafting of the Roadmap document.
Outside-in		
What?	**How?**	**Results**
Externally moderated second workshop and World Café	World Café and Brainstorming	Validation of inside-out results with the help of UT colleagues outside of the working group and with members from industry; workshop report provided by PNO. “THE SMART INDUSTRY ROADMAP MODEL” v2.0
Survey about Smart industry	Questionnaire	Top priorities and concerns of organisations relating to Smart industry
Site visits, participation in other workshops and Industry 4.0 events	Meetings and exchanges of ideas	Gathering information on the experiences and strategic orientations of industry and other research organisations (e.g., Fraunhofer, IBM’ IoT Lab, TUM, etc.[3])
Analysis of international research on Smart industry	Bibliographic analysis	Conceptual maps (in the form of a network visualisation) of the key terms used within international publications
Overview of universities and organisations with EU funded projects	EU project database queries (PNO)	Insight into the universities and organisations which have received funding from the EU for projects relating to I4.0 (Supplement 5)
Funding possibilities	Selection based on relevance to the SIRM (PNO)	Insight into the upcoming calls for projects at EU and national level

[3] Visit to IBM IoT Lab Munchen (Erwin Hofmann); Visit to TU Munchen Center for Technology in Society (Katrin Hahn); Participation in Digitising European Industry Stakeholder Forum – EU Comission (Katrin Hahn); Participation in Arbeit 4.0 conference (Anna Bos-Nehles); participation of several IWG members at Fraunhofer’s workshop “Industry 4.0 - Impact on Manufacturing” and CTIT “Digitisation” workshop

3 THE SMART INDUSTRY ROADMAP MODEL

All industrial revolutions started with the development of new ***technologies*** in support of production, which allowed for efficiency gains. Subsequently, firms had to adopt them, and adapt their ***business*** models, since they would not be able to withstand more efficient competitors. Gradually, ***society*** also had to change as result of the adoption of such new technologies on a large scale, and of the impact new business models had on economy at a macro level. This had important consequences for ***people***, as they had to adjust to a new way of working, of being educated and of living, in order for them to be able to respond to the needs of a more modern economy and society. We observe the exact same pattern emerging now in the context of the 4th industrial revolution. Therefore, we followed this line of reasoning to structure our Smart Industry Roadmap Model (SIRM). In the remainder of this section the SIRM is introduced. It should be noted that we provide here just a brief definition of the focal areas included in the model, while in the following chapters we will extensively discuss all the parts of the model in more detail: Chapter 4 (business), 5 (society), 6 (people) and 7 (the whole model).

As result of several workshops, exchange of ideas and literature research, four major focal areas of change have been identified as target of BMS strategic research for the coming years: technology, business, society, and people (see the four layers of the onion model shown in Figure 3). Each of the focal areas is further divided into several sub-areas that reflect both the research interests of BMS researchers, and the information we collected on I4.0-related industry needs. Next each of the sub-areas is described.

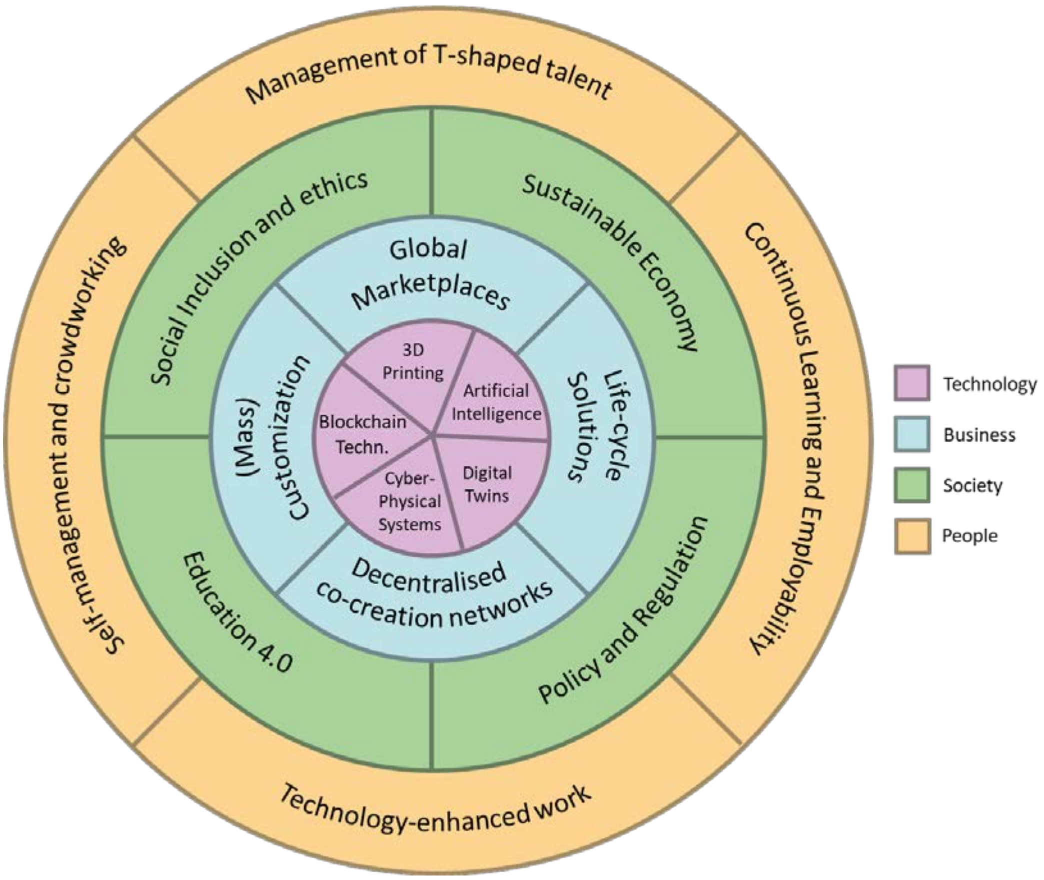


Figure 3: The SMART INDUSTRY ROADMAP MODEL - different aspects of the three focal areas: business, society, and people

I4.0 technology

As mentioned before, the fourth industrial revolution is fuelled by many different technologies which have a multitude of applications in different areas of society, business, and people. For example, autonomous cyber-physical systems became possible due to advances in the sensor technology and to some extent in the advances in robotics, in order to link the digital to the physical world. For instance, a variety of new transportation devices are available, from small automated guided vehicles in a factory to unmanned cargo aircraft or even robots – unmanned robot-driven cargo vessels. The following are examples of technologies which are driving the fourth industrial revolution, which were identified as important by the participants of Second World Café, conducted together with the Industry 4.0 consortium (see Table 1). For a comprehensive list of Smart industry technologies, please refer to Figure 4.

- **Cyber-physical system**: mainly based on advances in sensor technology, the connection between the physical world and the digital world becomes possible, as physical signals are transformed into data.
- **Digital twins**: Devices can have a "digital twin", which is a technology allowing to represent the physical object as a digital replica of itself. The digital twin will reproduce all key properties, real-time state, components of the physical object. The digital twin can be used, for instance, to run simulations and to analyse the interactions between different systems involved in a process. A digital twin may also incorporate some form of artificial intelligence and ability to learn and make improvement recommendations based on context/sensor data.
- **Blockchain technology**: relies on distributed ledger technology, which essentially means that many nodes or even the entire network stores all relevant data, ensuring maximum transparency. A key relevant feature of a blockchain is that many servers along one chain redundantly store all data. Data security and nonrepudiation is increased, because all chain members are able to verify the activities of their peers.
- **3D printing:** with additive layer manufacturing physical objects are designed and produced in a decentral fashion by transferring the digital plans to a 3D printing unit which then creates the physical object.
- **Artificial intelligence** and machine learning are actually not new. They have been around for more than four decades. However only now, due to the availability of huge volumes of data it is becoming increasingly critical to develop techniques that can cope with such volumes while is extracting knowledge from data in (quasi) real time and using it to improve the execution and planning of future and in progress business processes. Furthermore, machine learning is increasingly used to improve the abilities of robots and software agents to take decisions and to interact with/learn from humans.

Most of these technologies are also identified at the European and the Dutch government levels. The EU has identified 3 technologies for I4.0. These are: advanced manufacturing processes, mechatronics for advanced manufacturing systems, and information & communication technologies. The Dutch government has identified: Robotics and sensors; Big data; High Tech Systems and Materials, and ICT-infrastructure and cybersecurity as the technologies where most of the investments are needed.
Another avenue to explore when looking at technology enablers is to look at the different fields in which I4.0 will have the most impact. Thus, in Industry 2.0 the biggest impact was on production lines in general and the automotive sector in particular. In Industry 3.0 the biggest impact was on manufacturing and the digitization of business processes. However, digital technology also influenced media and the retail sector. The third industrial revolution also meant new jobs such IT specialists, logistics experts and designers. The fourth industrial revolution will also influence businesses and society in different ways.

In the action agenda BOOST, they have identified several areas where I4.0 will potentially disrupt the current state of affairs and bring new innovations. The areas they identified are the automotive sector, the aerial- & space sector, food industry, agricultural sector, health care, energy sector and waste management. However, no explicit distinction between sectors has been made in the SIRM model, although this could potentially be an important issue to address as challenges may greatly differ from one industry to another, even if the supporting I4.0 technology is similar. For example, the issue of personal data protection is of the utmost importance in healthcare, whereas cost efficiency and safety is far more important in the automotive sector.

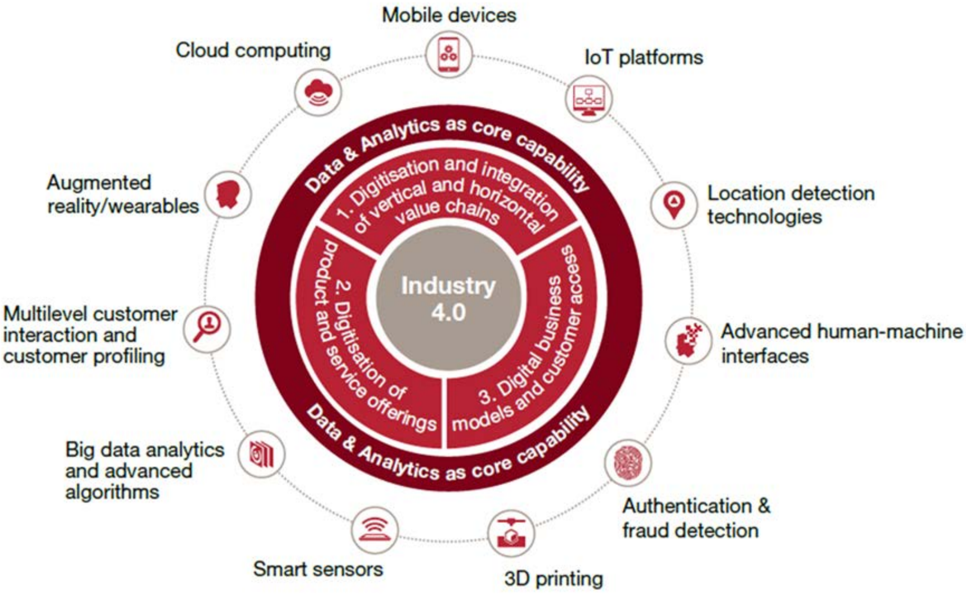


Figure 4: Industry 4.0 technologies[4]

<u>Business</u>: From integrated supply chains to global supply market

Smart industry will have a great impact on the types of business models organizations will employ. Many of these changes will be reflected in the way they create value, the type of value they offer to their customers, and the way they interact with other organizations. We consider the following aspects as important business developments relating to Smart industry:

- **Global marketplaces**: moving from the traditional supply chains to flexibly configured marketplaces which are more suited to serve a new generation of customers, but also to enable stronger and agile collaborations between organizations. New types of marketplaces can emerge which are centred around a sharing platform / economy in which transactions are done via online marketplaces rather than peer-to-peer.
- **(Mass) customization**: this represents the next evolutionary step in the way organizations offer their products to customers. While personalized offerings with some level of customization have become a standard for many industries, with the help of flexible computer-aided and additive manufacturing systems, organizations are able to combine the low cost of mass production with the intricacies of individual customization.
- **Decentralised co-creation networks**: refers to a new paradigm in which groups of organizations are no longer organizing themselves with the help of a central entity or control tower, but rather they take part in ecosystems in which functions and responsibilities are distributed. As a result, organizations and cyber-physical systems operating in such ecosystems are expected to function and interact autonomously, while still retaining the same level of coordination, which in some cases manifests itself as emergent behaviour. Additionally, I4.0 facilitates organizations to seamlessly integrate with each other in order to co-create highly customized offerings. It is expected that I4.0 may also lead to completely new business models driven by technological innovations.
- **Life-cycle solutions**: organizations are moving from offering a product to their customers to offering a series of services and solutions to address a specific customer problem/need. This entails that a customer will no longer purchase or own a product, but rather they would pay for the service of using it. For providers of such solutions/services, this means that they need to maintain and update them throughout their whole lifecycle in order to ensure that they remains relevant for their customers.

[4] https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf

Society: Impact of I4.0 on sustainability, policy and regulation, education, and social inclusion

Similarly to business, we expect that Smart industry will also have a great impact on multiple aspects of society ranging from the way organizations and individuals behave in relation to waste, to the education of a future generation of workers, to considering societal needs when developing new technology, and in general, to new policies and regulations. We consider the following aspects as important societal developments relating to Smart industry:

- **Sustainable economy**: the production, distribution, trade and consumption of goods in a manner which promotes reduction of waste and efficient use of resources. Organizations can make use of sustainability-driven management systems and big data analytics in order to ensure the achievement of such efficiency objectives and industrial symbiosis, and the development of a circular economy.
- **Policy and regulation**: one common aspect for all the Smart industry technologies is that they deal with large amounts of data of organizations and individuals which need to be shared and handled in a responsible, and secure way. Therefore, new policies and regulations need to be developed, together with standardization in areas, such as sustainable production and consumption, and interoperability of systems and organizations within the global value chain.
- **Education 4.0:** with the introduction of new technologies, processes and practices, the workforce of the future needs to be educated within a fundamentally new type of education system adequately tailored to I4.0 needs, and focusing on shaping professionals that master 21st century skills.
- **Social inclusion and ethics:** observes and discusses risks of excluding (large) groups of people from the gains of the socio-technical transformation. At the same time, it explores the ways to steer this technological transformation in an inclusive way, which helps to anticipate the risks, and challenges, already at an early stage of the technological development.

People: The future of learning and work

As it can already be seen from the previous two focal areas (business and society), the role of people as workers and consumers will be heavily impacted by I4.0. Therefore, changes are expected in the way workers are trained, organized, managed and in their interactions with new technology. We consider the following as important I4.0-related workforce developments:

- **Continuous learning and employability:** refers to the voluntary and ongoing pursuit of knowledge with the purpose of self-development for personal or professional reasons. It raises the question of how workers are trained in order to prepare them for jobs in Smart industry (on-the-job training vs formal education).
- **Self-management and crowd-working:** an organizational structure which reduces/removes the need for direct supervision due to the formation of teams which are empowered and able to work autonomously. At the same time, independent individuals may feel the need or prefer to offer their services on digital platforms in the gig economy[5].
- **Management of T-shaped talent:** the type of human capital needed by organizations in an era of Smart industry is predictably different than before. The nature of work often requires workers to have a different set of skills, acting as T-shaped professionals, who have boundary-crossing competences next to a deeper functional understanding.
- **Technology-enhanced work:** one of the distinctive aspects of Smart industry is the way workers are expected to interact with machines. Workers are expected to be enhanced by technology to perform tasks (enabled workers), while others interpret and organize the information provided by technology for decision-making and problem-solving purposes (knowledge engineers).

[5] "In a gig economy, temporary, flexible jobs are commonplace and companies tend toward hiring independent contractors and freelancers instead of full-time employees. A gig economy undermines the traditional economy of full-time workers who rarely change positions and instead focus on a lifetime career." Source: https://www.investopedia.com/terms/g/gig-economy.asp

4 **BUSINESS**: FROM INTEGRATED SUPPLY CHAINS TO GLOBAL SUPPLY MARKETS

The ongoing 4th industrial revolution produces new challenges and opportunities to existing firms and entrepreneurs. One of them is rethinking or designing of completely new business models that enable them to thrive the industrial revolution by exploiting novel ways to create and capture value through servitization and other co-creation practices in supply chains, and eco-systems. More concretely, the development of new strategic concepts and business models should harness digital technologies, such as, Artificial Intelligence, Big Data analytics, Internet of Things, (Mobile) Sensor Networks, Neuromarketing, 3D printing, Virtual / Augmented Reality etc. Given this scope, the uncertainties, and complexities at hand, there is a need to understand how entrepreneurs and existing firms deal with these challenges in their efforts to design sustainable new business models or transform existing ones.

4.1 Problem statement and research questions

Industry 4.0 will connect workers, machine components, products and services, and logistics, through a continuous exchange of data. The machines and objects will be given a digital “identity” throughout their lifetime, (e.g., made possible by means of sensors and actuators and digital twins), and the ability to communicate and inform “intelligence”.[6] Thus, from a mere digitalisation and automation of business processes in I3.0, I4.0 moves to autonomous systems, which also link to the physical world. I4.0 is therefore expected to influence the way organisations create value by changing their processes, the kinds of technologies used, and the involvement of humans in these processes. Additionally, the value propositions offered to customers are expected to be highly customisable and modular, with new products and services offered based on data collected from connected devices[7]. Therefore, we expect that Smart industry will have the following impacts on business:

A. The shift from tightly coupled supply chains to **global marketplaces** and/or business ecosystems
B. **Life cycle solutions** and servitization instead of finished products
C. **Mass customization** and personalization instead of standard mass production
D. Value **co-creation** with customers and/or within **decentralised** business ecosystems

A. Global marketplaces

One of the effect of a large scale of block-chain technology adoption, could be that it enables fully transparent value systems leading to new technology driven business model opportunities. Transaction costs would shrink, trust and safeguards would become a less important concern (as it would be guaranteed by design) and new value propositions might exploit the information about (and generated by) the actual status of a product’s components. Therefore, the shift (observed already since I3.0) from integrated (transaction/production)-cost optimising factories, to networked enterprises will accelerate. Subsequently, as transparency increases, and transaction costs diminish, business models built around a tightly connected supply chain will be gradually replaced by competence-based networked models, or by more open, marketplace like value co-creating systems. In such models autonomously negotiating systems can flexibly reconfigure their supply planning systems depending on the demand.

[6] https://www.unido.org/sites/default/files/2017-8/REPORT_Accelerating_clean_energy_through_Industry_4.0.Final_0.pdf
[7] https://repository.tudelft.nl/islandora/object/uuid:3177d804-06d5-455c-a508-87222c1d602a/datastream/OBJ/download

Platform markets are a key example of these competence-based models. “Platformization” of the economy is an important and disruptive phenomenon for incumbent firms. Not less than 70% of the “unicorn” companies are platform companies.

We distinguish between two major streams of such models. In the *market as intermediary stream*, the platform enables a marketplace, creating market efficiencies in two-sided markets. In this stream, the market platform provides the medium for connecting supply and demand and establishes and exploits market power. For the *platform as ecosystem stream*, the platform is a set of shared core technologies and standards underlying an organizational domain, and supporting value co-creation through specialization, and complementary offerings. This stream is the broadest and most heterogeneous and it draws on a variety of theoretical perspectives, including industrial community, economic externality, and resource dependence perspectives.

In this field multiple related questions exist that require scholarly attention and a cross disciplinary ‘systems view’ that is so typical to the UT. Whereas the systems engineering literature explains how to design product platforms and achieve their intended benefits, such as faster product development and higher degree of customization, other important questions prevail on how to align these platforms with the business (ecosystem) model. For example:

- What competitive strategies work best in platform markets?
- How to govern platform markets such that both platform leaders as well as complementers can capture value.

B. Life-cycle solutions

One of the most important trends triggered by I4.0 in recent years concerns servitization, which essentially entails the shift of traditional manufacturing companies from the delivery of finished (physical) products to selling the service that product is fulfilling. One of I4.0’s visionary scenarios is that in the future due to servitization no finished product is going to be sold, but rather a solution to a problem, which may continuously be updated during its lifetime, thus creating a so-called life-cycle solution. One the most common servitization examples is “lighting-as-a-service”, in which manufacturers of light bulbs, such as Phillips, stop selling them. Instead they sell “lighting”, meaning that they will take care of the management of the lighting infrastructure (lamps, light bulbs, led lighting, wiring, light and movement sensors, etc.) of a building, while remaining owners of it. Light management would entail not only the timely maintenance of this infrastructure, but also the provisioning of personalised lighting services made possible by the IoT technology installed in the serviced building (personalised smart apps for adjusting the intensity or colour of light, for energy management, for monitoring performance of the system, for coupling the lighting of certain rooms to the schedules/movements of their users etc.).

This example is illustrative for the essence of the concept of servitization, which in the context of I4.0 goes far beyond “product-service” combinations. I4.0 servitization consists of a form of an integrated product-service solution called product-as-a-service”, in which the physical product is owned by the provider, does not deliver any value to the total offering and doesn’t require any technology to be added to the service. Thus, the product is merely used as a means to be able to deliver the service. The usage of the product is sold, not the product itself. The implications of this form of servitization are various and far-reaching.

For the customers, the most valuable implications of the Product-as-a-Service concept are the unburdening of responsibilities and the limitations of risk. Now that the provider will remain owner of the product and will take care of everything that is necessary to use the product, the customers can be fully unburdened and the risks (of for instance value loss, broken products or constant product innovation) are limited. Furthermore, the user is controlling the design and service levels of the delivered service.

For the business, the benefits could be the complete control of the physical products throughout their lifetime, which also means the possibility to design implement a very efficient lifecycle management, and predictive maintenance for the provided solutions. In I4.0 terms, for lifecycle solutions it becomes possible to link real-time performance data to lifecycle management (e.g., for predictive maintenance). For example, a digital twin will reproduce all key properties, real-time state, components of the physical product and can be used to assess whether a certain component is due for replacement/servicing.

Another consequence of lifecycle solutions is the fact they inherently assume a longer term and close involvement with the customer, which may mean business stability and predictability, and customer intimacy for the business. Finally, Product-as-a-Service lifecycle solutions also make possible the actual implementation of another paradigm: the circular economy (see Figure 8). Companies following a lifecycle solution model do not get paid for the product that they sell, but for the function this product has. This fundamentally changes the way in which companies look at production. As they only get paid for the function, companies will be motivated to think about how they can make their products as cheap, as durable and as economic as possible, instead of as many and as expensive as possible. They will do this, so that they can deliver the function of the lifecycle solution for a very low production cost and thus maximize the revenues from the recurring fee customers pay for the service. At the end of the lifecycle, instead of throwing the product away (and losing its total value), companies will now reuse as much of the product as possible and create a new product so that it (the material) can enter another lifecycle. Thus, only very limited resources get wasted.

If we add another level of complexity to the concept of Product-as-a-Service by acknowledging the fact that some of these products may have a complex modular architecture of sub-systems might be each produced by different companies, we can conclude that product modularity and sustainability might become a precondition by design. Furthermore, this modular product architectures are mirrored by modular networked business-model architectures, in which different partners cater to different sub-systems and components of the product system over the entire life cycle of a solution/product-as-a-service. However, in order to make possible mixing and matching exiting and newly developed sub-systems into complex solutions in and agile and flexible fashion, more effort will have to be invested in the development and adoption of standardized interfaces, and in the design science type of research concerning product engineering and enterprise architectures.

From the analysis above, it might seem that servitization is the silver bullet for the manufacturing industries. We should not underestimate the problems manufacturing companies may face when engaging in such a complex transformation process. They not only have to re-define their business model, they have to fundamentally change their culture, vision, mission, and way of working.

Research questions relevant for this focal area include:

- What migration strategy and method should guide the transition process from traditional manufacturing to lifecycle solutions?
- What are the organisational implications of servitization? What cultural changes are needed? Which new core competencies should be developed?
- How are the company's value proposition and revenue model changing as result of lifecycle solutions?
- How to switch and gain market share in a service market and at the same time maintain sufficient control on the current product market during the transition to the Product-as-a-service model such that business continuity is maintained?

C. (Mass) customisation

Industry 4.0 fosters the next evolutionary step in the way organizations offer their products to customers. While personalized offerings with some level of customization have become a standard for many industries, with the help of flexible computer-aided and additive manufacturing systems, organizations are able to combine the low cost of mass production with the intricacies of individual customization. Furthermore, customers play a significant role in co-designing the services and products they choose to purchase from organisations. To conclude, it is expected that due to easy reconfiguration of production, to I4.0 technologies, and to end user involvement, **mass customised production** becomes the rule, rather than the exception. However, mass customisation comes with a cost and with high risks for smaller companies that have neither the resources/technology, nor the expertise to adjust to such demanding customer requirements. More specifically, future research should address and find feasible solutions for the problems mentioned below:

- How will mass customisation impact the different industries, e.g. food production, automotive, and the pharmaceuticals?
- What is optimal balance between economies of scale (e.g., costs of production line reconfiguration) and customisable features?
- What is the impact of mass customisation on production planning and control?
- How should be production processes be designed to accommodate product and process variety complexity induced by frequently changing customer requirements and, thus by the constant need to change and reconfigure? Which design methods are suitable to handle such a high process and product variability?
- What is the impact of mass customisation on waste generation and resource utilisation?
- In which ways can I4.0 technologies enhance mass customisation in the different industries (e.g., virtual reality, 3d printing, etc.)?

D. Decentralised co-creation networks

We argue that business models will remain one of the key areas of BMS research for the coming years, due to the critical role value co-creation is playing in the context of I4.0. Currently, the topic of business model innovation is gaining considerable attention in information systems and the management literature. Thus, tooling, methodological support and design patterns for business model innovation is becoming a specific area of scholarly interest. Furthermore, approaches in the area of business modelling have been brought in relation with other disciplines, such as enterprise architectures and business process management. However, fairly little research has been done with respect to the specific aspects of I4.0-driven business model innovation. The time is now right to call for theoretical and empirical underpinnings of research on digital innovation of business models (DIBM) creating the supply markets of the future.

We distinguish two central directions in the research concerning business model innovation: business model emergence, and decentralisation. They are explained in the sequel.

The question of how novel ***business models emerge*** is crucial. Following the “Does planning pay” debate of strategic management, the entrepreneurship literature discusses causational or effectual approaches to business building. Recently, the topic of Lean Startup and the use of the Business Model Canvas are being explored. These topics extend the narrow venture perspective and explicitly take the tension between the venture, its network partners, and technology into account. Further analysis into an effective way of business building that depend to technological and network conditions informs the actors of the emerging I4.0 industry about the best way to action. At this moment we observe two patterns that govern the emergence of new I4.0 business models (Figure 5): one type business model innovation is technology induced, i.e. for which the value proposition consists of services built around a new emergent technology. The other one is business induced and typical for the transformation of existing business models/value propositions through technology adoption. This latter category is typically described with the term “digital transformation” of business models.

Research focusing on the emergence and/or transformation of business models in the context of I4.0 could address the following questions:

- How does the configuration of value chains change due to new technology and how can collaboration be improved?
- What aspects of current business models need to change/transform to make them ready for I4.0? Redefinition of old or emergence (trial and error?) of new business models through I4.0 technology? Which additional elements on top of technology have to be added?
- What migration strategies and approaches (e.g., business transformation frameworks, I4.0 maturity and readiness assessment frameworks) should large traditional organizations adopt, follow and use to become I4.0-proof?
- “Mini-industries”, e.g. through decentral energy production and smart grits, but possibly also other technologies
- What differences between industries can be observed w.r.t. DBMI? What business model patterns can be identified? Fintech (new finance / insurance start-ups), Ecological business model (amplification of classical understanding of industry, expanding the scope), Public procurement of innovation, e.g. economical-ecological nexus (people, planet, profit), nudging by government action

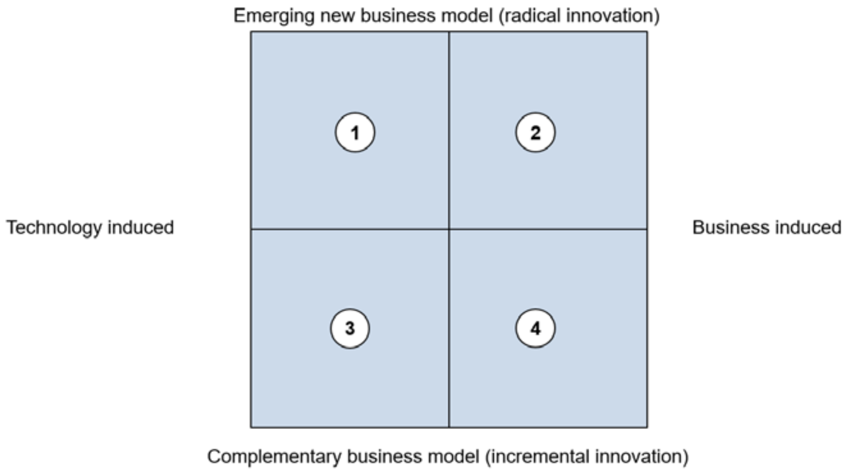


Figure 5: Two-dimensional classification of business model innovation research

Decentralisation. In management sciences, much research follows “classic” approaches such as Operations Research. Thus, many solutions aim at designing, predicting and controlling the performance of business activities, while assuming a high degree of control, certainty, stability, linearity, perfect information, and strict causal relationships. Furthermore, such solutions typically prescribe the existence of control structure in the supply chain. In most cases such a control structure is a “Control tower” system, owned or controlled by one of the supply chain partners. Common functionality of control towers includes supply chain data collection and management, business process planning and coordination, performance monitoring. Performance is seen here as a broad concept covering aspects such as business/process performance, service quality, sustainability, waste reduction, from a supply chain/business network perspective. However, the reality of the management practice is far from predictable, stable, or linear. Not only all kinds of external disturbances (e.g., incidents, peaks and lows in demand, weather conditions, etc.) have an impact on the performance, also business activities continuously evolve due to new technologies, due to decentralisation and due to autonomy and heterogeneity of the organisations and systems involved in the supply chain. These are also part of the vision put forward by I4.0, in which one of the core trends is the shift from control tower type of architectures (and therefore from classical supply chains) to ecosystems of businesses which interact autonomously.

Moreover, variations in the behaviour of the people involved, changes in the operating conditions, and lack of complete information require agility and flexibility of planning systems that must be capable of supporting re-planning decisions real. Next to these types of complexity, which are very much related to the time and behavioural dimensions of business processes, another source of complexity is the decentralised structure of business networks. The large number, complexity and distribution of systems, devices, vehicles, modes, infrastructures, sensors, locations, organizations, data etc. add new orders of difficulty to the problem. These are also part of the vision put forward by I4.0, in which one of the core trends is the **shift from control tower type of architectures (and therefore from classical supply chains) to ecosystems of businesses which interact autonomously**. This is why there is a great deal of tension between, on the one hand, the rationality of available planning and management models striving towards the achievement of predictability, and control, and, on the other hand, the “complexity” of the business reality, governed by uncertainty, distribution, incomplete information, dynamics, increased competition, evolution, lack of coordination, and autonomy.

Therefore, there is need to advance the state of the art with new approaches that are able to handle this level of complexity and decentralisation while aiming for improved business ecosystem performance in the broad sense. Of course, these novel methods will not be able to fully automate the decision processes but would do a much better job than existing models in assisting the human decision maker in his work. By sensing the environment and collecting big data, it would be possible for software agents to detect disrupting events and take them into account for real time planning and execution of (business) processes. Furthermore, increasingly more decisions could be automated by attributing them to light-weight distributed software agents. The human decision maker would be relieved of an important portion of his routine tasks and would only have to deal with those parts of the complex decision process that require creativity, expertise, and understanding of social aspects and human behaviour (e.g., strategic or opportunistic behaviour). We refer to this socio-technical approach for achieving a symbiosis between the human and the software agent, in which the human stays in control, as Intelligence Amplification (IA). More specific research questions to be addressed by research in this area could be:

- What criteria should govern the design of planning systems and methods?
- How to maximize the localization (i.e., decentralisation) of production, through sustainable planning, e.g. by selling designs instead of products (and use 3d printing to organize the production locally)?
- What data acquisition and data analytics techniques need to be developed in business ecosystems?
- How to design data governance in a distributed environment, such that it allows secure access and sharing of data with care for privacy?
- How to enrich multi-sided platforms with functionality for data analytics and decision support (in the context of data distribution and decentralization) that benefit in a fair way all ecosystem stakeholders involved?

4.2 Quantitative bibliographic landscaping

Query: ("business model" OR "platform" OR "serviti*tion" OR "marketplaces" OR "global marketplaces" OR "electronic marketplaces" OR "mass customization" OR "decentrali*" OR "life cycle" OR "co-creation" OR "lifecycle") AND ("smart industry" OR "industry 4.0" OR "smart manufacturing"); This has resulted in 1976 publications. All author-keywords from these publications have been extracted to create the keyword map below, which is essentially based on the frequency of keyword co-occurrence.

Analysis: The author-keyword map constructed for the focal area “Business” (Figure 6) indicates the following trends:

Core concepts: The keyword map reveals the importance of a certain item through the size of the node associated with it. A quick look at the diagram indicates that the keywords with most frequent occurrences are: big data, cyber-physical systems, smart factories, internet of things.

Clustering: VOS viewer’s clustering algorithm produced three clearly contoured clusters (the cluster colours are red, blue and green) shown in Figure 6. A keyword density map is shown in Figure 21 (Appendix 2). Next, we point out a few trends we observed in the map that seem to characterise the published research belonging to the focal area Business:

- o Sustainable manufacturing (green): The keywords in this cluster indicate a line of research focused on the sustainable manufacturing of mass customizable products with the help of automation and control systems. This is in line with our vision on of how manufacturing is changing due to I4.0.

- I4.0 technology (largest cluster, red): The four main keywords indicate a very strong focus on research concerned with the technologies of Smart industry. By contrast, research focusing on aspects, such as product lifecycle management and logistics, is less represented.
- Digital business model innovation (blue): The keywords in this cluster suggest a focus on innovating business models and supply chains. These are very much linked to digitisation, servitization, and 3d printing, which seems to play an rather prominent role in this cluster.
- With respect to the connections between clusters, we observe that the red and green clusters are quite tightly connected as numerous edges connect green and red nodes (meaning that these keywords appear often together in publications). At the interface, we mostly find concepts that are very much related to data, data analytics and artificial intelligence. This is a confirmation of the fact that these together are the toolbox that must be used to make manufacturing smart. The blue cluster has somewhat less connections with the other two clusters. More precisely, the interface between blue and green is realised by concepts such as supply chain management and additive manufacturing, which are related to both clusters, while most connections between the blue and red clusters go through the umbrella concept of "smart factory" (which covers developments concerning most of the concepts from the blue cluster).

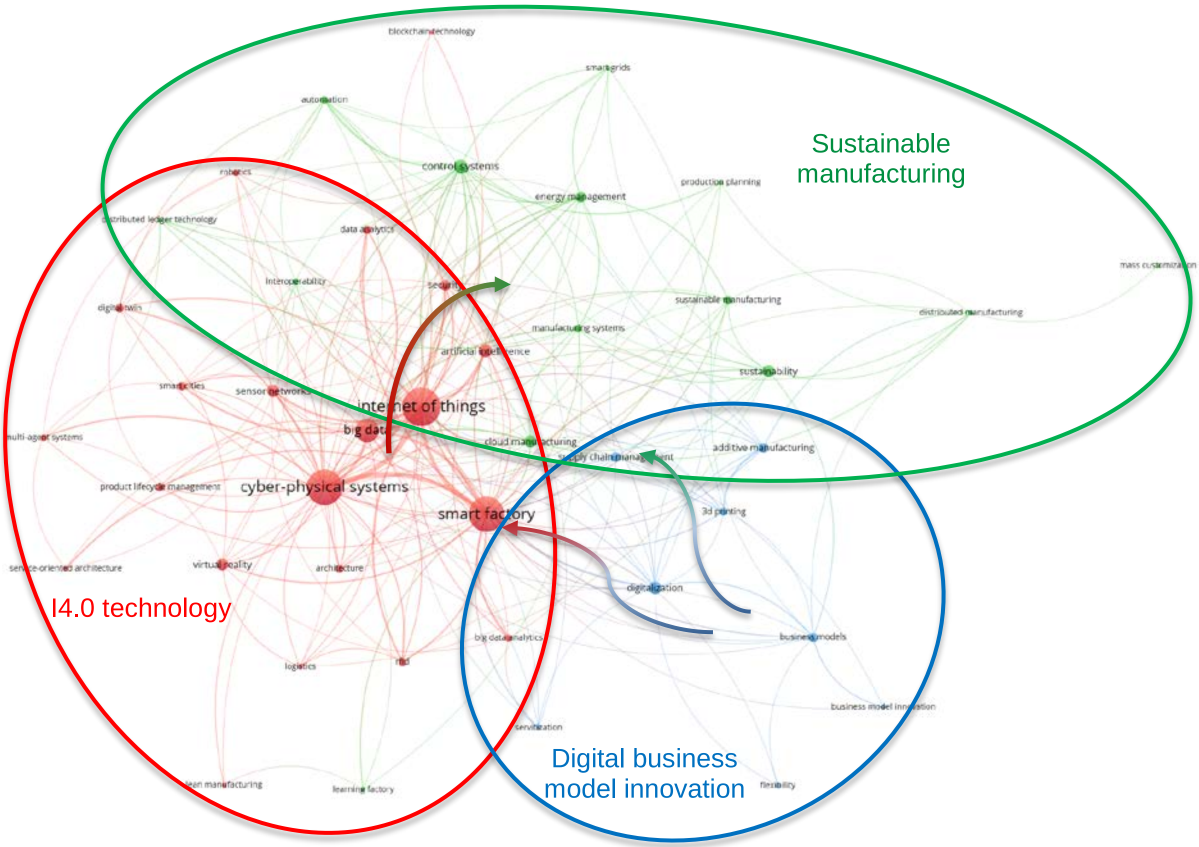


Figure 6: Keywords map of the Business focal area

5 **SOCIETY**: IMPACT OF SMART INDUSTRY ON SUSTAINABILITY, POLICY AND REGULATION, EDUCATION AND SOCIAL INCLUSION

Industry 4.0 is most of all a techno-economic concept to prepare mature industries for the digital future and to increase their productivity and competitiveness with more resource efficient and intelligent production concepts. However, the expected fundamental changes in production and consumption will go beyond industrial value chains but rather impact our society and environment, as well. For this reason, these impacts need to be anticipated and assessed in its different shapes in order to respond in an appropriate way to current and future challenges.

5.1 Problem statement and research questions

In our workshops, discussions and ongoing research we identified four main fields of attention: education, policy regulation and sustainability and social inclusion. The expectations of I4.0 is that it will transform the workplace, the job market and the production of products. This later part will have a large impact on sustainability and the development of the circular economy. As I4.0 is expected to deliver more demand driven, specialized products which are user centric the expectation is that there will be less waste and that production processes could be made circular, with less impact on the environment in terms of pollution, energy, water, and other natural resources consumption.

A. Education 4.0

Global connectivity, smart factories, big data and the whole range of I4.0 technologies will reshape the way we think about the workspace, about what work is, and about how to educate future generations to prepare them for living and working in the digital society. The speed of innovation has already reached the point at which most professionals have to spend majority of their active lives learning to keep pace with change. This also means that soon most people will have to adapt their skills and continuously qualify themselves during their lifetime, due to the ever-increasing speed of innovation which will constantly demand new skills and knowledge to meet work requirements.

One of the trends already evident in the industry is the fact that repetitive routine work (driving, cleaning, etc.) or will be automated, or will be fully taken over by autonomous robots. Since a large portion of the active population is currently employed in such work, the core question that arises is of course how we will (re)educate them to shift towards creative type of professions in which humans will remain a critical resource, and how to prepare them for lifelong-learning and for continuously acquiring new skills/knowledge. We argue that I4.0 will lead to a fundamental change in the education system starting from the primary school and ending with the higher education. Education 4.0 must provide the means to facilitate continuous learning, and its contents must focus on skills required by I4.0 (produce both technology enabled workers, but also knowledge engineers). Research questions that could be addressed in this focal area include:

- How to develop new education plans and programmes tailored to I4.0?
- How can education contribute to the 21st century skills needed for I4.0?
- How to create the institutional context to support the provisioning of this new type of education?
- How to involve social actors, such as local and national governments, social and professional organisations in the development of this fundamentally new education system?

B. Social inclusion and ethics

Transforming industrial production and consumption towards Industry 4.0 will brings open questions about the future of employment and social participation while at the same time increasing welfare in industrialised economies. Therefore, these transformations need to be tackled in a responsible and inclusive way. In doing so, social inclusion has two research dimensions: The first research dimension asks how to ensure inclusiveness in a fast-changing digital society and the second-dimension deals with the development of inclusive policy instruments. These questions about social inclusiveness do not only appear on the level of a state but do rather touch different levels of a society and should not be limited to the national economy but can rather be extended to questions of global (in-)equality.

A negative impact of the introduction of digital technologies such as robots or artificial intelligence within companies might increase unemployment in a dramatic number. Today, experts in this field do not agree on a single positive or negative employment scenario. However, there are serious concerns about the decreasing demand for workforce and an increasing number of long-term unemployed parts of the society. The concern about an increasing imbalance between employed and unemployed people leads to the following open questions that concern the local level of companies as well as the national level of the state and on a global scale:

- How can companies establish a responsible human resource management and how do societies deal with an increasing number of unemployed people?
- Which alternatives to full-employment need to be discussed? Ideas might range from decreasing weekly workings hours (as currently negotiated in the German metal industry) to basic income models.
- (Global perspective) How do regions and nations develop (especially in economies of the global south) when powerful western companies relocate their production since the former competitive advantage of cheap workforces is no crucial any longer?

Another field which raises questions of inclusiveness is the access to technologies and internet. There are still people within our societies, regions and countries who do not have access to internet and digital technologies (“digital divide”). In order to avoid increasing inequality and to ensure social participation, research needs to identify social exclusion and suggest social policies which let people and regions participate in the ongoing socio-technical change towards a smart industry.

This calls for adequate responses from regulatory and scientific authorities, as well as from educational institutions to prepare people. And it brings the issue of public trust to the table, with governments being called upon to provide for equality of opportunity, ensuring that large parts of society do not feel left behind and that those that are employed are carrying out meaningful work – work that is challenging and interesting for the worker. The central question to be addressed by this focal research area is:

- How can we ensure inclusiveness in a world where employees are at risk of being replaced by machines, in particular when some workers are not yet well-equipped to use these technologies?
- How can we avoid the expansion even further of the digital divide between the people with and without technology-driven education?

The second research dimension focuses on designing inclusive policy instruments which include societal actors and their ideas and concerns already at the beginning of the technological development process. The basic idea of this approach is to anticipate (societal) challenges, needs, concerns and requirements for new technologies and societies already at the early stage of the technology development. Examples for such policies and spaces to experiment and anticipate socio-technical futures are field labs which are not limited to engineers and researchers but open their doors for a socially inclusive process together with societal actors.

C. Policy & Regulations

The need for suitable legislation/regulations to support the transformations initiated by I4,0 follows from an inherent feature of smart industry, namely data sharing. The most important reasons that make data sharing a critical precondition include collaborative design of products and services in which different public and private actors may be involved, smart transparent collaborative value chains, extended product/service lifecycle management (by using e.g. digital twins), from cradle to recycling, etc. To make all of the above possible, information has to be shared that might be subject to intellectual property rights and privacy requirements.

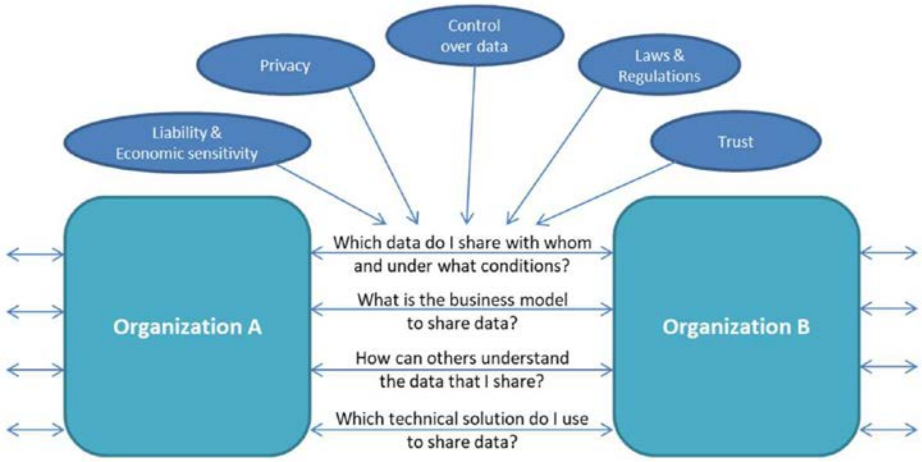


Figure 7: Data sharing (source "Smart Industry roadmap Onderzoeksagenda voor HTSM en ICT en routekaart voor de NWA")

This is why policy and regulations with respect to data management are vital aspects of the Industry 4.0 roadmap, being relevant both as an enabler and as a constraint for the role of (future) cyber-physical systems in society. A key challenge is to ensure policy and regulations keep pace with new technologies, while being "future proof"[8], not only by avoiding a regulatory disconnect that causes unnecessary hindrance to new business opportunities, but also by facilitation, such as through experimental regulatory regimes for living labs and incubators, or by being responsive to new business models, such as of internet platforms, business ecosystems, and the sharing economy. Meanwhile, regulation will need to respond to how Industry 4.0 brings further globalization and open geographies of business development and production by:

- reinforcing the already strong influence of transnational private law (of standard setting and certification),
- bringing the need for regulatory governance of regulatory capitalism
- by maintaining a global level playing field, and by
- (distributive) justice and open value chains.

At the same time, regulations themselves will change as machine-to-machine communication, and machine learning will lead to new forms of techno-regulations (by design) between machines, but also of machines over humans, such as in robotics.

The great regulatory challenges will undoubtedly lie, on the one hand, with the future of privacy and data protection, and on the other hand with new models of ownership and liability as Industry 4.0 will further blur existing legal concepts, through joined-up and networked business models. This will also go hand in hand with the rise of the gig economy that is already challenging the boundaries of labour law, and competition law. Last but not least policies and regulation will be tested on their ability to meet, preferably proactively, the demands of Grand Societal Challenges, such as sustainability through a circular economy, and social inclusion through the development of Education 4.0, etc.

The first steps in this direction have been made in the Netherlands, by the definition of the Commit2Data program focusing on safe and secure (big) data sharing (in which the BMS, in collaboration with EWI, is at the forefront of this type of research in the field of smart logistics, through a recently funded project: DataRel).

[8] https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/future-proof-regulation

- To what extent the current regulatory and legal frameworks have to be changed and extended to cope with the transformations imposed by I4.0, in the areas of data ownership, protection and privacy, liability, work?
- How must the current education system be changed to prepare the new generations for the future skills/knowledge requirements of work in the era of I4.0, and thus diminish the digital divide?

D. Sustainable economy

The industrial activities following from the 4th industrial revolution also need to be analysed from and aligned with a societal perspective. Claims have been made that these developments will also lead to less pollution, a more efficient natural resources utilisation, closed loop supply chains, a lower production of GHGs, to sustainable economic development and, in general to an increased wellbeing/welfare (e.g., through developments such as smart cities, e-health and tele medicine, etc.). However, smart industry still must prove its potential regarding these sustainability (environmental/ social responsibilities) claims.

We argue that research is needed to empirically measure/evaluate I4.0's ecological footprint. One of the important reasons to do this is the Climate Change agreements, in particular the "Protocol of Paris" which has obtained the international commitment of industrialized countries to reduce their CO2 and equivalent emissions (Greenhouse Gases (GHG)). In order to evaluate the GHG emission and other relevant environmental impacts, some tools have been developed in line with the I4.0 principles, e.g. at the Institute of management Science and Fraunhofer in Austria[9] where they developed a software that along the value stream of production can systematically collect ecological data and simultaneously visualize it. BMS has research published in this area includes as well, in the proposal of a reference architecture and methodology for real-time fuel consumption-based carbon management systems for the logistics industry[10]. The data collected by such systems can be used for diverse purposes, for instance enabling the circularity of resources within and outside the factory (Figure 8), monitoring, calculating corporate carbon footprints, re-training/rewarding employees to establish sustainable working practices and organisational culture etc.

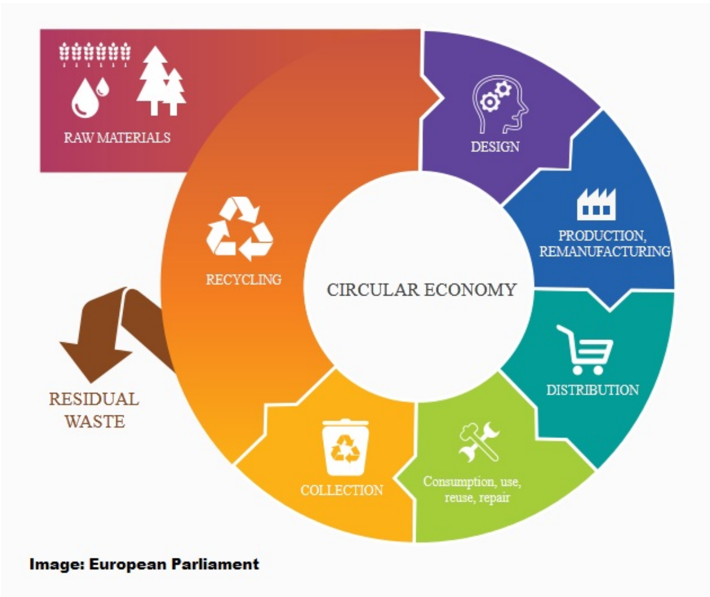


Figure 8: Core principles behind the concept of circular economy

[9] https://www.researchgate.net/publication/318645767
[10] https://research.utwente.nl/en/publications/towards-a-reference-architecture-of-fuel-based-carbon-management-

Such research can be directly linked to different concepts such as industrial symbiosis, industrial ecology, circular economy, etc. Further studies should consider the smart industry implications at all levels of society and should investigate to what extent pressing societal problems such as environmental pollution, depletion of natural resources, climate change, are positively impacted. To conclude, the BMS has worked and will continue working on the mechanisms that foster the formation, and coordination of supply chains in the Circular economy, Industrial Symbiosis, Carbon Management, and Social and environmental Lifecycle Assessment.

More specific research questions to be answered here could be:

1. How to design marketplaces and closed loop supply chains to foster industrial symbiosis and to support the exchange of waste into fuel, by reusing products, components or materials in the manufacturing sector?
2. What business models are needed (in a multi-stakeholder environment) for sustainability by design (e.g., the FAIR phone, Social entrepreneurship, such as micro-credits, moving from physical to cyber-physical in products, services, production, resources) to convince industries to move towards closed loop supply chains?
3. What (psychological) barriers exist in moving towards a circular economy model? What financial barriers? What barriers in legislation?
4. How to design lifecycle assessment frameworks of any product/service, based on their impact on sustainability? How to define these sustainability goals, and how to measure them?
5. How to develop sustainability frameworks, with a focus on carbon footprinting methodologies, standardization, sustainability measurement instruments (e.g., activity-based carbonning, sustainability accounting, etc.)?

5.2 Quantitative bibliographic landscaping

Query: ("policy" OR "regulation" OR "sustainability" OR "industrial symbiosis" OR "circular economy" OR "digital workplace" OR "social inclusion" OR "diversity" OR "ethics") AND ("smart industry" OR "industry 4.0" OR "smart manufacturing"); This search has resulted in 1080 documents.
Analysis: The author-keyword map constructed from the publication list generated for the Scopus search designed for the focal area “Society” (Figure 9) indicates the following trends:

- **Core concepts**: Similar to the Business keyword map (Figure 6), the most core concepts of the “Society” focal area concern the most prominent I4.0 technologies and include cyber-physical systems, internet of things, smart factory, big data, and digitisation. In contrast with the “Business” keyword map, this time a series of keywords concerning sustainability (e.g., sustainability, sustainable manufacturing, circular economy, energy consumption, energy management, etc.) become quite prominent, which also confirms the importance we (and the published literature) assigns to the topic of sustainable economy in our SIRM.
- **Clustering:** resulted in three clearly delimited clusters (the cluster colours are red, blue and green, and correspond to those in Figure 9). The keywords with highest density in each cluster are shown in Figure 23 (Appendix 2).
    - Smart and sustainable factories (green): The keywords in this cluster indicate a line of research focused on smart factories with the help of technologies, such as the internet of things. Another core aspect of this cluster is sustainability, which can lead to organisations innovating their business models and products.
    - I4.0 technology (largest cluster, red): Similarly to the business I4.0 technology cluster, we see here also a very strong focus on research concerned with technologies, such as cyber-physical systems, big data, and sensor networks. These technologies are related to Society aspects, such as smart cities, energy management and smart grids, which can help prevent waste and improve resource utilisation.
    - Sustainable supply chains (blue): Similarly to previous clusters, this one also includes aspects of sustainability, but there is a stronger focus on supply chains and logistics.

- o As far as the interfaces between clusters are concerned, we observe the following. There is a quite tight coupling between the blue and green clusters. Notably, concepts related to sustainability occur in both clusters and are rather equally important. The essential difference between the two clusters is actually caused by the level of abstraction: the blue cluster is mostly about supply chains, while the green cluster is about the smart factory (i.e., one organisation). Together these clusters would reflect the research published on sustainable business. Another quite interesting observation is related to the tight coupling between the red and the green clusters. A quick look at the keyword map confirms the role of I4.0 technologies (red) as enablers of I4.0 sustainable business innovation (green), which in turn, due to the development of "smart factories", will lead to sustainable supply chains (blue).
- o In contrast with the map for the "Business" focal area, this time concepts such as "human factors" (blue) and "engineering education" (green) show up, suggesting that from the societal point of view such topics start receiving attention.

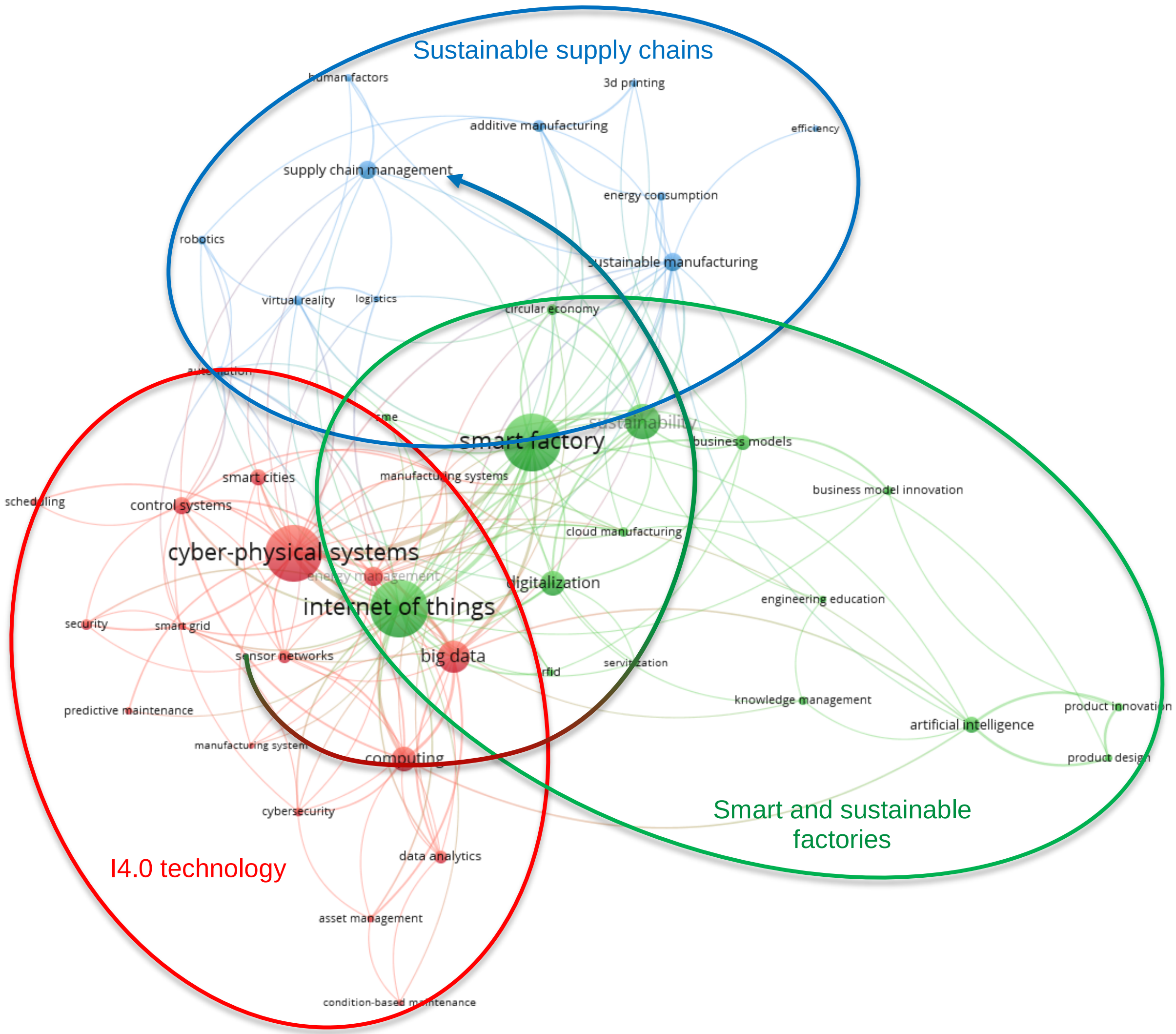


Figure 9: Keywords map of the Society focal area

6 **PEOPLE**: THE FUTURE OF LEARNING, AND WORK

Having discussed what the fourth industrial revolution implies for our society and businesses, we now focus on how I4.0 affects people, and specifically their work and jobs in the coming years. We see various developments in how automation, robotization and artificial intelligence (AI) affect our work now and in the future. The digital transformation of the economy and society will disrupt entire systems of production, management, and governance. It will have an impact on the role of labour – of human capital – in the production processes in both the for-profit and the not-for-profit (including the public) sectors.

New production technologies are reshaping the availability and nature of work. As argued in the previous chapter (Society), they could yield greater inequality, particularly in their potential to disrupt labour markets (a decrease of the number of jobs in the manufacturing industry has already been observed). In this chapter we will identify a number of research themes that focus on the I4.0 implications for the individual – i.e. the worker and her/his occupation: The changing nature of work, the organisation of work, the training/education of workers and the talent they require to remain employable.

While the availability of new supportive tools/technologies give rise to new opportunities, some tasks may be doomed to disappear. However, there is also the promise that tasks that cannot be substituted by computerisation will be complemented by it. The displacement of workers by technology and the complementarity between humans and machines in the workplace potentially result in a net increase in safe, creative, and rewarding jobs. I4.0 is thus expected to offer a huge opportunity – in particular for countries that currently possess a highly-educated population well-endowed with digital capabilities and innovative skills. Our focus here goes further than looking at those jobs and activities that may become automated and thus disappear from the labour market. We also focus on how organizations need to adopt to I4.0 developments by organizing and structuring work differently and how individuals need to prepare and develop themselves to enjoy their work and keep productivity levels high.

Below we will focus on questions related to how I4.0 affects people, and specifically their work and jobs in the years to come. This research theme will be broken down into a number of sub-areas for research that all show a large degree of affinity to the research currently going on in the Faculty of BMS and also connect to research agendas of external organisations and research funders. Therefore, in the following, we present four research themes focusing on the People implications of I4.0: (1) technology-enabled jobs, (2) self-management, (3) continuous learning and employability, and (4) management of the T-shaped talent.

6.1 Problem statement and research questions

The above introduction points at a number of research questions. In this section we present five questions that each show some degree of affinity to the research currently going on in the Faculty of BMS. All five questions also connect to research agendas of external organisations and research funders.

A. Technology-enhanced work

Technological developments not only modify blue-collar workers performing routine jobs, but also white-collar employees in knowledge industries (e.g. banking, law firms). Changing the nature of jobs, employees are being augmented with, robotics, AI, virtual reality, sensors and software. Examples are the jobs of operational workers who become enhanced (or complemented) by technologies that support their work, and the jobs of engineers who organize and interpret the information provided by technologies and use their expertise to design new systems and tools. We call individuals in the first job group ‘enhanced workers’, and those in the second ‘knowledge engineers’. Technology-enhanced developments bring the promise of higher productivity. As such, enabled workers use e.g. virtual reality glasses or robot arms to guide them through the physical manipulation needed to execute their work. Technology can be used to support and train these workers to perform new (repair and maintenance) tasks.

At the same time, many traditional engineering activities and even parts of decision-making in organisations might be executed better by AI systems with more calculation power than any team of humans. Instead of doing it themselves, knowledge engineers will need to organize the tasks of the AI to execute, interpret the provided information and define the requirements and interface with the customers. Thus, knowledge engineers become strategic decision-makers and flexible problem solvers. These developments also influence other jobs, such as those of medical doctors, who are supported by Da Vinci robots, or farmers, who can organize their work by using ‘data centres’.

B. Self-management and crowdworking

In addition to the nature of jobs, also the organization and structuring of work will be subject to change. The emergence of the gig economy is reshaping the traditional employer-employee relationship as more contractors and freelancers fill roles once reserved for workers having more permanent jobs. The very concept of the nine-to-five job and 40-hour work week is quickly being reshaped by technology-enabled independent work that can be done anywhere, at any time (Katz & Krueger, 2016). Independent individuals may feel the need to or prefer to offer their services on digital platforms such as Upwork, Uber, and Airbnb.

New technologies are enabling workplace innovations such as remote working, co-working spaces and teleconferencing. Organizations are likely to have an ever-smaller pool of core full-time employees for fixed functions. In order to operate in a flexible way, organizations will increasingly make use of crowdworkers, talent platforms and contractors for project work. Organizations may be offering offline contracts and freelance work to independent workers, leading to questions such as how the work should be structured in order to manage job autonomy and self-regulation.

At the same time, organizations choose to structure the work in self-managing teams based on technology-enabled, self-employed individuals. If these employees will be complemented by machines, they are able to work more independently and with less direct supervision. There are two reasons for expecting more emphasis on entrepreneurial attitudes, more decentralized decision-making and self-management among workers. First, cyber-physical systems allow for monitoring and controlling individuals autonomously. Second, since objects and people become more interconnected and information of various sources becomes more transparent, individuals at the operational level can utilize the provided information sources at the same time. Both trends suggest the implementation of more self-managing teams, in which individuals are empowered to take responsibilities and decision-making authority based on the provided data. Planning tasks are coordinated by the team, assisted by technology, instead of being dictated from above, implying questions about the role of line managers and supervisors. This requires the team members to collaborate and share their knowledge.

C. Continuous learning and employability

In the I4.0 context, employees (i.e. enabled workers and knowledge engineers) will have to adopt to permanently changing conditions. The new jobs undergoing significant computerisation will increasingly demand workers to carry out complex non-routine tasks that require new competences and skills. This results in questioning the adequacy of skill- and training systems – their design, effectiveness and their contribution to build up an entrepreneurial workforce (see previous chapter). The future workforce will need to align its skillset to keep pace. Hence, a continuous (say life-long) learning approach is required on the part of the worker to remain productive. In the I4.0 context, individuals will need to prepare and develop themselves to enjoy their work and keep productivity levels high. Thus, it is mainly the individual employee who will need to take responsibility for updating her/his own skill set and staying employable. Surely, there is a role for the government, businesses and labour unions in facilitating this through financing, regulation and quality assurance systems, but it is the individual who will be in charge. To do that, it is no longer enough to have gained a thorough education, employees need to get continuous retraining to stay on track. Firm-level training will gain in importance, given that production technologies will need constant adaption. To allow continuous learning, novel forms of virtual and modular education are already developing. For instance, students may follow and combine short-term modules from different knowledge providers to earn micro-certificates – with some of these courses offered through platforms and on-line providers. As a consequence, knowledge market places may emerge, replacing fixed curricular educational chains.

D. Management of T-shaped talent

In an I4.0 context, one may expect jobs to be designed differently, with e.g. more task variety. Added to this the requirements for 21st century skills, working with robotics, AI and sensor technologies, and interacting with largely independent, self-employed and technology-enabled individuals, require new talents. The expectation is that in the I4.0 era talents need to have soft skills – a term associated with how people get along with one another, communicate, and work in teams – as well as relevant technical skills. Since workers need to closely interact with other self-managed workers, they need to have a fair understanding of the activities of their partners. Thy will need boundary crossing competences. The breadth and depth needed for workers in I4.0 is illustrated in what is often referred to as the T-shaped professional. The vertical bar of the T represents a person’s deep understanding of one subject matter – history, for example – as well as one industry, perhaps energy or health care. The horizontal stroke of T-shaped people is the ability to work across a variety of complex subject areas with ease and confidence. Without these two skill sets, the model of self-management in decentralised workplaces cannot work.

Attracting and recruiting these talents becomes increasingly important. However, to do that, organizations need to offer appropriate development opportunities and rewards. New forms of talent acquisition are needed: social networking, analytics and cognitive tools (e.g. AI) to determine the talents who will best fit the job, team and organization. It has become apparent that their focus is now shifting to identifying T-shaped skills and capabilities. The challenge is to design smart strategies for talent scouting. However, once these talents are successfully selected, the real challenge may be to cultivate and retain them.

To conclude, the BMS has and will continue working within this research line by focusing on the people implications of I4.0. As such, we plan to research how work and the nature of jobs will change and how organizations need to structure work and focus on the education of people to deal with the technological developments.

More specific research questions to be answered here could be:

1. In what way does the nature of work change jobs in I4.0 and what does it imply for the employer-employee relationship?
2. In what way do jobs need to be designed to structure work to allow for decentralized decision-making and self-management among workers?
3. In what ways can workers take responsibility for their own retraining and employability?
4. In what way can organizations develop HRM systems to attract, develop and retain T-shaped talents?

6.2 Quantitative bibliographic landscaping

Query: (("continuous learning" OR "lifelong learning" OR "employability" OR "e-learning" OR "learning systems" OR "talent management" OR "self-managing team" OR "self-management" OR "self-designing team" OR "empowered team" OR "autonomous team" OR "self-directed team" OR "team effectiveness" OR "team design" OR "crowdworking" OR "t-shaped professional" OR "t-shaped talent" OR "21st century skills" OR "t-shaped skills" OR "t-shaped capabilit*" OR "technology-enhanced" OR "knowledge engineer" OR "enhanced worker") AND ("smart industry" OR "industry 4.0" OR "smart manufacturing"); This has resulted in 240 documents.

Please note that the results of this query mostly reveal the publications which are written in the English language, or which contain English language keywords. Therefore, publications which are written exclusively in Dutch or German do not appear in these results. This is important to note since there are many publications written in both German and Dutch which focus on aspects such as Work 4.0 (Arbeit 4.0 / Arbeid 4.0). However, we have chosen to focus only on the English language publications in order to understand the international research landscape, since BMS research is usually aimed at an international audience.

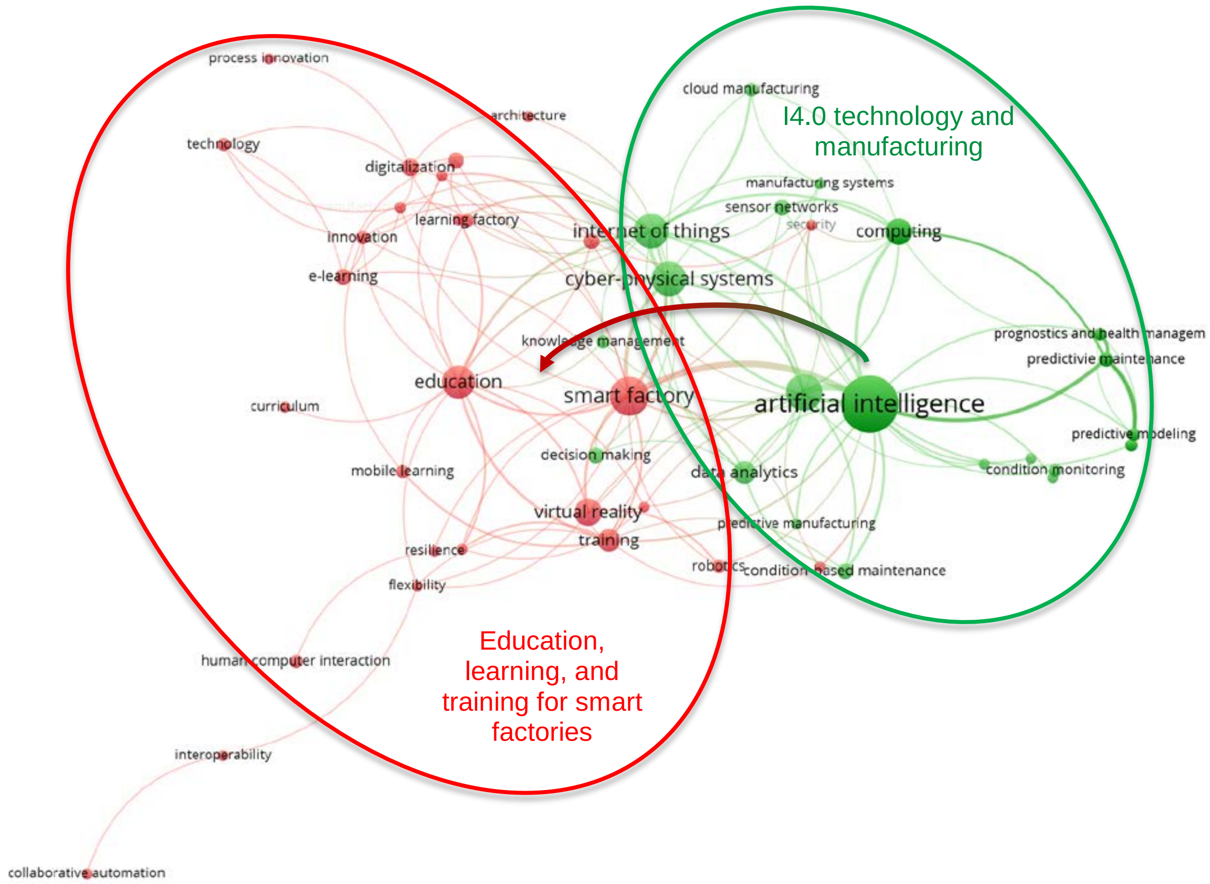


Figure 10: Keywords map of the People focal area

Analysis: The keyword map constructed from the publication list generated for the Scopus search designed for the focal area "People" (Figure 10) is based on a quite limited number of publications that could find based on the keywords of relevance. This is why the trends we detect in the keyword map may still have to be confirmed and strengthened as soon as more research becomes available. The scarcity of publications in this area is anyway an indication that so far, little attention has been paid to human factors, education and learning in the published I4.0 research.

- **Core concepts**: The core concepts are artificial intelligence, education, training, smart factories, Internet of things, big data, and cyber-physical systems. In contrast to the other two focal areas, the predominance of I4.0 technology concepts in the core set of concepts clearly decreased within the "People" research. This suggests that People-research is not so much about I4.0 technology, but rather about the consequences of these technologies for work, education and how people use technologies in their jobs. Of the I4.0 technologies, Artificial intelligence clearly plays the most important role. This is also not a surprise, considering the relationship between machine learning and human learning.

- **Clustering:** VOS viewer clustered the key-word map into two clusters (Figure 10). The keywords with highest density in each cluster are shown in Figure 25.
    - I4.0 technology and manufacturing (green): Similarly to previous keyword maps, the structure of this cluster suggests a strong focus on I4.0 technologies seen mostly as enabler of smart manufacturing. This time however, they both fall into the same cluster. The manufacturing keywords cover topics such as production planning and control, predictive maintenance and manufacturing. All of them are also directly connected to artificial intelligence, which reflects and confirms its growing importance in manufacturing. This combination of keywords, and the general structure of this cluster is of great relevance also from the BMS point of view as it matches well the type of research done, for example, in the IEBIS group.
    - Education, training and learning for Smart factories (red): This cluster of keywords suggests research topics which are related to acquiring the right talent, educating them, and ensuring that they continuously develop their skills and knowledge. All of these aspects are very relevant from a Smart industry perspective.
    - The interface between the two clusters is primarily realised by three concepts: smart factories, IoT and cyber-physical systems. Most of the links at the borders of the two clusters go through these nodes. Quite notable is also the very strong interface relation between the most important two concepts in the people map: smart factory (red) and artificial intelligence (blue). To conclude, the two clusters are quite tightly connected through numerous and strong border crossing links. This suggests that I4.0 technology is not only the trigger that will fundamentally change learning, training and education, but also the very object of learning teaching and training.

7 INTEGRATED ROADMAP – SMART INDUSTRY FOR BMS

In this chapter we present the main deliverable of the IWG: **the smart industry roadmap**. The artefact we created is a roadmap as it defines strategic research directions for the coming 10-15 years. It should be however noted that it is not a roadmap in the traditional sense, since it does not provide any detailed sequencing of activities projected on a precise timeline. We believe that academic research (in particular in an emerging field such as I4.0) does not lend itself for such projections, as research is an ongoing, often risky process, with highly unpredictable outcomes and duration. This is why we thought it would be more valuable if our smart industry roadmap could provide clear research lines accompanied by an as objective (and as quantitative) as possible maturity assessment and comparison of both the BMS state of research, and of the state-of-the-art literature along those lines (see the overview in Appendix 13). We have defined maturity in quantitative terms (by looking at the size of the scientific output) and interpreted maturity in terms of gaps in the literature and opportunities for novel research, on the one hand, and in terms of BMS strengths, competencies, and competitive edge, on the other hand. Following this reasoning we ended up with a consolidated and integrated maturity model, which forms the very core of this chapter and is the foundation for our final conclusions (Section 10).

The chapter is structured as follows. First, we pay some attention to several cross-cutting issues that traverse and impact all of the layers of the SIRM model (Section 7.1). Section 7.2 gives an account of the bibliographic analysis we carried out for the whole SIRM model (i.e., for all the I4.0 published research to date). Additionally, we use citation analysis to generate an overview of the journals and conferences that publish most of the I4.0 research. Section 7.2 also contains the research landscape of the BMS faculty. This is used as input for the comparison of the BMS core research competencies and the current I4.0 state of the art research. Section 7.3 is built around this comparison formalised in terms of an integrated SIRM maturity model. The model gives a clear overview of our strengths and opportunities in the I4.0 field. Section 7.4 gives an overview of BMS' I4.0 flagship projects. Section 7.5 briefly explores the relation between I4.0 research and its relations with the education programs. Finally, in Section 7.6 includes a list of technologies BMS researchers need for their I4.0 research.

7.1 Relationships between the three focal areas

The frequent discussions the IWG had during the development of the SIRM lead to the realisation that the three focal areas of the SIRM (and their refinement into quite abstract and broad disciplinary domains) cannot be treated in isolation. Building the SIRM was quite a tedious and difficult process because we were trying to break the world of I4.0 into logical and nicely ordered pieces, which is not easy when everything is related and/or depends on everything else, and people see causal relationships everywhere. This is why we avoided to add any lines in the SIRM (Figure 3) and we also avoided suggesting any ordering between its items. However, often concrete examples of research problems have been given that span over all of the Business, Society and People layers of the SIRM, while addressing major societal, or research challenges. This is why we eventually concluded that the SIRM would not be complete if we do not add to it a list of such important, more concrete, cross-cutting I4.0 concerns, that could give rise to even more specific and tangible project ideas. Therefore, next to the three layers that make up the SIRM, the IGW has also identified a number of cross-cutting problem-areas that will assume the consideration of aspects from (and thus will cross) all, or at least two of the layers in SIRM. An overview of them is given in Table 2. Please note that it is not our intention to be exhaustive. These are just examples of problems that could become the main research focus in future project proposals.

Table 2: Cross-cutting concerns and their tensions

	Tension/Societal challenge	Business[11]	Society[12]	People[13]
Future of work	Digital divide vs. equal opportunities and social inclusion within and between societies self-employed individuals vs. social human beings	1; 3	2; 3; 4	1; 2; 3; 4
Platform economy	New opportunities through open digital marketplaces vs. segmentation of labour markets; emergence of a new self-employed working class; employer-employee relationships; people as suppliers	1	2; 4	3; 4
Regional development	Globalisation of organisations vs. Collaboration and development within a geographical region, localisation of localisation of manufacturing	2; 3	1; 2; 3; 4	2; 3
Social enterprises	Public services provided by the government vs. Business-provided public services	3	1; 2; 4	1
Sustainable business models	Growth policies and increasing productivity vs. resource exploitation (rare-earth; limited raw materials) and climate change	1; 2; 3; 4	1; 2	3
Efficient planning	Increasing economic efficiency for higher returns and business growth vs. resource depletion and pollution/global warming	1; 2; 3; 4	1	2; 3; 4
Industrial symbiosis and circular economy	Increasing economic efficiency for higher returns vs. Eco-innovation to reduce resource depletion/scarcity, prices and pollution/global warming	1; 2; 3	1; 2	2; 3
Digital transformation of large traditional (manufacturing) organisations	Stable and mature innovation and business paths, stable market share vs. dynamic new digital opportunities and ideas: Risk of market-share loss; inertia and lack of agility; resistance to change; competing on price/quality/speed with young, agile, innovative start-ups and SMEs	1; 2; 3; 4	1	1; 2; 3
Servitization	Selling physical products vs Selling lifecycle solutions and services; customization of service/product combinations vs mass production; infrastructure; ownership; moral hazard	2; 4	2	2; 4
Ownership models	Online-Platforms, new decentralised modes of production, consumption and innovation vs. power imbalances and data protection in co-creation networks; MNC, platform providers vs. SMEs and consumers; data ownership vs. data sharing	1; 3	2; 4	3
Socio-technical change – new ways of production and consumption	National growth agendas (Industrie 4.0) vs. decentralised, global value chains	3	2; 4	1; 2; 3; 4

[11] 1. Global marketplaces; 2. Life-cycle solutions; 3. Decentralised co-creation networks; 4. (Mass) customization
[12] 1. Sustainable economy; 2. Policy and regulation; 3. Education 4.0; 4. Social inclusion and ethics
[13] 1. Management of T-shaped talent; 2. Continuous learning and employability; 3. Technology-enhanced work; 4. Self-management and crowdworking

7.2 Quantitative bibliographic landscaping

7.2.1 Smart industry research

This time the scope of the bibliographic analysis is I4.0 research. This is reflected by the formulation of the Scopus query below, which is the most inclusive so far.
Query: ("smart industry" OR "industry 4.0" OR "smart manufacturing"); This has resulted in 4911 documents. This list of publications includes all of the other three lists (for Business, Society and People).

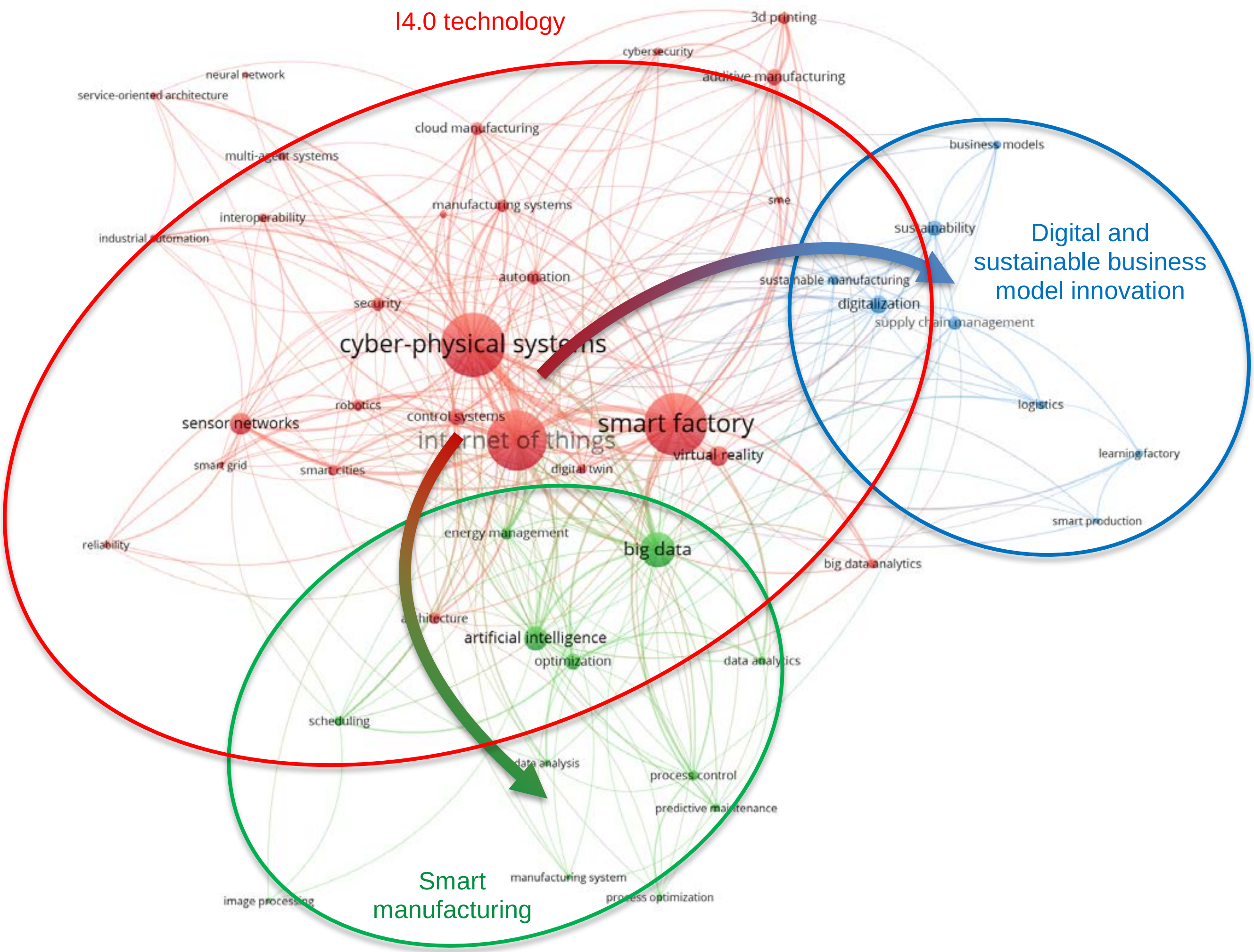


Figure 11: Industry 4.0 Keyword map

Analysis: The author-keyword map for the whole SIRM (Figure 11) has been constructed from the publication list generated by the Scopus query mentioned above. The following trends can be observed from this map:

- **Core concepts**: Not surprisingly, core concepts are all of the I4.0 important technologies: cyber-physical systems; internet of things; smart factory; big data; artificial intelligence; sensor networks. This is due to extremely high frequency with which these keywords have been chosen by author. When we look at the big I4.0 picture, all other issues that we identified as important for a certain focal area (e.g., sustainability, learning, manufacturing, etc.) seem to become by comparison secondary or even seem to disappear (e.g. education) due to the significant discrepancy between their much lower occurrence frequency (note the size of the nodes in the keyword map) and the frequency of I4.0 technologies. ***This suggests that, at this moment,***

I4.0 research still predominantly focuses on I4.0 technology development and validation/implementation (i.e., the "High tech"), and clearly significantly less on the social/societal, and organisational implications of delivery, adoption and usage of I4.0 technologies (i.e., the "human touch"). We perceive this as a fantastic opportunity for us as "high-tech / human-touch" researchers, as we have the right expertise and track-record to fill this gap in the state-of-the-art research. This has become even more evident when we analysed (Section 7.2.2) the BMS research published in recent years.

- **Clustering**: The map resulted in three clearly delimited clusters (Figure 11). The keywords with highest density in each cluster are shown in Figure 25.
  - I4.0 technology (red): ***It is evident (also from the previous bibliographic analyses that) I4.0 technologies are the most intense researched area in the published literature***. The size of the nodes in the "I4.0 technology" cluster illustrates the most prominent technologies which have been researched in the past years. From this we can conclude that technologies, such as 3d printing, digital twins, and block-chain, which were identified during our workshops are still under-researched by comparison. This implies that since the technologies are not well researched, the applications and impacts of these technologies are also not sufficiently covered. Here is where BMS research could contribute, by providing a better understanding of the implications of these technologies.
  - Smart manufacturing (green): Similarly to previous maps, the keywords in this cluster indicate a line of research focused on manufacturing of products in a smart way, primarily driven by a combination of big data and artificial intelligence for achieving an efficient control of manufacturing processes.
  - Digital and sustainable business model innovation (blue): This cluster suggests a combination of topics which were identified in the previous maps as well (in particular in the Business map), with a focus on digitising and innovating business models and supply chains. Additionally, the only keyword somewhat related to People aspects appears in this cluster: "learning factories". Other aspects are not seen due to the rather low amount of publications relating the combination of Smart industry and people keywords. ***This also clearly indicates, an under-representation of People-related research in the extant literature. The situation is not much better for "Society" research. Of the four aspects we identified in the focal area "Society", only sustainability is receiving a fair amount of attention in the literature.*** All others, are missing or are weakly represented.
  - Two main conclusions are to be drawn when we examine the relationships between the three clusters: i) ***I4.0 technology (red) is positioned in the literature as enabler and/or trigger of everything else*** (i.e., green and blue: smart manufacturing and digital/sustainable business models innovation), and ii) very little links exist between the green and blue clusters – they only seem to connect through "big data (analytics)".This suggests that research related to business model and supply chain innovation is pretty much disconnected from research on making manufacturing processes smart. This also means that digital transformation of manufacturing organisations and processes, is not yet explicitly seen as a form of business model innovation. ***Here we identify a second important gap in the literature concerning the innovation methodologies and patterns traditional organisations follow during their migration to I4.0. This is also a confirmation of the significance of the research problems we put forward in Section 4.1.***
  - We projected the conclusions of all bibliographic analyses so far on the SIRM. To this end we created a "heat-map" that gives a visual representation of the state of I4.0 literature.

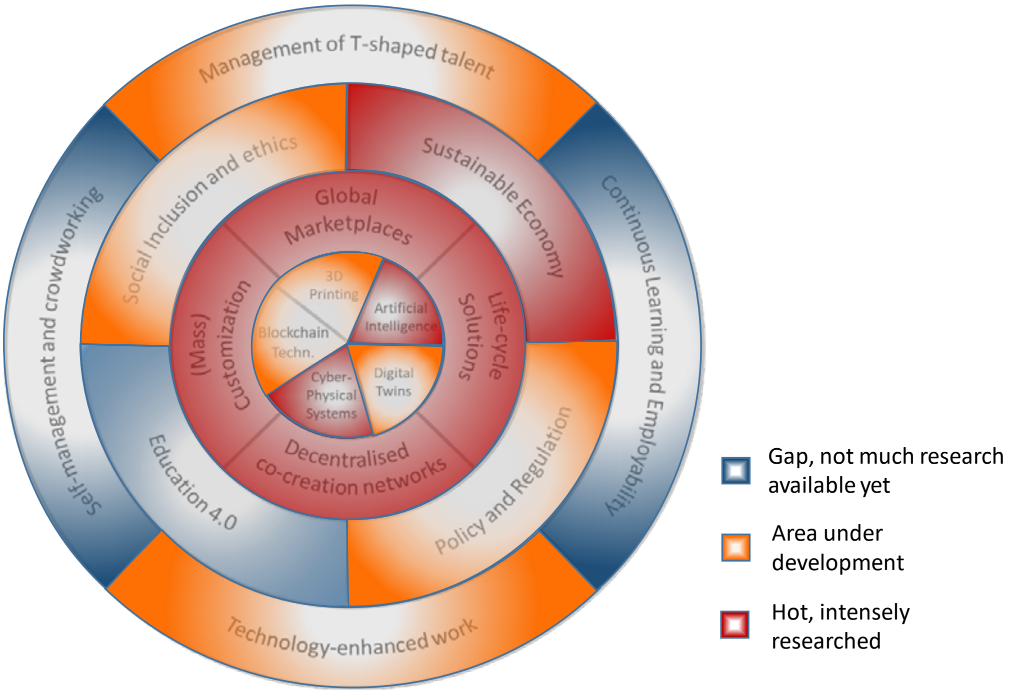


Figure 12: Heat map of the I4.0 literature projected on the SIRM

Conferences and journals

We conclude this section with overview of the journals and conferences that publish most of the I4.0 research. To get a better understanding of which journals and conferences would be at this moment suitable for us as publication outlets, we have created the map in Figure 13. This is based on the results of the query for Smart industry, presented in Section 7.2, but it uses a different type of analysis, namely the citation analysis based on publication sources. In this way we can create an overview of the journals and conferences in which most papers from our query were published. The complete list can be found in Appendix 11.

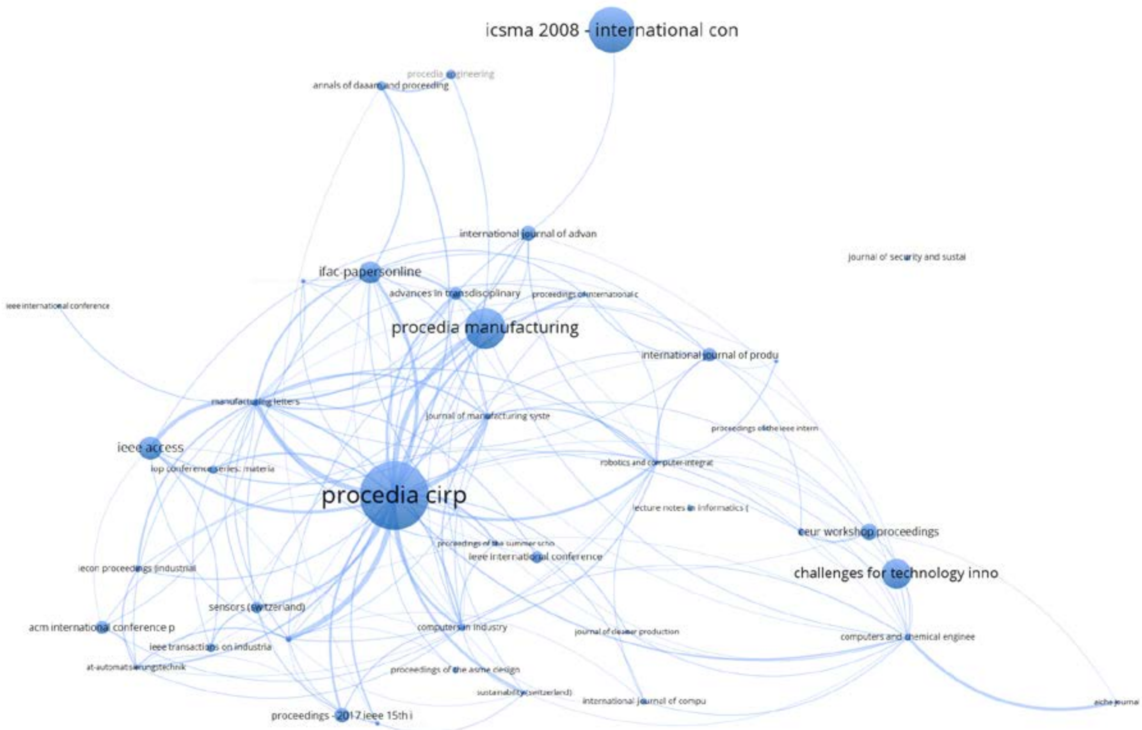


Figure 13: Journals & Conference proceedings citation analysis map

Analysis: From Figure 13, we can see that there are several outlets which are used by many of the papers included in our query, namely Procedia CIRP (proceedings from CIRP conferences on production engineering research), Procedia Manufacturing (proceedings on manufacturing engineering), Challenges for Technology Innovation (proceedings on smart manufacturing), etc. However, even though these top publication outlets are relevant for the topic of I4.0 (please note the overwhelming dominance of manufacturing journals and conference proceedings), it is important to note that they might not be entirely suitable for publications relating to all aspects of the SIRM. Nonetheless, since we consider that research about the implications of technology on business, society and people is still at an early stage, we expect that i) the publication outlets presented in Figure 13 could include in the future relevant calls for papers, which deal with these aspects, and ii) the configuration of the map shown in Figure 13 might change significantly, as more research gets published.

7.2.2 BMS research between 2000 – 2018

The first approach we took in order to compare the current state-of-the-art in I4.0 research with the research profile of BMS was to limit the results of the query used in Section 7.2.1 for authors with the affiliation containing the word "twente". ***This resulted in a set of 7 UT publications that explicitly mention any of the keywords: "smart industry", "industry 4.0", "smart manufacturing"***. Of these publications just one comes from the BMS[14]. This rather disappointing result can be explained by the fact that I4.0 is a rather young phenomenon. Although we are very much convinced that I4.0-relevant research has been produced by BMS in recent years, this has not yet been explicitly labelled as "I4.0" research. Also much BMS research, which is going to be labelled as I4.0, is currently starting in projects which were just recently funded (see Section 7.4).

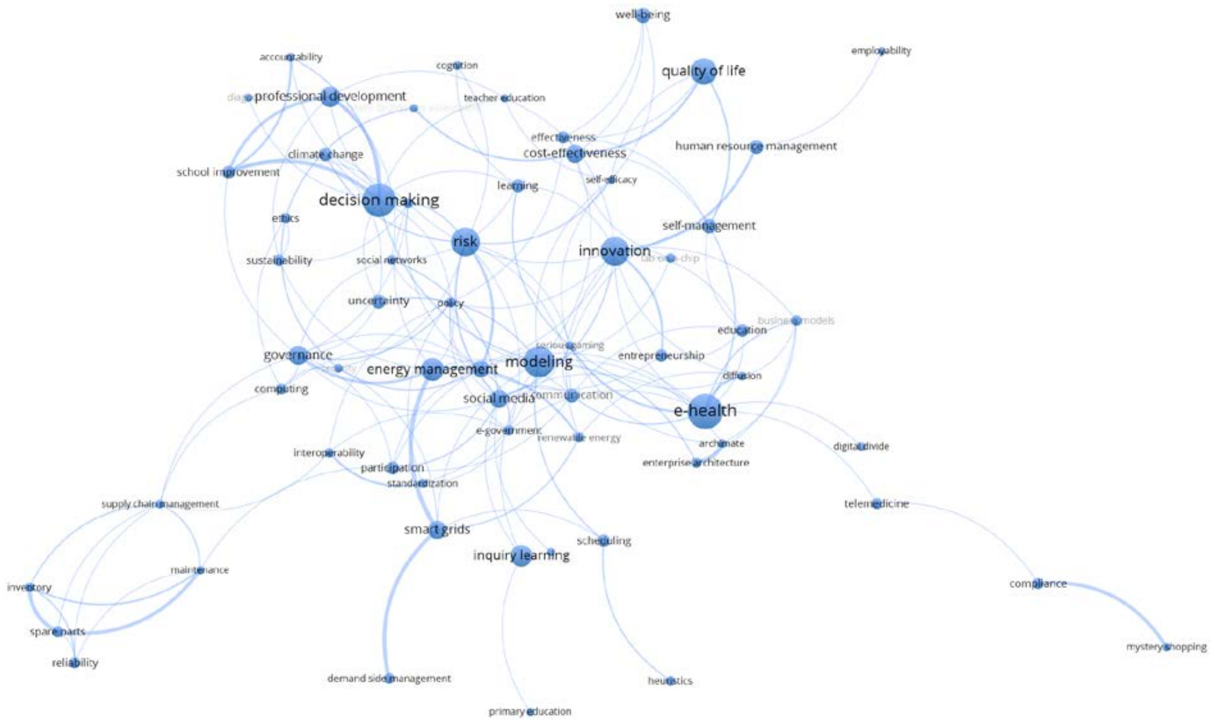


Figure 14: BMS research keyword analysis (based on 10098 publications between 2000-2018)

This situation forced us to find other ways to come up with a BMS research landscape. One idea was to carry out a bibliographic analysis of all BMS publications between the years 2000 and 2018.We thought that the work published during this period should reflect sufficiently accurate the whole research landscape within BMS. Our motivation was that in such way we could identify those topics that are overlapping with the different focal areas in SIRM or which could give rise to novel research in combination with I4.0 specific concepts and technologies. However, since our intention was to include all of the research performed within the BMS, we created a query which only contains the names of all current BMS scientific staff. To make sure that the resulting publications were from the UT, we added

[14] https://research.utwente.nl/en/publications/towards-an-integrated-architecture-model-of-smart-manufacturing-e

the filter AFFIL (twente). The full query can be seen in Appendix 12. This has resulted in 10.098 BMS publications.

Before generating the BMS research keyword-map with VOS viewer, we have filtered out several keywords, such as depression, arthritis, cancer etc. Our intention with this filtering operation was to exclude publications purely focused on psychology and healthcare, which would form the body of BMS research associated with the Learning and Health themes (these are currently subject to complementary roadmapping efforts). This was the reason to limit the scope of the BMS keyword-map to topics that are more likely to be relevant for the Industry roadmap. The results of this analysis is shown in Figure 14.

Analysis: The keywords in Figure 14 give a general overview of most important BMS research lines. As expected, even though there is nearly no explicit relation to Industry 4.0, we do have a good track record in research topics which can be easily associated with I4.0 research, such as sustainability, supply chain management, maintenance, scheduling, modelling and architecture, energy management, decision making, business models, entrepreneurship, cost-effectiveness, governance, ethics, human resource management, education, smart grids, professional development, human resource management, etc. This landscape encouraged us to run more precise queries to extract BPM publications that are specifically relevant for each area in the SIRM.
These queries have helped us to assess the maturity of the BMS track-record in relation with the specific areas of the SIRM. The queries we used for this purpose, and their results are as follows:

- **Global marketplaces**: "global marketplace" OR "platform economy" OR "e-commerce" OR "electronic commerce": 200 documents
- **Life-cycle solutions**: "life-cycle solutions" OR "product as a service" OR "serviti*ation": 3 documents; Life-cycle: 168 documents;
- **Mass customization**: Mass customi*ation: 11 documents
- **Decentral co-creation networks**: "enterprise architecture" OR "supply chain management" OR "control towers" OR "business model innovation" OR "entrepreneurship": 342 documents
- **Social inclusion and ethics**: "social inclusion" OR "social participation" OR "inclusive policy" OR "social responsibility": 96 documents; ethics: 359 documents
- **Sustainable economy**: "industrial symbiosis" OR "circular economy" OR "ecological footprint" OR "carbon footprint" OR "efficient resource utili*ation" OR sustainability: 378 documents
- **Policy and regulation**: "data policy" OR "data sharing" OR "data management" OR "policy instrument": 96 documents
- **Education 4.0**: "education 4.0": 0 documents
- **Continuous learning and employability**: "continuous learning" OR "lifelong learning" OR "employability" OR "e-learning" OR "learning systems": 288 documents
- **Self-managing teams and crowdworking:** "self-managing team" OR "self-designing team" OR "empowered team" OR "autonomous team" OR "self-directed team OR “team effectiveness" OR "team design" OR "crowdworking" OR "self-management": 220 documents
- **Management of T-shaped talent**: "t-shaped professional" OR "t-shaped talent" OR "21st century skills" OR "t-shaped skills" OR "t-shaped capabilit*" OR "talent management": 20 documents
- **Technology enhanced-work**: "technology-enhanced" OR "knowledge engineer" OR "enhanced worker": 44 documents.

If we project this state of affairs onto the SIRM we end-up with the BMS research heat-map shown in Figure 15.

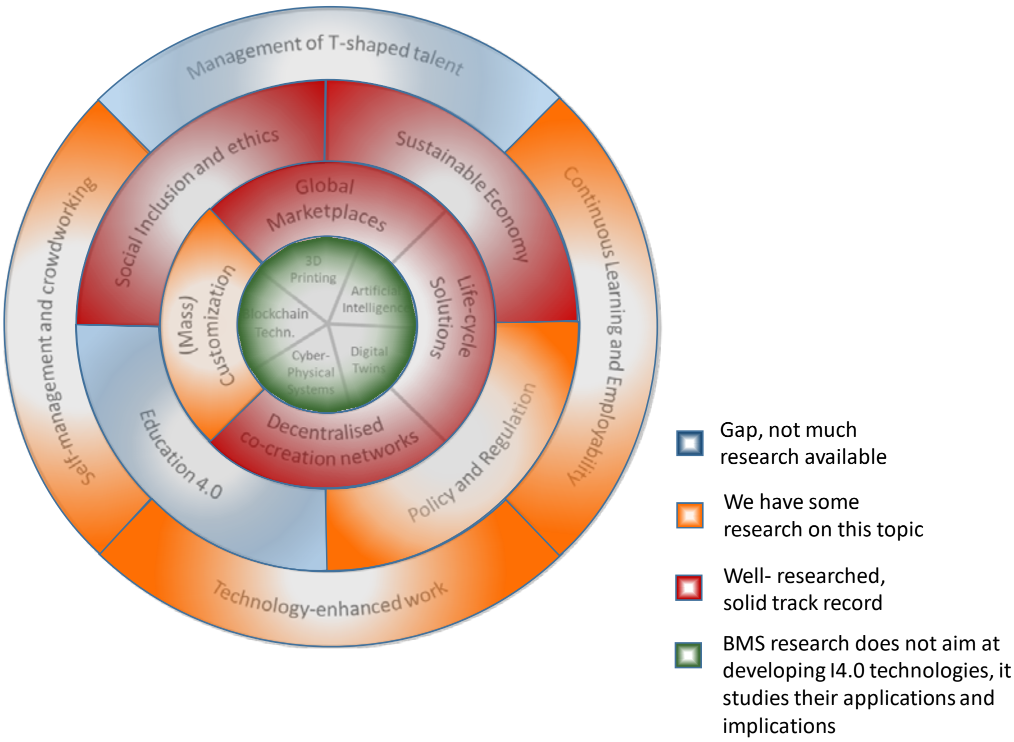


Figure 15: BMS research heat-map

7.3 The SIRM maturity model: a comparison of extant literature and BMS research

In this section, we provide an assessment of the research maturity of the different areas in the SIRM model (Table 3). For this purpose, we use a simple maturity model, with the following levels:

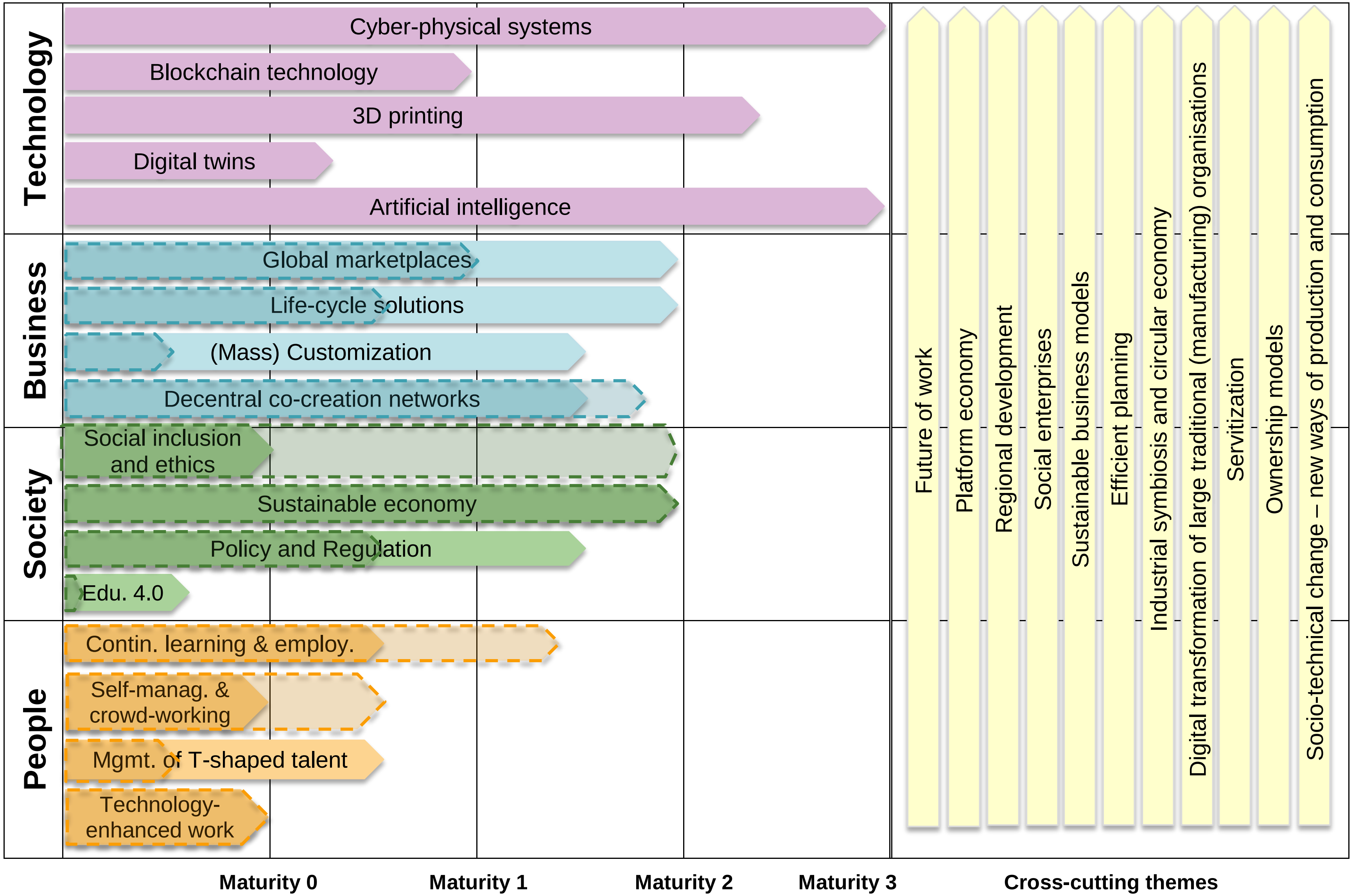
- Maturity 0: No Industry 4.0 specific research on the topic
- Maturity 1: Investigation and Conceptualisation
- Maturity 2: Validation and application
- Maturity 3: Knowledge transfer and valorisation

This is also the final result of this roadmap document. Not only it brings into one picture the SIRM areas and the I4.0 cross cutting issues, but it also assesses and compares the maturity levels of I4.0 research from two perspectives (resulting from our investigations so far): the perspective of extant literature (also described in the Chapters 4, 5, 6, and Section 7.2.1) and that of BMS research. More concretely, in this maturity model (Table 3) we integrate the two heat-maps from Figure 12, and Figure 15 with the cross-cutting concerns identified in the beginning of this chapter.

What we can observe is that the research related to the business aspects of the SIRM is relatively mature (see the solid arrows in the Business layer of Table 3), with two of the topics (Global marketplaces, and Life-cycle solutions) being at the point of entering the knowledge transfer to industry and valorisation stage. Similarly, in terms of research relating to society, the topic of sustainable economy is also entering the valorisation stage, while the topic of Education seems to not be covered by research, in relation to Smart industry. Unlike the other two focal areas of the SIRM, in the case of "People" (based on English language publications), there is little research in relation to I4.0. This is why all People-topics have a maturity of 0 or slightly above 0.

As mentioned earlier, in Table 3, we have also included the maturity of BMS research (shown as arrows with a dashed line border), which has been assessed based on the results of queries for each topic in the three layers, combined with the large query containing the names of the BMS research staff. The number of documents which have resulted from this search are mapped onto the aforementioned maturity levels, as follows: Maturity 0: Up to 50 documents; Maturity 1: Up to 250 documents; Maturity 2: Up to 500 documents; Maturity 3: More than 500 documents.

Table 3: Research maturity model



7.4 Flagship projects

In this section we give just a few examples of I4.0 projects that have recently started or are in progress in the IWG. For a complete list of relevant research projects please refer to Appendix 1.

Table 4: Flagship projects per group/department

Name[15]	**People**	**Society**	**Business**
CHEPS			
HEINNOVATE (Stimulating innovation and entrepreneurship in higher education)	✓	✓	✓
DASCHE (Developing, Assessing and Validating Social Competences in Higher Education)	✓	✓	
CSTM			
Sustainable Industrial Parks	✓	✓	✓
Social and environmental life cycle assessment to increase transparency in the Textile sector	✓	✓	✓
HRM			
HRM in the Platform Economy	✓		
Smart Industry and HRM	✓		
IEBIS			
DATAREL - big data for resilient logistics		✓	✓
SHAREBOX (Secure Management Platform for Shared Process Resources)		✓	✓
Logistic miners (Autonomous Logistic Miners)	✓		✓
NIKOS			
Industry 4.0 for SMEs (with Fraunhofer)			✓
Servitization of SMEs (with IEBIS and Fontys)			✓
OWK			
E-PLM 2.0 (Extended Product Lifecycle management 2.0)			✓
STePS			
IIT-Industrial Innovation in Transition		✓	✓
EU-MACS (climate services)		✓	
TS/M			
PERFECT skills and competences needed by purchasers in Industry 4.0	✓		✓
Machine-Based Mapping of Innovation Journeys (text mining distinguishing between exploration and exploitation projects)			✓

7.5 Relation with our education programs

Many of the existing BIT, IBA and IEM course can be extended with knowledge, research results and case studies relating to I4.0 and its impact on business innovation. As an example, the E-commerce course has already introduced a lecture on Blockchain and how it can be used by organisations to change their business model. Another example is the HRM minor that offers a

[15] In alphabetical order of group/department name

course on High Tech Talent Management in a Global Context[16], which is considered as an important aspect of I4.0. Additionally, BMS is involved in the development of an Industry 4.0 minor programme, together with other faculties, and there are also first ideas for a dedicated master. See Appendix 9 for more information about the minor.

The following master programmes are likely to receive a substantial I4.0 update:

- BIT-MA: Enterprise architecture; Data science and business; IT-management & innovation;
- BA-MA: Entrepreneurship, innovation & strategy; Strategic marketing & business information; Human resource management; Purchasing & supply management; Financial management.
- IEM-MA: Production & logistic management; Financial engineering & management;

Furthermore, case studies and guest lectures can be arranged for many courses to emphasise and explain the current opportunities and challenges brought on by I4.0 to organisations. Moreover, BSc, MSc and PhD assignments can be formulated based on this research question, since there are many angles which need investigating.

7.6 Required infrastructure

Purchased technology: Portable audio recording and processing setup, Work stress and mindfulness measurement devices, Audio transcribing software, Collaboration and brainstorming software.

Other relevant technology: Big Data and Smart Sensor Technology, Artificial Intelligence, Multi agent systems, Cloud Infrastructure, IoT platforms, System Integration technologies/platforms, Advanced man-machine interfacing, User profiling, Machine learning, etc.

16 https://osiris.utwente.nl/student/OnderwijsCatalogusSelect.do?selectie=cursus&cursus=201600001&collegejaar=2016&taal=en

8 UT EMBEDDING

In this chapter we provide an overview of the UT groups/institutes which are currently involved in initiatives relating to Smart industry. Currently, besides IWG, there are four other initiatives, as follows: the Industry 4.0 Consortium, the PDEng cluster for Smart industry, the CTIT Science for a Smart Society, and the Fraunhofer Project Centre. More details about these initiatives can be found in Table 4. Additionally, the table contains an overview of other BMS and non BMS staff which are working on topics relevant for Smart industry[17]. Please note that this list is not exhaustive and does not contain the members of the IWG.

Table 5: Overview of Smart industry initiatives

Groups	**Initiative description**
Industry 4.0 Consortium (Holger Schiele is the intermediary)	The University of Twente has expertise along the complete smart industry supply chain: design (cyber physical systems and customer intimacy), supply (supplier embedding and machine-to-machine negotiation), logistics (drones, physical distribution, materials handling) and production (automation, robotics and mechatronics, predictive modelling, zero defect manufacturing, additive manufacturing, flexible production), as well as adjunct functions ICT (data mining, value creation based on big data, Internet of Things), Business models, physical readiness (sensors and actuators, advanced materials, MEMS/NEMS technology), human/ change management (I4.0 skills, future of work) and legal/ policy / societal impact (smart society, machine-to-machine contracting). Scholars from all faculties engaged in smart industries work together in the Industry 4.0 consortium @ University of Twente.
PDEng Cluster for Smart Industry (Timo Meinders)	The PDEng Cluster for Smart Industry aims to build on the strong regional position of SMEs, promoting cooperation between SMEs, enhancing the university's activities in the field of knowledge transfer, and acquiring new knowledge about Smart Industry in practice.
CTIT Science for a Smart Society (Iddo Bante)	At CTIT we conduct the ICT research that make the societies of today and tomorrow smart. Societies are important to us: we are concerned about the relevance of our research for society, we embed our solutions into societies and preferably in a way that it seems normal to you and that it feels as if it's supposed to be that way.
Fraunhofer Project Centre (Common project with NIKOS)	The Fraunhofer Project Centre, a collaboration between the University of Twente and Saxion with the Fraunhofer Institute for Production Technology in Aachen, is now starting a project in which, the large amount of business intelligence already present in a company can be used in the transition of product supplier to service supplier - also called servitization: a development that fits I4.0. FPC @ UT will investigate this transition together with the UT faculties Engineering Technology (ET) and Behavioral, Management and Social Sciences (BMS), and together with an internationally operating company that is active in industrial automation.

[17] Information provided by Jannette Visser – Groeneveld, and by Leontien Kalverda

People	Topics in which involved
Boudewijn Haverkort	Communication technology; Cyber-physical systems; IT Focus on quantitative methods and techniques to support the design of computer and communication systems (cyber-physical systems)
Celeste Wilderom	Smart technology and video-based research Aiming to aid SMEs regarding digitization projects (working together with Henseler)
Eric Lutters	Working in PLM systems (part of that domain rebranded to 4.0) Working on learning factories (currently) Use simulation models to see what happens when design is changed Understand how a company and the interaction with stakeholder's changes
Henk Zijm	Design, planning and control of discrete manufacturing systems Supply Chain Management Design, planning and control of material handling systems Planning in maintenance and service logistics Industrial Symbiosis
Iddo Bante	Input for HTSM roadmap smart industry Oversees the CTIT's international network of research institutes, universities and industrial partners Helping companies in the region to look for market opportunities and business models
Juan Manuel Jauregui Becker	Management of design complexity Development and implementation of DFX methods Engineering modelling and leaning of design processes Multidisciplinary model integration
Milou Habraken	Focus on smart industry, expected skills, and skills needed in smart industries Broader characteristics of work and the relationships of employees - supervisors
Petra de Weerd-Nederhof	Business model innovation Organisation and network perspective
Roy Damgrave	VR labs that are used for showing what the consequences of our decisions will be; not only for visualisation purposes but also see how methods can be adjusted
Sipke Hoekstra	Production systems and robustness with production systems Working with supply chain configurations and M2M communications Maintenance of production systems
Timo Meinders	Contributor to the HTSM Smart industry roadmap Coordinator of the PDEng Cluster for Smart industry
Ton van den Boogaard	Numerical simulation of forming processes Numerical modelling of biomaterials Stability of plastic deformation and stability of material models in FEM analysis Optimization and robustness in forming processes Object Oriented Programming
Wessel Wits	Physics in design and manufacturing
Carsten Gelhard	Marketing, innovation and strategic management

	How firms can sustain competitive advantage by managing trade-off situations that are associated with value creation activities and by collaborating with external partners across the value chain
Marcus Pereira Pessoa	Work with systems and business models (how the system supports the business model)
Jos van Hillegersberg	Logistics, supply chain integration distributed planning with multi-agent systems, agent-based order dispatching, agent-based coordination in healthcare, Software mass customization, Sensor networks
Jasper Goseling	Logistics, healthcare logistics (largest part) but also automotive. Currently running cyber-physical systems. Complex networks, related to I4.0 scaling up networks of elements interaction, analysing these networks with new methods Communication networks, M2M communications, not yet there
Ariane von Raesfeld	Business development and networks
Fred van Houten	Ranging from design to manufacturing processes Faculty cross smart city involvement
Victoria Daskalova	Regulation of labour (what will they do, with unions and stable jobs or people as freelancers) Consumer protection can be adjusted. Thinking about competition: access to networks. Many products are dependent on companies to be able to connect to the grid to have access to the consumer, how to you manage connections, IP, collusion etc. Issues for standardization, were power accumulates and how this struggle for power can be better regulated, also for smaller companies.

9 NATIONAL / EU EMBEDDING

9.1 EU research agendas

The EU has identified several Research and Innovation Priorities relating to Smart industry (**Error! Reference source not found.**). These are related to several Challenges and Opportunities, which are mostly focused on the Society layer of the SIRM. Additionally, several Technology and Enablers are mentioned, which have an overlap to aspects of the People layer (Knowledge workers), Business layer (Manufacturing strategies), and Technology layer (Information and Communication Technologies) from the SIRM.

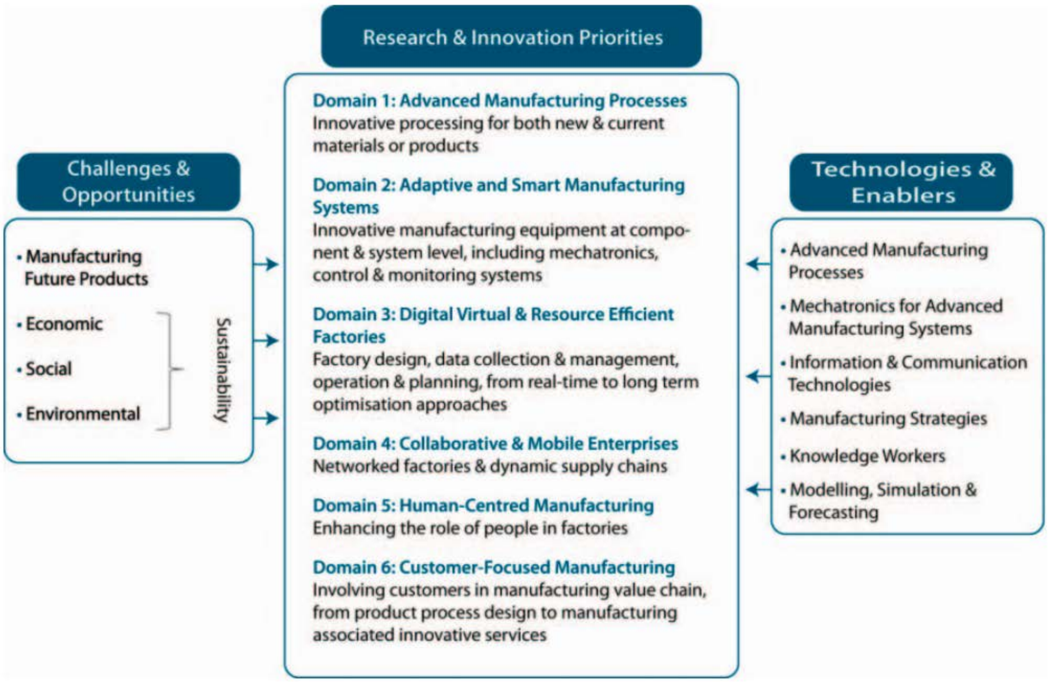


Figure 16: Industry 4.0 Factories of the future PPP – Strategic multi-annual roadmap[18]

The European Commission created a Public Private Partnership to support smart industry in Europe. This PPP is called “Factory of the Future impact on growth and jobs”. The PPP is a cross-disciplinary approach aimed at support Research & Development and Innovation.

The aim of the PPP is to increase the European industrial competitiveness, but to also promote the sustainability of this competitiveness. Thus, the production plans that are going to be developed in the coming year will need to be competitive with the World market but should also be sustainable. This will be done by developing industrial automation, state-of-the-art machinery and robotics. Next to this R&D will be done in the field of industrial software which can be used for the design and managements of the plants.

Next to this a second aim of the PPP is to look at energy- and resource-efficient manufacturing processes. Not only in terms of raw materials, but also in terms of socially sustainability. The new

[18] https://ec.europa.eu/research/industrial_technologies/pdf/ppp-factories-of-the-future-strategic-multiannual-roadmap-info-day_en.pdf

workplaces should be safe and attractive workplaces. To achieve these objectives high-tech companies should be actively involved in innovative manufacturing. The final objective is for the EU to remain the leading trade region in the world, keeping the share of EU trade in goods between 15–20 %.

The previous aims were related to the current work plan for EU 2020, however the EU has also formulated a Manufacturing Vision till 2030. This vision can be summarized in four main bullets:

1. Factory and nature → green & sustainable;
2. Factory as a good neighbour → close to the worker and customer
3. Factories in the value chain → collaborative
4. Factory and humans → human centred

The green & sustainable aim is related to achieving the lowest resource consumption as possible. This is related to energy and the use of materials. The aim of the factories of the future should be to be as lean, clean and green as possible. This can be achieved by developed closed loops for products and/or production and by the efficient use of scarce resources. Sustainability in materials and production processes is the key aim.

A second aspect of the factories of the future is that the manufacturing should be close to people. This is meant literally in terms of the factories being in cities and metropolitan areas. And figuratively in terms of event-oriented production and the integration of customers.

The third aspect of the factories of the future is that the factories should be collaborative. They should strive for highly competitive distributed manufacturing which is flexible, responsive and can cope with high speed of changes. The factories should have European production systems which are design oriented products and mass customised products. This can be achieved by integration of the product and process engineering. The collaboration should be agile, and demand driven from simple to sophisticated products in the value chain.

The final aspect of the factories of the future is that it is human centred. The factories should have human-oriented interfaces for workers. The process should have a process-oriented simulation and visualisation. The products and work should be tailored for different types of labourers. It should consider the aging population, education demands and training with IT support. There should also be a regional balance in that work conditions are in line with the way of life of the region the factory is located. This means that flexible working times and wage-systems should be possible. Finally, the organizations in this field should work on knowledge development, management and capitalisation of human capital.

9.2 National smart industry agendas (e.g.: Actieagenda)

At a national level, there are many other programs which focus on Smart industry. While some are defined at a national level, others are focusing on certain areas, such as the East part of the Netherlands.

9.2.1 Smart Industry Action Plan

In the Netherlands the Action Plan: Smart Industry – Dutch industry fit for the future was introduced. This report was commissioned by the Dutch government in 2014. The main aim of this action plan is to show that the Dutch industry is very well prepared for I4.0, but that a coherent approach is necessary to come to the best outcomes.

The action plan also identified areas where investments are needed. The main investments are needed in Robotics and sensors, Big data, The future of work (connecting education with new work), and ICT-infrastructure and cybersecurity.

The Smart industry action program also formulated 3 action lines which help guide the development of the smart industry agenda of the Netherlands. These actions lines are Capitalising on existing knowledge, Accelerating in field labs, and Strengthening the foundation.

As the report was developed in 2014 a lot of steps have already been taken. The fieldlabs for example have been developed. Field labs are practice-oriented environments in which companies and knowledge institutes develop, test and implement goal-oriented Smart Industry solutions and an environment in which people learn to apply these solutions. They also strengthen links with research, education and policy on a specific Smart Industry theme. Some have a regional focus, others a national and even European focus.

Currently 32 Smart Industry Fieldlabs are active in the Netherlands. For new Smart Industry Fieldlabs an application procedure has been developed with criteria such as a radical innovation objective, a program of at least three years with a program coordinator and a number of projects with various private and public partners, including financing and coordination with other Field Labs. The topics covered by these fieldlabs cover topics, such as smart and sustainable factories, 3D printing, blockchain, composite materials, robotics, connect supplier networks, etc. A complete overview of the topics covered in these fieldlabs can be found in Appendix 10.

In terms of strengthening the foundation the report identified three key areas: knowledge, skills and parameters (ICT):

- **Knowledge:** Capitalising on existing knowledge and accelerating in Fieldlabs provides a lot in the short term. In the longer term, it is essential to invest in new knowledge to face the competition in a sustainable way. There are challenges in different subareas in exploring this knowledge in greater depth, such as in robotics and sensors. Major steps can still be made in the relatively young fields such as big data, which are truly coming to fruition only now. To make great strides in future, new knowledge is also needed in the field of complex systems and the interaction between man and machine.
- **Skills:** Now more than ever, company management is being forced to stay close to market developments and translate these developments into their own organisation. They cannot afford to linger in concepts that have proven themselves in the past; rather, they continuously need to think about how to distinguish themselves from the competition with new business propositions. The success of the organisation is largely determined by the skills of the employees. That demands involvement of these employees and therefore another management style and a different organisational design. Many professions will change and investments in digital skills are necessary for staff at all levels. This requires appropriate training at schools and intensive cooperation between education and the business community.
- **Parameters (ICT):** Parameters in the field of ICT as well as the legal area are necessary for Smart Industry, since the core of Smart Industry is the connection between machines and companies in the chain via ICT, particularly via internet. Organising companies in chains, exchanging data, cybersecurity and the quality of the ICT infrastructure are all critical[19]

[19] http://smartindustry.nl/wp-content/uploads/2017/08/opmaak-smart-industry.pdf

9.2.2 Top sector policy in the Netherlands

In the Netherlands the approach to research and development is embedded in the Top sector policies. There are currently 9 top sectors identified in the Netherlands. These are: High tech Systems and Materials, Horticulture & Starting materials, Creative industry, Life sciences & Health, Chemistry, Energy, Agri & Food, Water, and Logistics.

High Tech Systems and Materials

Although all are potentially related to I4.0 only one of these has specifically focussed on this topic. In the top sector policy High-tech Systems and Materials, a roadmap was developed till 2025. In the roadmap two main priorities were formulated as follows: Innovative materials and Smart industry. These two priorities are of course linked as the development of I4.0 will need innovative materials to develop.

The HTSM roadmap specifically calls for cooperation between companies and universities. The NWO calls will be used to realize scientific research projects on materials for industries and at universities. Most of the projects will be organized via the High-Tech Materials call. These calls are a cooperation between NWO (FOM and STW). The NWO calls are included in the funding opportunities pages of this roadmap.

Following the general roadmap of HTSM a specific roadmap on Smart Industry (Industry 4.0) was developed. This roadmap defines the research agenda for HTSM and ITC and contains a map for the NWA. In this roadmap several technologies are further identified which drive industry 4.0, these are: Internet of Things, 5G, Blockchain, big data and artificial intelligence. Quantum computers are mentioned as a future development with an impact on Industry 4.0. According to the roadmap the developments in industry 4.0 will influence society on many different levels and the consequences of Industry 4.0 need to be researched by both beta sciences, engineering, social- and economic management studies.

According to the roadmap a large impact of industry 4.0 will be on aspects of employment. Examples include the digitals skills of employees older than 35, the (expected) scarcity of technical personnel in the coming years and the cooperation & interaction of robots with people. An overarching concept in with these challenges is Life Long Learning.

Next to the effect on people, industry 4.0 is also expected to have an effect on businesses. The main challenge identified is how businesses can enlarge their production. Within industry 4.0 organizations are faced with different challenges such as:

- How to develop different, smarter products which are more energy efficient and use recycled materials?
- How to produce on a smaller scale, faster and more reliable?
- How can you provide employees with better and more productive tools and how can you train them to use these tools?

The HTSM roadmap identifies research areas envisioned to be relevant in the next 5 to 10 years. The question posed in the roadmap is: what is needed to ensure that the Dutch economy and Dutch society benefit from the opportunities offered by Smart Industry? The answer to this question is refined along 3 development areas: technologies, business and society. These are combined in a matrix together with smart industry concepts: smart products & services, smart manufacturing & processes and smart systems, as shown in Figure 17.

	IMPACT/development areas		
	Technologies	Business	Society
Smart Products & Services	1. Smart Design & Engineer. 2. Integrated Life-cycle Mgt.	11. New Business Models	15. Human Centered Technology
Smart Manufacturing & Processes	3. Additive Manufacturing 4. Advanced Manufacturing 5. Robotics& Mechatronics 6. High Precision Equipment	9. Mass Customization 10. Production Mgt. 13. Condition-Based Maint. 16. Employee Mgt.	15. Human Centered Technology
Smart Systems	5. Robotics & Mechatronics 7. Cyber Physical Systems 8. Digital Twin 14. Cyber Security	7. Cyber Physical Systems 13. (Trusted) Data Sharing	17. Smart Response 14. Cyber Security

Figure 17: Smart Industry model according to the HTSM roadmap with knowledge and technology challenges

Since the HTSM roadmap is the only national research roadmap on the topic of Smart industry, we also compare it to the SIRM. In Figure 18, the results of this comparison can be seen. The green colour represents an overlap between the HTSM and SIRM, while the colour is used to signify the aspects which are included in the SIRM but not covered by the HTSM roadmap.

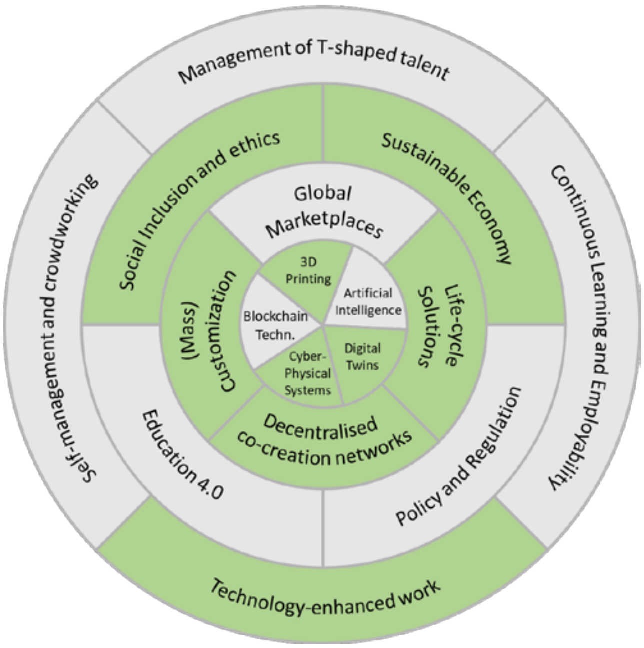


Figure 18: Overlap between the HTSM research roadmap and the SIRM (the green areas are in both roadmaps)

As can be seen from Figure 18, there is a significant overlap between the HTSM research roadmap and the SIRM, in terms of development areas and topics which are covered. However, unlike the SIRM, the HTSM roadmap does not contain an explicit development area relating to People. Rather these aspects are implicitly included in their Technology, Business and Society areas. Therefore, we consider that our proven track-record of research on aspects relating to People would help provide knowledge and insights to an area which is not very well covered in other agendas and research.

Another distinction between the two roadmaps is that the HTSM has a very strong focus on technology. Therefore, technologies are included as topics within the Business and Society areas as well. This also reflects the current approach of international research on the topic of Smart industry, which has a strong focus on the technology aspects and less on the implications to Business, Society and People. Therefore, we consider that the BMS faculty could contribute greatly to advancing the state-of-the art on the implications of Smart industry on these three areas.

9.2.3 Regional programs in the Netherlands

In the East Region of the Netherlands, where the University of Twente is also located, the BOOST program was introduced. According to this action agenda Industry 4.0 or Smart industry can be captured in several aspects, as seen in Figure 19.

According to the BOOST agenda there are three main enabling technologies (the orange circle): digitization, manufacturing technologies and network centric. The grey circle represents the outcomes of smart industry thus: automation, high value information, customer intimacy, value chain participation, flexibility and improving quality.

Not only have they identified the technologies and the outcomes, they have also identified the main sectors they feel will benefit from I4.0. They have identified the automotive, aerial- & space sectors as they are advanced industrial sectors. Next to these sectors they also see possibilities for the food industry, agriculture, health care, energy and waste management. Examples in these sectors include precision agriculture, surgical robots and smart grids. Next to this they have also identified that I4.0 will have an effect on production lines, changing skills of workers and new business models and service concepts with a central role for customers.

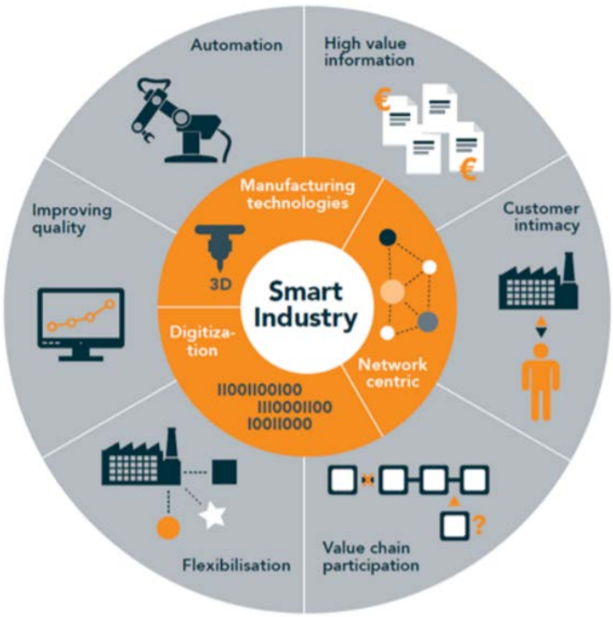


Figure 19: Smart industry agenda for the East region of the Netherlands (BOOST)

Thus, according to this action plan the main challenges are: changing skills, new business models, more technologies and international competition. Apart from the international competition these challenges have also been identified by BMS. International competition could be considered as part of the new business models that are needed.

9.3 Business needs

While the EU and national agendas provide a good understanding of the societal and, to some extent, people implications of Smart industry, in order to have a complete understanding, it is necessary to consider the business needs and priorities. Therefore, we have created and distributed a survey questionnaire which captured two main questions relating to the top 3 priorities and (expected) problems with respect to the adoption of / migration to Smart Industry. From the results of the survey, we can conclude that the priorities of the organisations which have responded have a large overlap with the SIRM on several aspects:

- **Business**: improved efficiency and productivity, enterprise and manufacturing architectures, digital transformation, stimulating research and start-up initiatives based on I4.0 principles;
- **Society**: Privacy, security and findability of data, understanding 21st century skills;
- **People**: managing the work load of employees, communication, matching between techniques and employee skills, encouraging lifelong learning;

When looking at the results relating to the top problems/issues the responding organisations expect to face, the following aspects are mentioned:

- **Business**: unawareness and low acceptance of I4.0 in industry, contact with customers might become more impersonal, small organisations are unsure of how to stay competitive and innovate, questions regarding how to gain and maintain speed and scale, issues regarding slow pace of transition and too little (financial) capacity;
- **Society**: varying perceptions of sense of urgency, underestimation of the impact of changes in the environment;
- **People**: 'old fashioned thinking' with regard to skills development by decision makers in both politics, companies and institutions;

We also consider the survey performed by PWC with 2.000 participants, in 9 major industrial sectors and across 26 countries[20]. The survey reflects the status of I4.0 across several industries, which can be summarized as follows:

- **From talk to action**: I4.0 is no longer a buzzword, with many organisations making substantial investments that deliver strong results. Many organisations expect to have a significant increase in their digital portfolios of products and services until 2020, with almost three quarters expecting to have highly digitised horizontal and vertical value chain processes;
- **Digitisation drives quantum leaps in performance:** Organisations expect that I4.0 will help them reduce annual costs (by an average of 3,6%) and increase their annual revenues (by an average of 2,9%). These kinds of gains could reshape the competitive landscape and bring fundamental changes to established industries;
- **Deepen digital relationships with more empowered customers:** It is expected that products, services and systems will be increasingly more customised to the needs and preferences of customers. Organisations plan to use data analytics to understand and meet the expectations of their customers;
- **Focus on people and culture to drive transformation:** Many organisations consider that their greatest challenge is not implementing the right technology, but rather the lack

[20] https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf

of digital culture and skills in their organisations. The success of investing in a technology depends of the right kind of leadership and of the ability of organisations to attract, retain and train digital natives;

- **Data analytics and digital trust are the foundation:** Data is considered as one of the core aspects of I4.0, and therefore successful organisations need to master data analytics to help drive decision-making. Strong risk management and data integrity systems are crucial aspects for organisations to consider in order to avoid breaches and disruption of operations;
- **Robust, enterprise-wide data analytics capabilities require significant change:** In order to support the required data analytics capabilities, organisations need to develop robust organisational structures. Half of the organisations which responded stated that they already have data analytics capabilities, but a majority of them still rely on ad-hoc capabilities of single employees;
- **Accelerating globalisation, but with a distinctly regional flavour:** Another key characteristic of I4.0 is that it will foster digital networks and ecosystems that span the globe, while still having a strong regional presence. High investments in technology and employee training could bring organisations gains in operational efficiency, cost reduction, and quality assurance;
- **Big investments with big impacts:** The main focus of the investments organisations make will be on digital technologies like sensors/connectivity devices and on applications that can help organisational processes. Additionally, organisations are making substantial investments in the development of their employees and for fostering organisational change. It is estimated that global industrial products organisations will make investments of around $900bn per year, through 2020.

Another viewpoint on the business needs of organisations can be found in the survey performed by CGI among 1,000 executives in 10 manufacturing industries and 20 countries. The key takeaways from this survey are as follows (Figure 20):

- Digital transformation is accelerating across the value chain;
- Reducing costs, improving agility and speed to market are main priorities;
- Internet of things, mobile and cloud solutions are crucial for facilitating the digital transformation;
- Modernizing IT and removing legacy applications are key enablers;

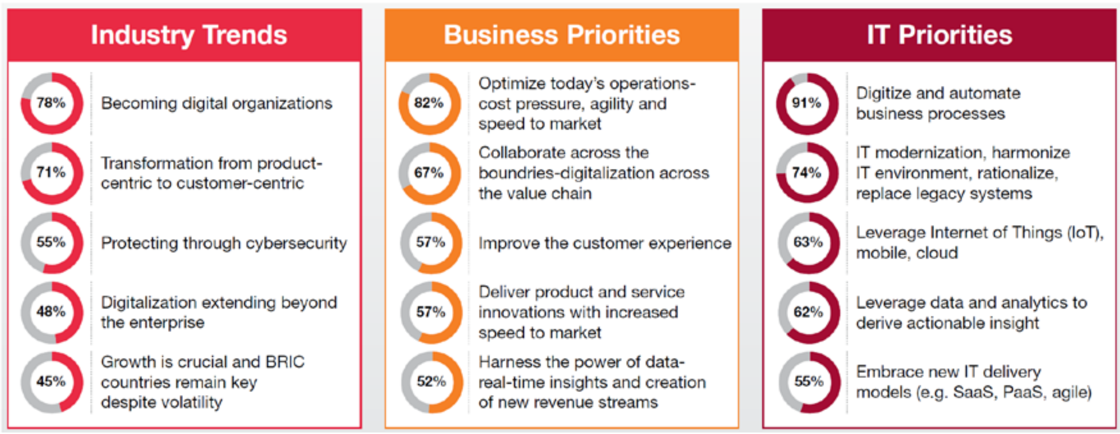


Figure 20: CGI Industry 4.0 survey (2016)[21]

[21] https://www.cgi.com/sites/default/files/white-papers/manufacturing_industry-4_white-paper.pdf

9.4 Funding schemes

Within the current Horizon 2020 program there are several funding possibilities related to I4.0. The current work program will run from 2018 till 2020. The next program, tentatively called Framework Program 9, is not yet developed. The EU is currently preparing this new program. The current is that the EU is consulting with stakeholders and holding key policy debates. A potentially interesting site and organization in this regard is Science Europe. Science Europe is an association of European Research Funding Organisations (RFO) and Research Performing Organisations (RPO), based in Brussels[22]. PNO also has an office in Brussels and we are constantly monitoring the latest information on FP9. Information that we receive is regularly communicated to our partners via the 'Subsidieflits' and our Matchpoint site.

In the sections below the focus is on current calls for the period 2018 till 2020. These calls are structured along the lines of the SIRM. Some calls can be used by all these research lines while others are more focussed towards one research line. The included calls have been chosen using the results of the consultation, the stakeholder analysis and knowledge of the sector by PNO. The list is geared towards the concepts and are not yet geared towards potential partners. As almost all calls need a consortium from different European Member states to be eligible for funding, this would be the next step. The first step is defining the key research areas and identifying potential calls (as is done in this roadmap) and the next step would be to combine these into potential project consortium (currently outside of the scope of this roadmap). This can be done in different settings which are outlined in the final paragraph of this chapter. A complete overview of these programmes and calls can be found in Appendix 8.

Table 6: Overview of upcoming funding possibilities

Programmes	Details	Deadline
H2020	Research and Innovation Actions (RIA) (TRL 1-4)	-
	Innovation Actions (IA) (TRL 5 – 9)	-
	Coordination and Support Action (CSA) (TRL < 2)	-
	Fast Track to Innovation (FTI) (TRL 4 – 9)	-
Marie-Sklodowska-Curie	Innovative Training Networks (ITN)	15.01.2019
Erasmus+	Strategic Partnerships	-
Science with and for society (SwafS)	SwafS-16-2019 – Ethics of Innovation	02.04.2019
Smart Anything Everywhere	DT-ICT-01-2019 - Digitising and transforming European industry and services	02.04.2019
INNOSUP	INNOSUP-04-2019: Workplace innovation uptake by SMEs	17.01.2019
	INNOSUP-07-2019: European Open Innovation network in advanced technologies	01.08.2019
	INNOSUP-01-2018-2020: Cluster facilitated projects for new industrial value chains	03.04.2019 12.09.2019
NWO/STW programmes	Duurzame Living Labs - Ontwikkelsubsidies voor consortiumvorming (transport/logistics)	27.03.2018

[22] https://www.scienceeurope.org/policy/policy-areas/framework-programmes/

	Open Technologieprogramma – technical research projects	All year
	Perspectief programma – economic and societal impact in the Netherlands	Q4 2018
	OPEN mind – ideas with significant societal impacts	Nov 2018
	Commit2data - public private partnerships between business and science	Coming soon
M.Era-Net network	Societal challenges and evolving technological advancements	Q4 2018
Interreg	Spatial and regional development	All year

9.5 Smart industry initiatives from other knowledge institutes

Within the Netherlands and other EU countries, several initiatives relating to Smart industry can be found (Table 6). It is worth noting that this list is not exhaustive, and we intend to update it as we gather more information about this topic.

Table 7: Overview of national and European Smart industry initiatives

Netherlands	
4TU.Federation	This project aligns the key R&I community in the Netherlands in the field of ICT for smart industry, in order to be better prepared for the future. Through a series of workshops, input from European policy documents and funding program descriptions, and interactions with foreign experts we intend to strengthen the Dutch R&I position in this field working towards a tailored R&I agenda for ICT in smart industry.
VSNU Digital Society Research Agenda	Aims to secure the Netherlands a leading international position in the field of human-centred information technology. The seven research programme lines incorporated in this agenda offer enormous opportunities with the potential for global impact. These themes range from democratic decision-making and eHealth to cyber security and responsible algorithm design. The Digital Society is a cross-cutting programme through nearly all of the routes of the Dutch National Research Agenda (NWA). In this effort, the fourteen collaborating Dutch universities are actively taking the lead on this subject.
University of Groningen academic roadmap	The aims of the roadmap are to develop new fundamental knowledge, to create a conceptual foundation for current smart industry initiatives, and to train and inspire students in a variety of Master programs. It presents themes of on-going and future research on smart industries, such as business innovation, advanced production processes, agile demand-driven manufacturing, and embedded intelligence.
Fieldlabs	Many of the Dutch universities are involved in Smart industry fieldlabs which cover topics, such as personalised products and services, extended product lifecycle management, automated production and distribution of fresh foods, multimaterial 3D printing, flexible manufacturing, digital factory for composites, optical instruments, robotics, blockchain, innovation hubs, and big data.
European level	
Acatech	The national academy of science and engineering in Germany has provided a comprehensive report in which their vision for Industry 4.0 is

	described. Aspects, such as novel business opportunities and models, new social infrastructures in the workplace, novel service-based, real-time enabled CPS platforms are mentioned as main aspects that will be fostered by Industry 4.0.
LeanLab	The Institute of Innovation and Industrial Management operates a learning factory (LeanLab) since 2014 to enhance academic education, company trainings and hands-on research in the fields of industrial engineering and logistics. The aim is to enable practice-oriented learning in an environment close to industrial reality for facilitating effective knowledge-transfer.

10 CONCLUSION

The goal of this document was to develop a **BMS smart industry roadmap**. The artefact we created is a roadmap as it defines strategic research directions for the coming 10-15 years. It should be noted that it is not a roadmap in the traditional sense, since it does not provide any detailed sequencing of activities projected on a precise timeline. The reason for this is that I4.0 is a rather broad new topic, far from the status of being an established field with clear research directions, well defined theoretical foundations, and paradigms. We believe that academic research (in particular in an emerging field such as I4.0) does not lend itself for such projections, as research is an ongoing, often risky process, with highly unpredictable outcomes and duration. Therefore, our main focus was to identify, motivate and clarify focal areas with potential for BMS research in the coming years.

As result of several workshops, numerous exchanges of ideas, and literature research, three major focal areas have been identified as target of BMS strategic research for the coming years: Business, Society, and People. We refined each of the focal areas into several sub-areas that reflect both the research interests of BMS researchers, and the information we collected on I4.0-related industry needs.

In focal area “Business”, we established that future BMS research should have impact on:

- The shift from tightly coupled supply chains to **global marketplaces** and/or business ecosystems
- **Life cycle solutions** and servitization instead of finished products
- **Mass customization** and personalization instead of standard mass production
- Value **co-creation** with customers and/or within **decentralised** business ecosystems

In the focal area “Society”, with our research is aimed at having an impact on:

- **Sustainable economy**, through our research aimed at novel ways the manage the production, distribution, trade and consumption of goods in a manner which promotes reduction of waste and efficient use of resources
- **Policy and regulation**, by addressing the development of new policies and regulations, together with standardization in areas, such as data management, and interoperability of systems and organizations within the global value chain
- **Education 4.0**, by understanding how to create the institutional context to support the development of and migration to this new type of education, while focusing on how to shape professionals that master 21st century skills
- **Social inclusion and ethics**, by exploring the ways in which we can steer the I4.0 technological transformation in an inclusive way, in order to anticipate and avoid the risks, and challenges of excluding (large) groups of people from the gains of the socio-technical transformation.

In focal area “People”, we established that future BMS research should have impact on:

- **Continuous learning and employability:** through research on how workers are trained in order to prepare them for jobs in Smart industry (on-the-job training vs formal education).
- **Self-management and crowd-working:** through research on the mechanisms and organizational structures that lead to the reduction of the need for direct supervision due to the formation of teams which are empowered and able to work autonomously.

- **Management of T-shaped talent:** through HRM research that relates the nature of work in the smart industry era to a different type of workers, acting as T-shaped professionals, who have a different set of skills, and boundary-crossing competences, next to a deeper functional understanding.
- **Technology-enhanced work:** through research on the way workers are expected to interact/collaborate with machines.

In order to understand the gaps in the extant literature, and in order to position our research with respect to the current trends in the international literature we have carried out bibliographic analyses and we have explored the research landscape of the BMS faculty. These investigations lead to a number of conclusions, the most important of which are listed below:

- At this moment, ***I4.0 research still predominantly focuses on I4.0 technology development and validation/implementation*** (i.e., the "High tech"), and clearly ***significantly less on the social/societal, and organisational implications of delivery, adoption and usage of I4.0 technologies*** (i.e., the "human touch"). We perceive this as a fantastic opportunity for us as "high-tech / human-touch" researchers, as we have the right expertise and track-record to fill this gap in the state-of-the-art research.
- It is evident (from all the bibliographic analyses) that ***I4.0 technologies are the most intensely researched topic in the published literature***. I4.0 technology (red) is positioned in the literature as enabler and/or trigger of everything else.
- Although the topics falling under the focal area ***Business have received a fair amount of attention from the research community***, the keyword maps we constructed reveal an ***under-representation of People-related research in the extant literature***. The situation is not much better for Society research. Of the four aspects we identified in the focal area ***Society, only sustainability is receiving a fair amount of attention in the literature***. All others, are missing or are weakly represented.
- We identified a second important ***gap*** in the literature concerning ***the innovation methodologies and patterns traditional organisations follow during their migration to I4.0***. This is also a confirmation of the significance of the research problems we put forward in Section 4.1.
- Even though there is ***nearly no explicit relation to Industry 4.0 in BMS research*** published so far, ***BMS has a solid track record in research topics which can be easily associated with I4.0 research***, such as sustainability, supply chain management, maintenance, scheduling, modelling and enterprise architecture, energy management, decision making, business models, entrepreneurship, cost-effectiveness, governance, ethics, human resource management, education, smart grids, professional development, human resource management, etc.
- The areas in which ***BMS has a competitive edge or has produced a significant output have been identified in the heat-map from Figure 15.*** A comparison the BMS research landscape and the state of affairs in the international literature, and a maturity assessment has been given in Table 3.

10.1 Future work of the IWG

For the remainder of this year the IWG will primarily focus on three tasks: improvement of the current version of the roadmap, preparing for and participating in the mid-term review, and conducting community forming activities and strengthening the collaboration with other UT groups and with the industry. Concretely:

- We feel the working group should more actively seek contacts with UT's Industry 4.0 group and contribute with our roadmap to the general UT smart industry vision document. To this end we plan to actively get involved with other UT I4.0 activities and program writing initiatives by establishing regular contact moments with, among others, Timo Meinders, Iddo Bante, Holger Schiele, etc.

- We plan to broadly distribute the roadmap document, and improve it based on feedback we will receive from all the BMS groups involved in this field, from the chairs of the other BMS research themes, and the BMS dean & research dean.
- We plan to organise a match-making event in order to strengthen the relationship between our group and the industry. The main goal would be to facilitate the emergence of concrete project ideas and to form consortia around these ideas.
- Organising a series of monthly seminars with speakers from government, industry and academia for the Smart industry audience within BMS.
- We plan site visits to the Factory of the Future, Field labs and companies which are actively involved with Smart industry.
- We plan a visit to Brussels, together with a larger BMS delegation for lobbying purposes.

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APPENDICES

Appendix 1 – About the BMS Groups/Departments Involved in Designing the Roadmap

Appendix 2 – Quantitative Bibliographic Landscaping Maps

Appendix 3 – Smart Industry EU Funded Projects

Appendix 4 – Business Theme EU Funded Projects

Appendix 5 – Society Theme EU Funded Projects

Appendix 6 – People Theme EU Funded Projects

Appendix 7 – Overview of Universities and Organisations Which are Heavily Involved in Smart Industry EU Funded Projects

Appendix 8 – Funding Schemes

Appendix 9 – Proposal Minor Industry 4.0/Smart Industry

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Appendix 11 – Overview of Smart Industry Journals and Conferences

Appendix 12 – Query for BMS Research

Appendix 13 – State-of-the-art research for Industry 4.0, Business and Sustainability

APPENDIX 1 – ABOUT THE BMS GROUPS INVOLVED IN DESGINING THE ROADMAP[23]

CHEPS (Center for Higher Education Policy Studies)

CHEPS is carrying out research on the impact and value of higher education, in light of demands placed on (future) graduates by industry, government and other societal stakeholders. What skills do graduates need in order to prepare them for the (future) labour market? How can providers of higher education ensure that the quality and relevance of higher education programmes is in line with what our knowledge-driven and increasingly technology-driven societies need? What enabling frameworks exist and where do they need revision in order to make sure students learn the skills and competencies needed? The smart design of (higher) education systems not just includes adequate enabling frameworks but also close connections between higher education and the world of work. CHEPS is a research centre that not just knows about the internal mechanics of higher education institutions but is also aware of how higher education may be linked better to the outside world in order to encourage business innovation and graduate employability. Industry 4.0 requires Education 4.0.

Key persons: Dr. B.W.A. Jongbloed (working group member); Dr. J.J. Vossensteyn (Head of department)

Flagship projects:

- HEREL (Promoting the Relevance in Higher Education). Funded by European Commission (DGEAC)
- PROBE (Professional Bachelors and Employability) funded by: Dutch Accreditation Agency
- Excellence in Higher Education (Evaluation of the SIRIUS programme): funder: Ministry of Education
- HEINNOVATE (Stimulating innovation and entrepreneurship in higher education). Funded by OECD and DGEAC
- DASCHE (Developing, Assessing and Validating Social Competences in Higher Education). Funder: ERASMUS+
- U-Multirank (a Multidimensional User-driven transparency tool to compare higher education institutions). Funder: European Commission, Bertelsmann Foundation
- HORES (Honours education: selection, effectiveness and effects on regular higher education): Funded by NWO

[23] In alphabetical order

CSTM (Department of Governance and Technology for Sustainability)

CSTM was established in 1988 to conduct research in environmental policy and cleaner production, expanding during the 1990s to a more general focus on technology and sustainable development. Its mandate mirrors the entrepreneurial goals of the University of Twente: to conduct and apply innovative research for the benefit of society. We specialise in governance, emphasising sustainable development, environmental quality and resilience, social inclusiveness, and technological innovation – from both developed and developing country perspectives.

Our research program ‘Innovation and Governance for Sustainable Development’ is built around three research themes addressing different areas of sustainable development: energy transition, water governance and sustainable production and consumption. The three areas can contribute to the “Smart Industry” field, because of their focus on changing governmental sustainability strategies towards environmental governance and industrial production and consumption.

Connectivity among multi-actors (network constellations), who join forces to collaborate in their goal to greening the industry, is here regarded as one of the effects of “smart industry technologies”. Furthermore, corporate collaborative strategies of companies are also studied, especially when network approaches and capacity-building partnerships are used for increasing corporate and product legitimacy. Topics as “Productive uses of energy in the informal food sector”, “Legal governance of innovative smart energy systems/grids”, “Legal governance of development and use of drones & robotics”, “PC3: Bottom of Pyramid Entrepreneurialism as STAR/T (living smart campus project)”, “Circular Economy”, “Life Cycle Analysis” and “Sustainable Industrial Parks” and are in the core of CSTM’s approach to the Smart Industry field.

Key persons: Dr. M.L. Franco-Garcia (working group member); Prof. Dr. J.T.A. Bressers (head of department); Prof. Dr. M.A. Heldeweg (main researcher Policy and Regulations)

Key projects:

- Sustainable Industrial Parks;
- Forestry management and climate change (Think global Act local)
- The transition towards circular cities
- Sustainability at food manufacturing SMEs
- Social and environmental life cycle assessment to increase transparency in the Textile sector
- Productive uses of energy in the informal food sector
- Legal governance of innovative energy infrastructures, particular of smart energy systems/grids and of heat grid systems
- Legal governance of development and use of drones & robotics
- Enviromentor (EU project) (finished);

HRM (Human Resource Management)

The HRM research group aims at exploring interdependence between HRM and social and technological (digital) innovations, contribution of HRM to innovation performance, and on the changes and re-structuring of the HRM function within for-profit and non-for-profit organizations. In our contribution, we depart from two definitions.

Two research sub-fields

Working in the environment of the technical university, we position our research and teaching in the interdisciplinary domain "HRM, Technology & Innovation". HRM & Innovation Performance; and Innovating HRM Function through Technology are two sub-fields of our research.

- The sub-field "HRM & Innovation Performance" focuses on the contribution of HRM to multi-level individual, team and organizational performance. In line with the notion that organizations need to develop new products and services, and individuals to adopt new roles and behaviours, to keep up with technological developments, this sub-field focuses on an impact of technological and social innovation.
- The sub-field "Innovating HRM Function through Technology" focuses on the outcomes of various innovations within the HRM function and their value creation for organizations. We view technology as part of a wider social and political system, not as a purely technical product of design, but grounded in, and constituted by, social forces. The technology itself is perceived as a social construct rather than only as a physical entity, and therefore it is seen as subject to change during the implementation process. We see our goal as to understand the implementation process instead of prescribing factors of success. The focus of our studies is on tracing the use of technology through the construction of different meanings by pre-existing social groups such as HR professionals, line managers, and employees.

Key persons: Dr. A.C. Bos – Nehles (working group member); Prof. Dr. T. Bondarouk (head of department and consultative group member)

Flagship projects:

- Human Resource Management for Employee-Driven Innovation
- Managing Self-Management and Self-Managing Teams
- Smart Industry and Human Resource Management
- The Implementation of New Ways of Working
- Implementation and Effectiveness of Digital HRM
- Human Resource Management in the Platform Economy
- Robotization of Human Touch

IEBIS (Department of Industrial Engineering and Business Information Systems)

The mission of IEBIS is to conduct high-quality interdisciplinary research and education in area of Industrial Engineering and Business Information Systems. We closely collaborate with industry, knowledge institutes and government agencies. We focus on projects that have substantial impact on innovating practice while significantly contributing to the international scientific knowledge base.

The focus of our research is on the logistics, healthcare and services sector. We have a special interest in decision support systems and inter-organizational systems connecting networks of businesses and governments. We study novel ways of organizing networks such as dynamic global sourcing and multi-agent coordination. We develop and apply quantitative models and algorithmic approaches, simulation and gaming, ICT architecture and business modelling and prototyping to create and evaluate innovative concepts.

The research of IEBIS is divided in four themes:

- Design, planning and control of logistics and supply chain processes in (networks of) manufacturing, retail and service industries.
- Design and engineering of IT based services for coordination and integration of business processes in supply chains and business networks.
- Design and optimization of operational processes in the healthcare sector.
- Risk and security management, financial engineering and financial decision support.

Key persons: Prof. Dr. M.E. Iacob (working group chair); Dr. A.I. Aldea (working group member); Dr. D.M. Yazan (consultative group member); Prof. Dr. W.H.M. Zijm (consultative group member); Prof. Dr. J. van Hillegersberg (head of department);

Flagship projects:

- SynchromodalIT (IT Services for Synchromodality)
- BATMAN (Barge Terminal Multi-Agent Network)
- 4C4More (Cross Chain Control Centers)
- Datarel (Big data for resilient logistics)
- SHAREBOX (Secure Management Platform for Shared Process Resources)
- Logminers (Autonomous Logistic Miners, Dinalog)
- SISCO4SME (Industrial Doctorate project proposal, submitted to NWO)

NIKOS (Department of Entrepreneurship, Strategy & Innovation Management)

Founded in 2001, NIKOS - Nederlands Instituut voor Kennisintensief OndernemerSchap (Netherlands Institute for Knowledgeintensive Entrepreneurship) is one of the first academic centers for Entrepreneurship in the Netherlands.

Research and teaching

The NIKOS staff in the Entrepreneurship, Strategy & Innovation Management department at the entrepreneurial University of Twente cluster their research endeavours in 3 thematic lines: (1) Technology Entrepreneurship (2) Collaborative Innovation & Networks and (3) Entrepreneurial Behaviour & Leadership. NIKOS is responsible for all entrepreneurship education at UT on bachelor and master level, including a one-year master specialization in Entrepreneurship, Innovation and Strategy and a Double Diploma in Innovation Management & Entrepreneurship with TUBerlin.

Entrepreneurship into practice

We offer a successful summer school called EntrepreneurialU, and a 30 credits minor which is also available for (HBO) students from other universities via KiesOpMaat. NIKOS has close ties with VentureLab International, offering a research-based business development programme for technology-based startups and a business growth accelerator for well-established high-tech companies. NIKOS works together with 2 other departments in the PC3 initiative (Product Co Creation Centres for Bottom of the Pyramid).

Key persons: Dr. R. Harms (working group member); Dr. R.P.A. Loohuis (consultative group member); Prof. Dr. IR. P.C. De Weerd – Nederhof (head of department)

Flagship projects:

- Industry 4.0 for SMEs - together with Fraunhofer (Preparing SMEs for Smart industry with a focus on strategizing with smart industrial solutions for SME's in several sectors instead of focusing on the technologies only (which used to be the scope of Fraunhofer))
- Servitization of SMEs - together with IEBIS & Fontys (Transformation of SMEs to servitization which is closely related to Smart Industry since it requires integrated processes, networks and a high level of digitalization)

OWK (Department of Educational Science)

The department of educational sciences is specialised in research on professional learning in organisations. Researchers at our department study the formal and informal learning climate in organisations, as well as the design of schooling and training programs. Our studies often take place in the high-tech, health, and educational sector with the intention to understand, evaluate and optimize learning behaviour in these professional contexts. We aim to understand the interactions between learning processes on the individual, team, and organizational level and design (technology based) interventions to optimize these processes. In our research group, we combine expertise from a range of disciplines (e.g., educational sciences, psychology, business administration, sociology). Staff members participate in the ICO research school (the Interuniversity Centre of Educational Sciences) and the Twente Graduate School. Our department is responsible for the courses of the Human Resource Development track of the Master Educational Science and Technology, and the corresponding pre-Master program.

Key persons: Dr. B.J. Kollöffel (working group member); Prof. Dr. A.J.M. De Jong (head of department)

Flagship projects: E-PLM 2.0 (Extended–Product Lifecycle Management) – Together with Consortium Thales Nederland B.V. (Hengelo, Overijssel), Demcon Advanced Mechatronics B.V. (Enschede, Overijssel), Demcon Nymus 3D B.V. (Enschede, Overijssel), GML Instruments B.V. (Hardenberg, Overijssel), R.M. Precision B.V. (Nijverdal, Overijssel), M.G. Twente B.V. (Almelo, Overijssel), SupplyDrive B.V. (Hengelo, Overijssel), Apollo Vredestein B.V. (Enschede, Overijssel), Visser Projectsservice B.V. (Assen, Drenthe). Eluxis B.V. (Enschede, Overijssel), Figo B.V. (Enschede, Overijssel), H.P. Valves Oldenzaal B.V. (Hengelo, Overijssel), Norma Holding B.V. (Hengelo, Overijssel), Opra Turbines B.V. (Hengelo, Overijssel), Parthian Technology B.V. (Enschede, Overijssel), Recreate B.V. (Rijssen, Overijssel), Stichting Saxion (Enschede, Overijssel), Serious VR B.V. (Enschede, Overijssel), Universiteit Twente (Enschede, Overijssel), USG Engineering Professionals B.V. (Almere, Flevoland), Viro Beheer B.V. (Hengelo, Overijssel) en VMI Holland B.V. (Epe, Gelderland).

STEPS (Department of Science, Technology, and Policy Studies)

Innovations in science and technology involve expectations of economic profit, concerns about social impact, and challenges for regulatory governance. Genomics, nanotechnology and e-health are examples of fields of technology that mobilize interests and stir debate among many diverse actors.

The Department of Science, Technology, and Policy Studies (STePS) takes the assessment and governance of innovations and emerging technologies as its central theme of teaching and research. STePS considers in particular strategic issues that are multidisciplinary: they involve developments in science, technology, politics and society, as well as interaction between them. Studies conducted within STePS link analytical and normative perspectives and consider not only technological innovations but also innovations in governance.

Our research programme focuses on the dynamics and governance of Science, Technology and Innovation (STI). The study of the nature and actual dynamics of the processes of STI is considered as a goal in itself but is also an important prerequisite to investigate the governance of STI.

The view that STI should be considered as social processes underlies the design of our research programme. The programme aims to cover the whole spectrum of the 'life trajectory' of techno-scientific developments, ranging from historical to forecast and policy studies.

Key persons: Dr. K. Hahn (working group member); Dr. P. Stegmaier (working group member); Dr. K. Visscher (consultative group member); Prof. Dr. S. Kuhlmann (head of department)

Flagship projects:

- IIT-Industrial Innovation in Transition (Horizon 2020)
- EU-MACS (climate services) – Horizon 2020
- InnoForESt (forest ecosystem services) – Horizon 2020
- DiscGo – Governance of the transformation/discontinuation of socio-technical systems (international ORA project)

TM/S (Department of Technology Management & Supply)

TM/S is responsible for diverse courses on technology management and innovation as well as for a bachelor specialization in supply management and a master profile purchasing and supply management. We are the second European public university to offer a master dedicated to the education of professional purchasers.

Our research focus is upon innovations in networks, exploring both, the inter-organisational level, for instance innovations from and with suppliers or the modularization of products and its impact on the management of its innovation network, as well as individual level, such as innovation in teams with members from diverse backgrounds or R&D and purchasing collaboration. Closely linked to the innovation research is our operations part, covering purchasing, production and logistics. In supply management research two main lines can be differentiated: purchasing and supply management in industrial firms as well as public procurement. The new Dutch law of public quotation has been drafted in Twente. A special research focus in Twente is upon customer attractiveness, supplier satisfaction and on how to achieve preferred customer status with leading suppliers. In this way, a strategic component to supply management is added.

Many staff members of TM/S are also affiliated to UTIPS – The University of Twente Initiative for Purchasing Studies. UTIPS is one of the business-oriented centres of expertise of Twente's IGS research institute. Twente regularly scores among the top 5 European universities in purchasing and supply management. Our teaching programme has been the first university programme to be awarded with the "Global Standard for Professional Excellence" administrated by the IFPSM, the international association of purchasing professionals.

Key persons: Prof. Dr. H. Schiele (head of department and working group member); Dr. Ir. E. Hoffman (working group member)

Flagship projects:

- PERFECT (skills and competences needed by purchasers in Industry 4.0); Erasmus+ project
- External PhD projects with industry (purchasing and supplier related: game theory based digital negotiation)
- "Machine-Based Mapping of Innovation Journeys": Text mining project financed by the university to distinguishing between exploration and exploitation projects (TTT project);

APPENDIX 2 – QUANTITATIVE BIBLIOGRAPHIC LANDSCAPING MAPS

Business

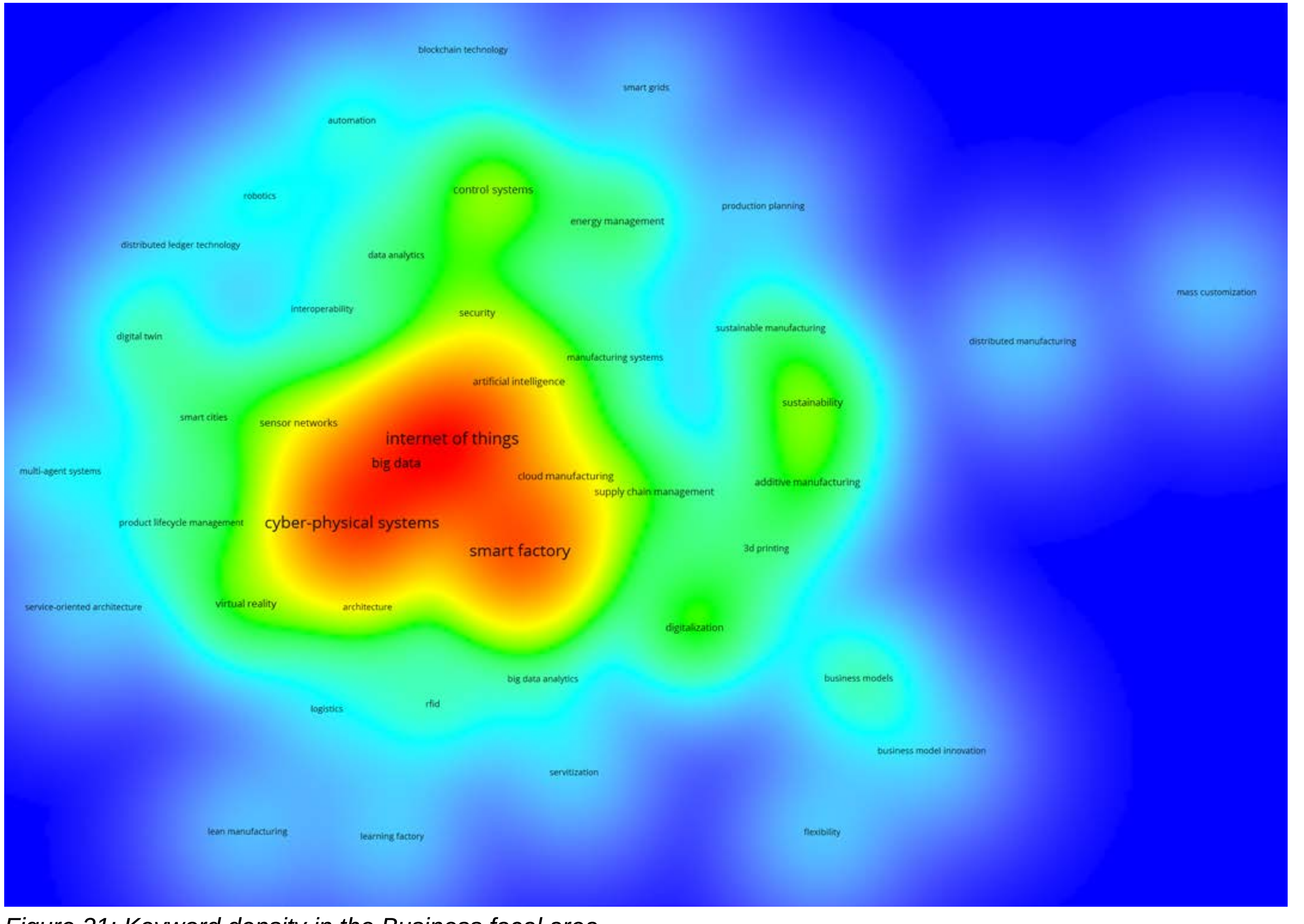


Figure 21: Keyword density in the Business focal area

Figure 22: Cluster density in the Business focal area

Society

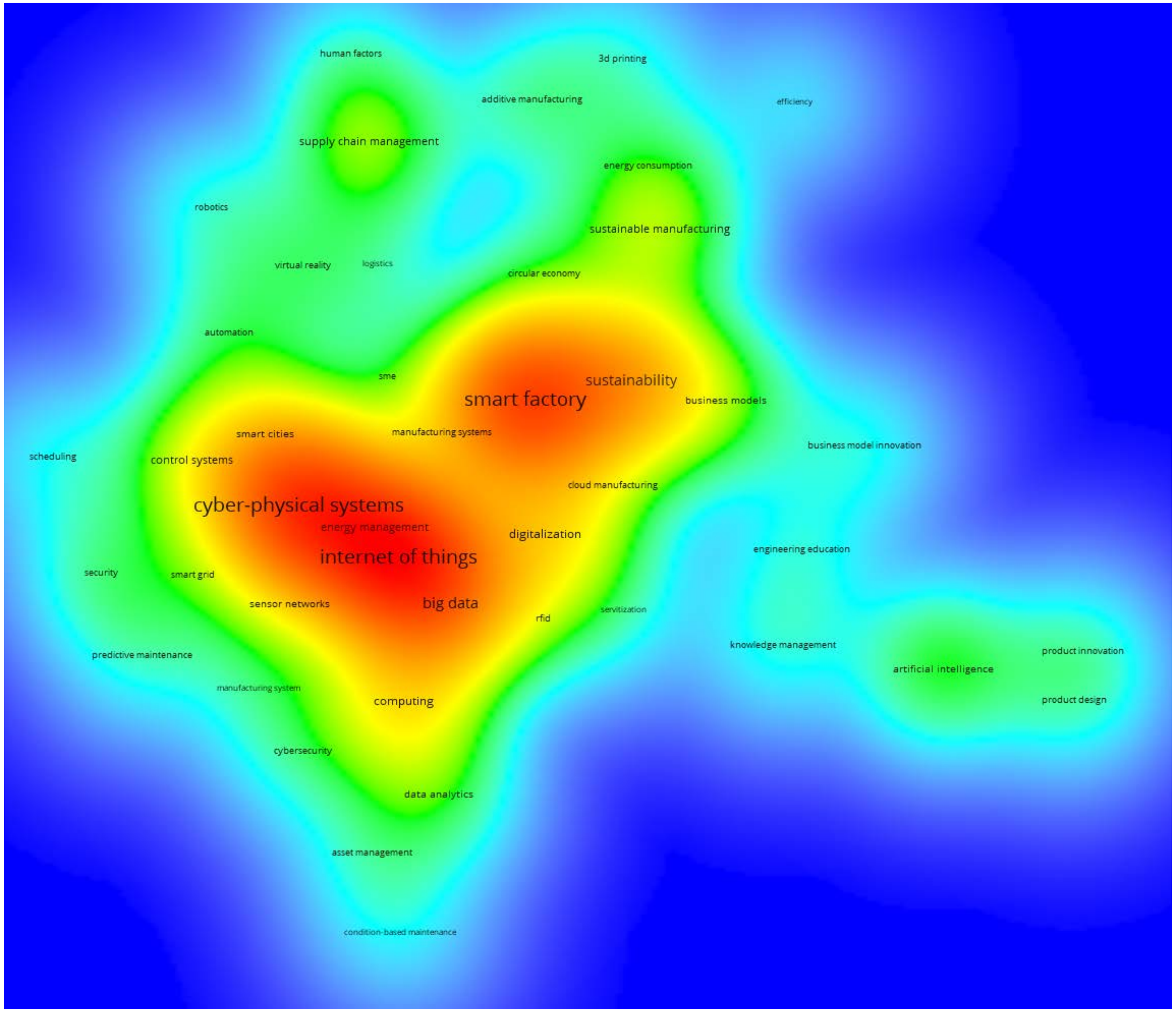


Figure 23: Keyword density in the Society focal area

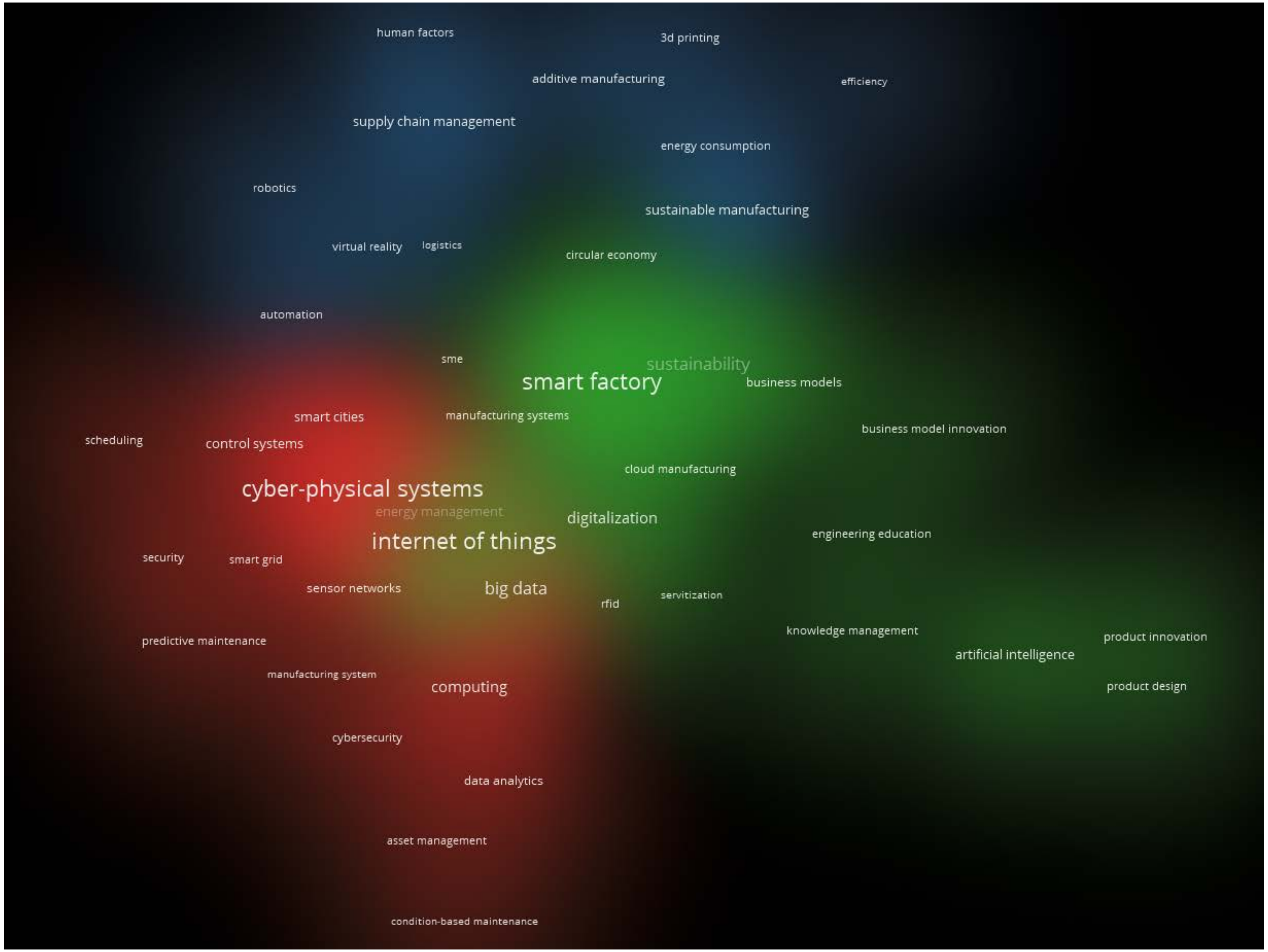


Figure 24: Cluster density in the Society focal area

People

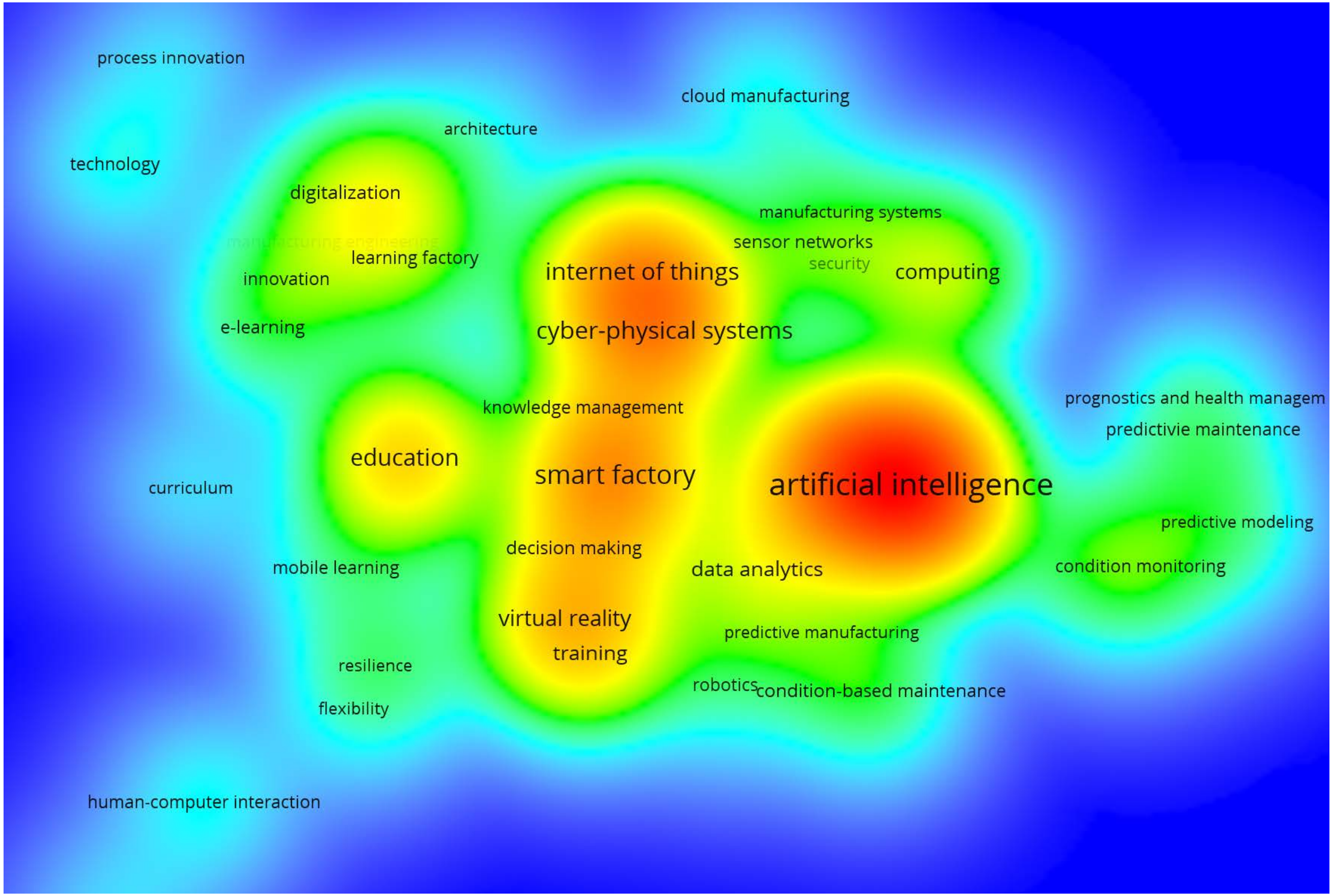


Figure 25: Keyword density in the People focal area

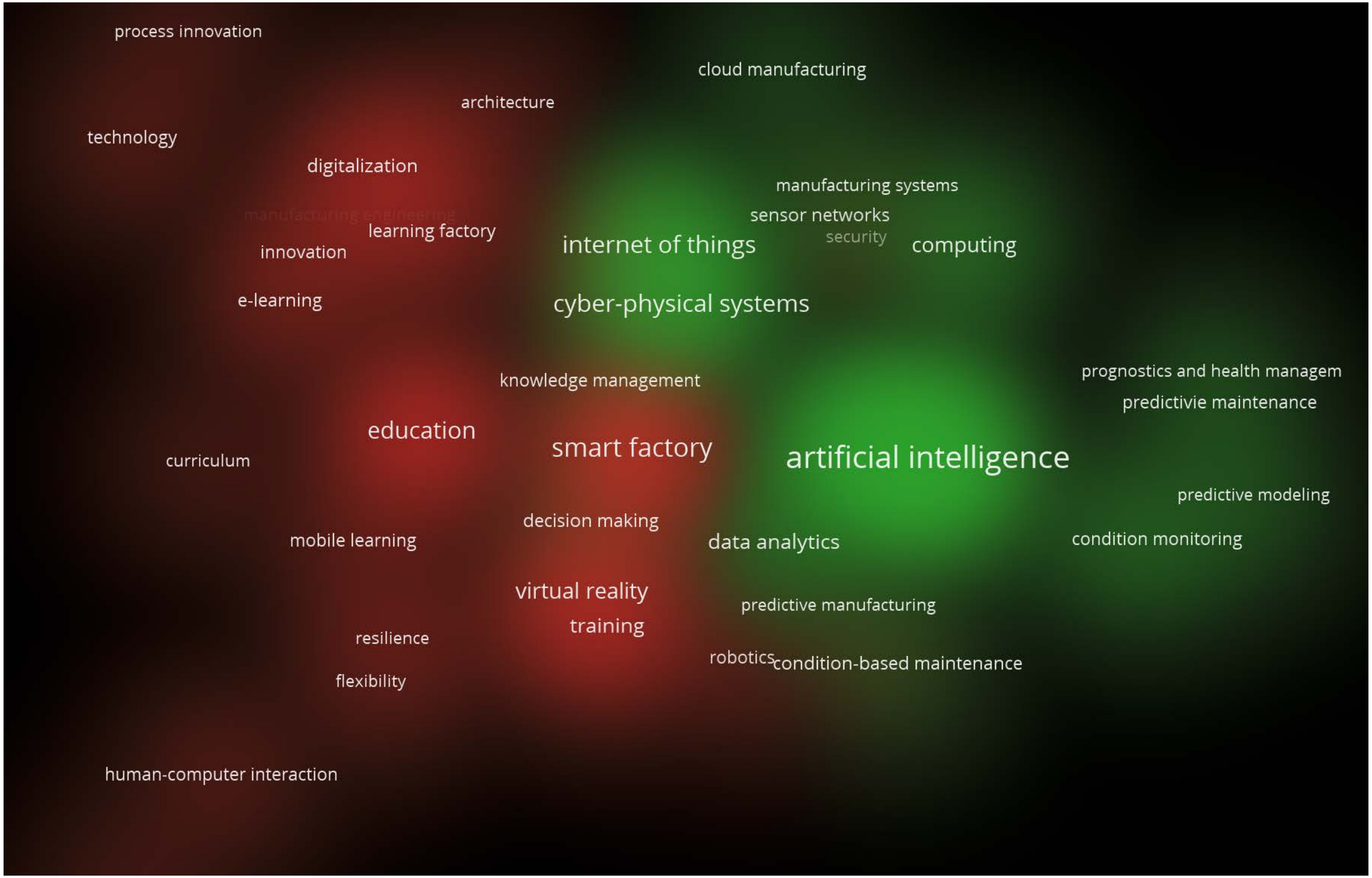


Figure 26: Cluster density in the People focal area

Smart industry

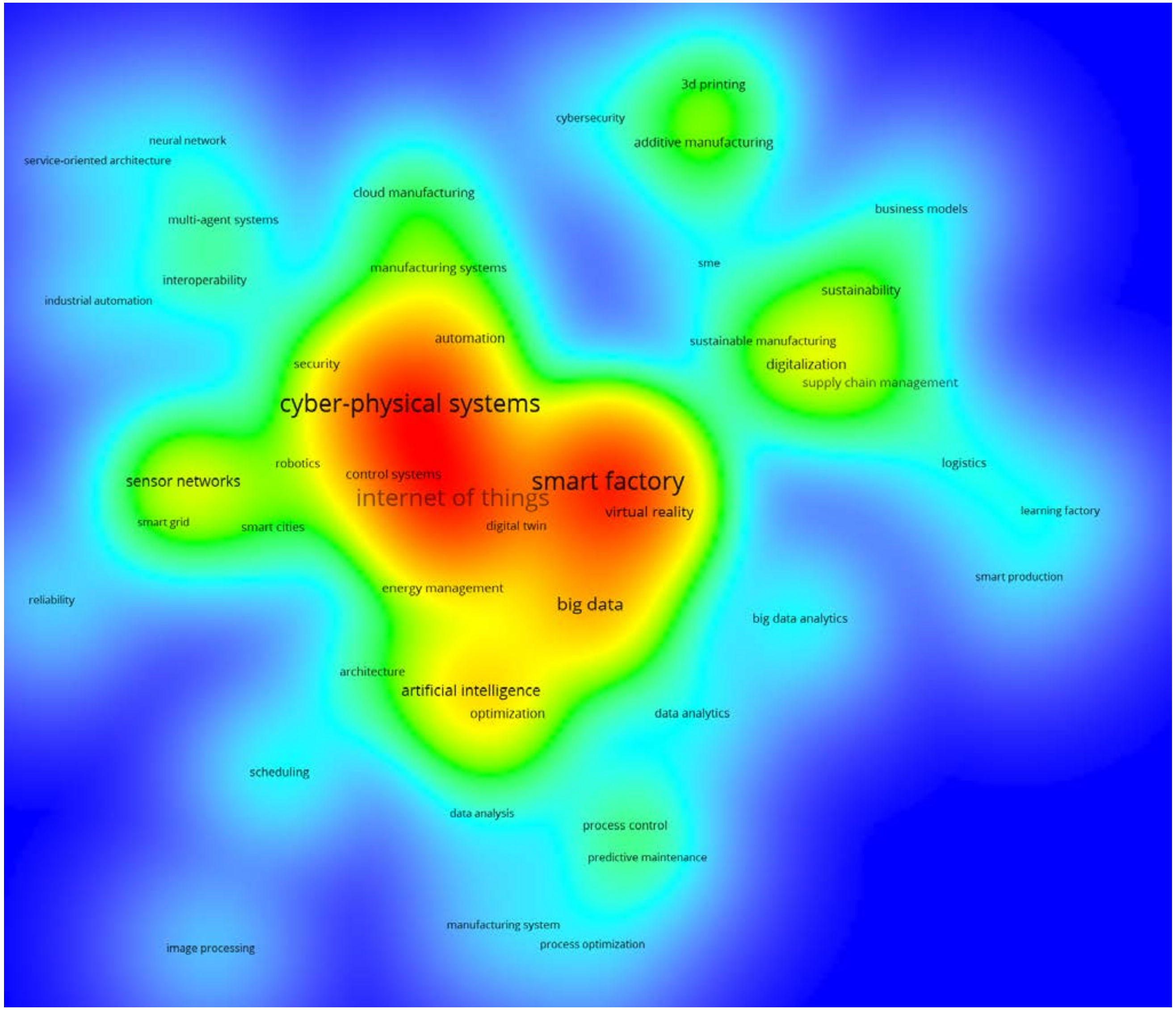


Figure 27: Industry 4.0 keyword density map

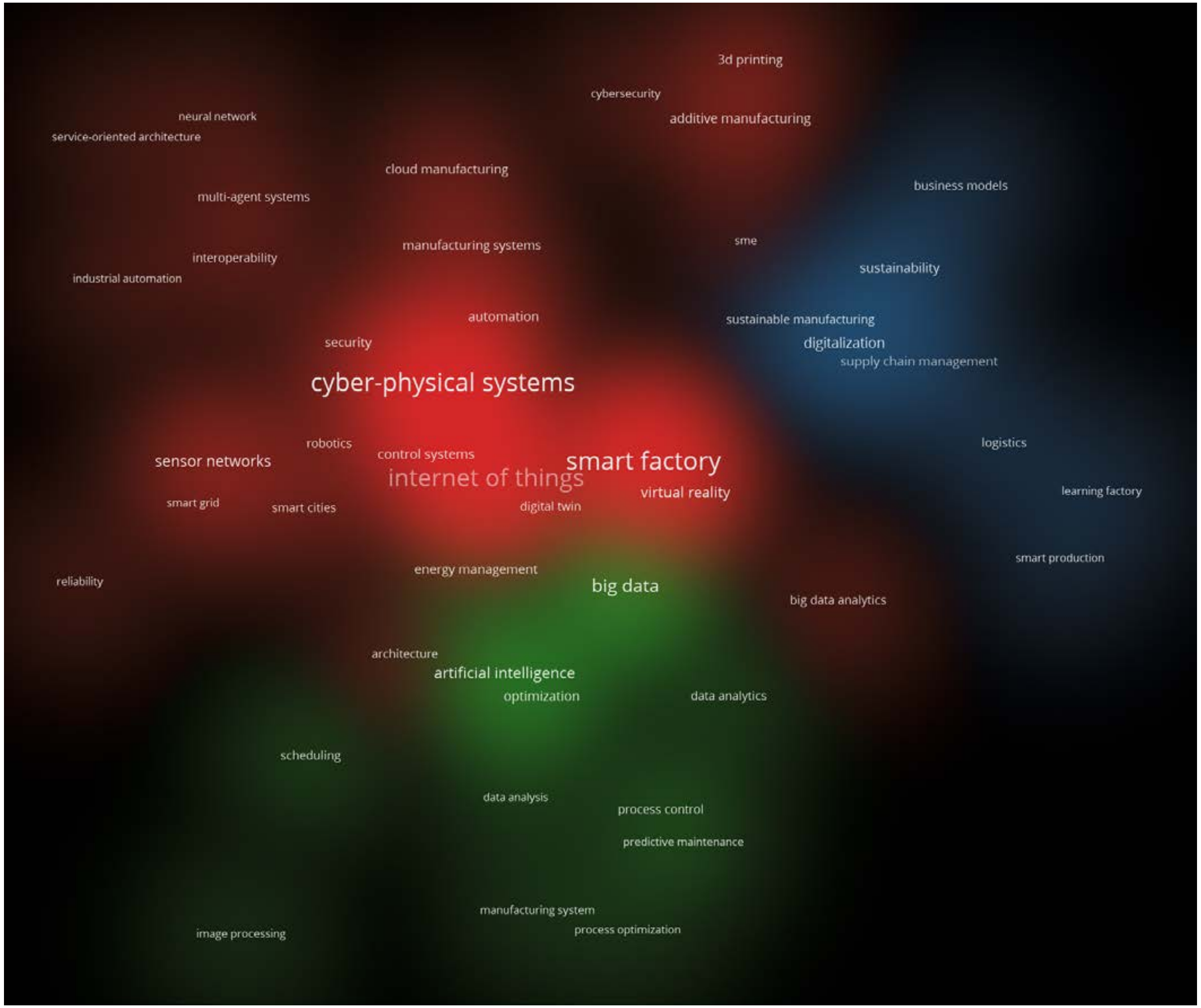


Figure 28: Industry 4.0 cluster density map

APPENDIX 3 – SMART INDUSTRY EU FUNDED PROJECTS

In the following table an overview is included of the organizations who have more than >5 projects in I4.0, Smart Industry and/or Advanced manufacturing. The organizations indicated in bold have more than 10 projects. In annex 2 a complete overview of all the organization is included.

Organization	Industry 4.0	Smart Industry	Advanced Manufacturing	Total	Comment
AIRBUS*			**12**	**12**	***Airbus defence and space GMBH, Espana SL, France SAS, Group Limited, Operations GMBH, Operations Limited, Operations SAS, UK Limited**
AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH	3		2	5	
APPLIED MATERIALS*	3		2	5	*Applied materials Belgium, France, Israel LTD
AVL LIST GMBH	4		1	5	
BEZIRKSVERBAND PFALZ	6			6	
BOSCH REXROTH AKTIENGESELLSCHAFT	5			5	
CARDIFF UNIVERSITY			5	5	
COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	3		5	8	
CONSIGLIO NAZIONALE DELLE RICERCHE	2		7	9	
FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.	**33**	**1**	**10**	**44**	
GKN AEROSPACE*			6	6	*Norway, Services LTD, Sweden AB
GLAXOSMITHKLINE (GSK)/PLC			5	5	
HAVITA BERLIN FRISCHGEMÜSE GMBH	**12**	**1**		**13**	
HERIOT-WATT UNIVERSITY			6	6	
HOCHSCHULE BOCHUM	5			5	
INFINEON TECHNOLOGIES*	**15**		**10**	**25**	***AG, Austria AG, Dreseden GMBH, IT-SERVICES GMBH, ROMNIA, UK**

JAGUAR AND LAND ROVER			7	7	
KARLSRUHER INSTITUT FUER TECHNOLOGIE	3		4	7	
LOUGHBOROUGH UNIVERSITY			7	7	
LULEA TEKNISKA UNIVERSITET	5	1		6	
NATIONAL PHYSICAL LABORATORY NPL			7	7	
NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO	1	3	5	9	
PLASTIC LOGIC LTD			5	5	
POLITECNICO DI MILANO	5	1	3	9	
POLITECNICO DI TORINO	1		4	5	
QUEEN MARY UNIVERSITY OF LONDON			5	5	
RENISHAW P L C	1		4	5	
RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN	6	1	2	9	
ROBERT BOSCH GESELLSCHAFT MIT BESCHRÄNKTER HAFTUNG	7			7	
ROBERT BOSCH GMBH	**6**		**4**	**10**	
ROLLS-ROYCE PLC			**19**	**19**	
TECHNISCHE UNIVERSITAET WIEN	3		4	7	
TECHNISCHE UNIVERSITAT DORTMUND	7	1		8	
TEKNOLOGIAN TUTKIMUSKESKUS VTT OY	**5**	**1**	**4**	**10**	
THE MANUFACTURING TECHNOLOGY CENTRE LIMITED			**29**	**29**	
THE UNIVERSITY OF MANCHESTER	2		4	6	
UNIVERSITY COLLEGE LONDON	**3**		**21**	**24**	
UNIVERSITY OF BATH	1		4	5	
UNIVERSITY OF BIRMINGHAM			**16**	**16**	
UNIVERSITY OF BRISTOL			**10**	**10**	
UNIVERSITY OF CAMBRIDGE	**1**		**10**	**11**	
UNIVERSITY OF HUDDERSFIELD			5	5	

UNIVERSITY OF LIVERPOOL			6	6	
UNIVERSITY OF MANCHESTER	2		5	7	
UNIVERSITY OF NOTTINGHAM	2		7	9	
UNIVERSITY OF OXFORD			7	7	
UNIVERSITY OF SHEFFIELD			**38**	**38**	
UNIVERSITY OF STRATHCLYDE	2	1	5	8	
UNIVERSITY OF WARWICK	2		6	8	
VYSOKE UCENI TECHNICKE V BRNE	2	1	3	6	

In the table below the Dutch organizations are included. Some are included in the table above as they have more than 5 projects, but in the table below all Dutch organization are included.

Organization	**Industry 4.0**	**Smart Industry**	**Advanced Manufacturing**	**Total**
ASML NETHERLANDS B.V.			1	1
DELFT UNIVERSITY OF TECHNOLOGY (TU DELFT)			**3**	**3**
EINDHOVEN UNIVERSITY OF TECHNOLOGY			2	2
MINISTERIE VAN ECONOMISCHE ZAKEN		1	1	2
NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO	**1**	**3**	**5**	**9**
NOORD-BRABANT PROVINCIE			1	1
NXP SEMICONDUCTORS NETHERLANDS BV	1		1	2
ONTWIKKELINGSMAATSCHAPPIJ OOST NEDERLAND NV			1	1
OPEN UNIVERSITEIT NEDERLAND	1			1
PHILIPS LIGHTING B.V.	2			2
PHILIPS MEDICAL SYSTEMS NEDERLAND BV		1		1
REDEN B.V.		1		1
RIJKSUNIVERSITEIT GRONINGEN		1		1
STICHTING BIOMADE TECHNOLOGY			1	1
STICHTING CENTRUM VOOR WISKUNDE EN INFORMATICA	1			1
STICHTING IMEC NEDERLAND	1		1	2

STICHTING KATHOLIEKE UNIVERSITEIT			2	2
STICHTING MATERIALS INNOVATION INSTITUTE (M2I)*		**1**	**2**	**3**
STICHTING NANONEXTNL		1	1	2
STICHTING NATIONAAL LUCHT- EN RUIMTEVAARTLABORATORIUM			1	1
STICHTING PUBLIC PRIVATE PARTNERSHIP INSTITUTE FOR SUSTAINABLE PROCESSTECHNOLOGY		1	1	2
TECHNISCHE UNIVERSITEIT DELFT	1		1	2
TECHNISCHE UNIVERSITEIT EINDHOVEN	**2**	**1**	**1**	**4**
THALES NEDERLAND BV	1			1
UNILEVER R&D VLAARDINGEN B.V.			2	2

APPENDIX 4 – BUSINESS THEME EU FUNDED PROJECTS

In the following table an overview is included of the organizations who have more than >5 projects in life-cycle solutions, global market place, entrepreneurship, mass customization and/or decentralization. The organizations indicated in bold have more than 10 projects. In annex 2 a complete overview of all the organization is included.

Partner	Life-cycle solutions	Global market place	Entrepreneurship	Mass customization	Decentralization	Total
AALBORG UNIVERSITET			**5**		**5**	**10**
AALTO-KORKEAKOULUSAATIO			4		3	7
AARHUS UNIVERSITET			4		3	7
AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS - CSIC			6		2	8
ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA			5		3	8
ASSOCIATION POUR LA RECHERCHE ET LE DEVELOPPEMENT DES METHODES ET PROCESSUS INDUSTRIELS			3		3	6
ASTON UNIVERSITY		1	3		1	5
ATOS SPAIN SA		1	1		5	7
CARDIFF UNIVERSITY			1		4	5
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE - CNRS			**13**		**4**	**17**
CENTRO RICERCHE FIAT SCPA		1		1	3	5
COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES			**6**		**4**	**10**
CONSIGLIO NAZIONALE DELLE RICERCHE			**6**		**4**	**10**
CRANFIELD UNIVERSITY			1	1	3	5
DANMARKS TEKNISKE UNIVERSITET			8			8
DEFENCE SCIENCE & TECH LAB DSTL		1	6			7
DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV					4	6

			2			
ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE			**4**		**6**	**10**
EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH		**1**	**5**		**9**	**15**
ELVESYS SAS			7			7
ENGINEERING - INGEGNERIA INFORMATICA SPA		**2**	**3**	**1**	**6**	**12**
ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS			**3**	**1**	**6**	**10**
EUROPE UNLIMITED S.A.			5		1	6
EUROPEAN BUSINESS AND INNOVATION CENTRE NETWORK			5			5
FOUNDATION FOR RESEARCH AND TECHNOLOGY HELLAS			**5**		**5**	**10**
FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.		**1**	**11**	**2**	**22**	**36**
FRIEDRICH-SCHILLER-UNIVERSITAET JENA			3		3	6
FUNDACION TECNALIA RESEARCH & INNOVATION			**2**	**2**	**7**	**11**
GOETEBORGS UNIVERSITET			3		2	5
HAVITA BERLIN FRISCHGEMÜSE GMBH			**2**		**10**	**12**
HELSINGIN YLIOPISTO			5		1	6
IMPERIAL COLLEGE LONDON (ICL)			7		2	9
IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE			**8**		**4**	**12**
INSTITUT MINES-TELECOM		1	1		3	5
INSTITUT NATIONAL DE LA RECHERCHE AGRONOMIQUE			4		4	8
INSTITUT NATIONAL DE RECHERCHE ENINFORMATIQUE ET AUTOMATIQUE					5	5

JOHANN WOLFGANG GOETHE UNIVERSITAET FRANKFURT AM MAIN			4		1	5
KARLSRUHER INSTITUT FUER TECHNOLOGIE			**7**	**1**	**2**	**10**
KATHOLIEKE UNIVERSITEIT LEUVEN			**12**	**1**	**3**	**16**
KING'S COLLEGE LONDON			4		1	5
KUNGLIGA TEKNISKA HÖGSKOLAN			**8**		**12**	**20**
LANCASTER UNIVERSITY			7			7
LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE (UNIVERSITY OF LONDON)			**13**		**3**	**16**
LULEA TEKNISKA UNIVERSITET		2	1	1	3	7
LUNDS UNIVERSITET			5		3	8
MAGYAR TUDOMANYOS AKADEMIA TERMESZETTUDOMANYI KUTATOKOZPONT			4		1	5
MAX RUBNER-INSTITUT BUNDESFORSCHUNGSINSTITUT FÜR ERNÄHRUNG UND LEBENSMITTEL					7	7
MAX-PLANCK-GESELLSCHAFT ZUR FORDERUNG DER WISSENSCHAFTEN EV			5			5
NATIONAL PHYSICAL LABORATORY NPL			5			5
NATIONAL TECHNICAL UNIVERSITY OF ATHENS			**4**		**6**	**10**
ORANGE SA		1	1		3	5
POLITECHNIKA WARSZAWSKA (WARSAW UNIVERSITY OF TECHNOLOGY)			4	1	2	7
POLITECNICO DI MILANO		**1**	**15**	**3**	**3**	**22**
POLITECNICO DI TORINO			2		3	5
QUEEN MARY UNIVERSITY OF LONDON			3		4	7
RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN			**2**	**2**	**12**	**16**
SIMPLEWARE LTD		4	2			6
STICHTING WAGENINGEN RESEARCH			3		2	5

SYDDANSK UNIVERSITET			4		3	7
TECHNION - ISRAEL INSTITUTE OF TECHNOLOGY			2		4	6
TECHNISCHE UNIVERSITAET BERLIN			3		5	8
TECHNISCHE UNIVERSITAET DRESDEN			3		2	5
TECHNISCHE UNIVERSITAET MUENCHEN			7	1	1	9
TECHNISCHE UNIVERSITAET WIEN			4	1	3	8
TECHNISCHE UNIVERSITAT DORTMUND			4		5	9
TECHNISCHE UNIVERSITEIT DELFT			**7**		**5**	**12**
TECHNISCHE UNIVERSITEIT EINDHOVEN			**5**		**6**	**11**
TEKNOLOGIAN TUTKIMUSKESKUS VTT			3		2	5
TEKNOLOGIAN TUTKIMUSKESKUS VTT OY		1	2		3	6
TELEFONICA INVESTIGACION Y DESARROLLO SA		1	1		4	6
THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF CAMBRIDGE			6			6
THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF OXFORD			7			7
THE PROVOST, FELLOWS AND SCHOLARS OF THE COLLEGE OF THE HOLY AND UNDIVIDED TRINITY OF QUEEN ELIZABETH NEAR DUBLIN.(HEREINAFTER CALLED TCD)			6		1	7
THE UNIVERSITY OF EDINBURGH			5		2	7
THE UNIVERSITY OF MANCHESTER			**7**	**1**	**2**	**10**
THE UNIVERSITY OF NOTTINGHAM			7	1	1	9
THE UNIVERSITY OF SHEFFIELD			7			7
UNIVERSIDAD POLITECNICA DE MADRID		**2**	**4**		**4**	**10**
UNIVERSITA COMMERCIALE LUIGI BOCCONI			4		2	6
UNIVERSITA DEGLI STUDI DI GENOVA			1		4	5
UNIVERSITA' DEGLI STUDI DI MILANO-BICOCCA			4		1	5
UNIVERSITAT AUTONOMA DE BARCELONA			5		3	8
UNIVERSITÄT HOHENHEIM					7	7
UNIVERSITÄT LEIPZIG				1	5	6

UNIVERSITAT POLITECNICA DE CATALUNYA			4		5	9
UNIVERSITE CATHOLIQUE DE LOUVAIN			4		3	7
UNIVERSITE DE LIEGE			4		1	5
UNIVERSITEIT GENT			4		2	6
UNIVERSITEIT MAASTRICHT			3		2	5
UNIVERSITEIT TWENTE			4		3	7
UNIVERSITEIT UTRECHT			6		3	9
UNIVERSITEIT VAN AMSTERDAM			5			5
UNIVERSITETET I OSLO			4		1	5
UNIVERSITY COLLEGE CORK - NATIONAL UNIVERSITY OF IRELAND, CORK			7			7
UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN			5		2	7
UNIVERSITY COLLEGE LONDON			**24**		**4**	**28**
UNIVERSITY OF ABERDEEN			4		1	5
UNIVERSITY OF BRISTOL			**13**		**1**	**14**
UNIVERSITY OF CAMBRIDGE			7			7
UNIVERSITY OF CYPRUS			4		3	7
UNIVERSITY OF EDINBURGH			**8**		**4**	**12**
UNIVERSITY OF EXETER			3		3	6
UNIVERSITY OF GLASGOW			**10**		**4**	**14**
UNIVERSITY OF LEEDS		**6**	**13**		**1**	**20**
UNIVERSITY OF LIVERPOOL			4		4	8
UNIVERSITY OF NEWCASTLE UPON TYNE			6			6
UNIVERSITY OF OXFORD			**11**		**7**	**18**
UNIVERSITY OF SOUTHAMPTON			**6**		**5**	**11**
UNIVERSITY OF STRATHCLYDE		**1**	**10**	**1**	**1**	**13**
UNIVERSITY OF SURREY			3		4	7
UNIVERSITY OF WARWICK			**3**		**8**	**11**
UNIVERSITY OF YORK			6		2	8

UNIVERZA V LJUBLJANI			5		2	7
UNIVERZITA KARLOVA			3		2	5

In the table below the Dutch organizations are included. Some are included in the table above as they have more than 5 projects, but in the table below all Dutch organization are included.

Partner	Life-cycle solutions	Global market place	Entrepreneurship	Mass customization	Decentralization	Total
ACADEMISCH ZIEKENHUIS GRONINGEN			2			2
ACADEMISCH ZIEKENHUIS LEIDEN			**3**			**3**
CAPGEMINI NEDERLAND BV			1			1
DELFT UNIVERSITY OF TECHNOLOGY					1	1
DSM INNOVATIVE SYNTHESIS B. V.			1			1
EINDHOVEN UNIVERSITY OF TECHNOLOGY			1			1
ELSEVIER BV					1	1
ENERGIEONDERZOEK CENTRUM NEDERLAND					1	1
ENERGY RESEARCH CENTRE OF THE NETHERLANDS (ENERGIEONDERZOEK CENTRUM NEDERLAND)					2	2
ENEXIS BV					1	1
ERASMUS UNIVERSITAIR MEDISCH CENTRUM ROTTERDAM			**3**			**3**
ERASMUS UNIVERSITEIT ROTTERDAM		1			1	2
KWR WATER B.V.					1	1
NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO			**3**		**1**	**4**
NOORD-BRABANT PROVINCIE			1			1
NXP SEMICONDUCTORS NETHERLANDS BV					1	1
ONTWIKKELINGSMAATSCHAPPIJ OOST NEDERLAND NV			1			1
PHILIPS ELECTRONICS NEDERLAND B.V.					1	1

PHILIPS MEDICAL SYSTEMS NEDERLAND BV			1			1
PNO CONSULTANTS LIMITED			1			1
PROVINCIE OVERIJSSEL			1			1
PROVINCIE ZUID-HOLLAND			1			1
SAXION HOGESCHOOL IJSELLAND - UNIVERSITY OF PROFESSIONAL EDUCATION			1			1
STICHTING BIOMADE TECHNOLOGY			1			1
STICHTING CENTRUM VOOR WISKUNDE EN INFORMATICA					2	2
STICHTING CETIM - CENTER FOR TECHNOLOGY AND INNOVATION MANAGEMENT			2			2
STICHTING DIENST LANDBOUWKUNDIG ONDERZOEK			1		1	2
STICHTING ECHO, EXPERTISECENTRUM DIVERSITEITSBELEID"			1			1
STICHTING EFFOST			1			1
STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND					**3**	**3**
STICHTING GREEN IT CONSORTIUM REGIO AMSTERDAM					1	1
STICHTING HET NEDERLANDS KANKER INSTITUUT-ANTONI VAN LEEUWENHOEK ZIEKENHUIS			1			1
STICHTING HOGESCHOOL VOOR DE KUNSTEN UTRECHT			1			1
STICHTING ICTU			1			1
STICHTING KATHOLIEKE UNIVERSITEIT BRABANT			**4**		**1**	**5**
STICHTING LEIDEN BIO SCIENCE PARK FOUNDATION			1			1
STICHTING LIVING LAB			1			1
STICHTING MATERIALS INNOVATION INSTITUTE (M2I)*			1			1

STICHTING NATIONAAL MUSEUM VAN WERELDCULTUREN					1	1
STICHTING NEDERLANDS BAKKERIJ CENTRUM			1			1
STICHTING PEER TO PEER ALTERNATIVES					1	1
STICHTING PLASTIC ELECTRONICS FOUNDATION			1			1
STICHTING PLATFORM31			1			1
STICHTING THE NETWORK UNIVERSITY			1			1
STICHTING VOOR FUNDAMENTEEL ONDERZOEK DER MATERIE - FOM			2			2
STICHTING VU			**4**			**4**
STICHTING VUMC			2			2
STICHTING WAAG SOCIETY					1	1
STICHTING WAGENINGEN RESEARCH			3		2	5
STICHTING WETLANDS INTERNATIONAL					1	1
STICHTING WETSUS, EUROPEAN CENTRE OF EXCELLENCE FOR SUSTAINABLE WATER TECHNOLOGY					1	1
TECHNISCHE UNIVERSITEIT DELFT			**7**		**5**	**12**
TECHNISCHE UNIVERSITEIT EINDHOVEN			**5**		**6**	**11**
TECHNOGROW B.V.					1	1
THE HYVE B.V.			1			1
TIE NEDERLAND BV				1		1
UNIRESEARCH BV					1	1
UNIVERSITEIT LEIDEN			2			2
UNIVERSITEIT MAASTRICHT			**3**		**2**	**5**
UNIVERSITEIT TWENTE			**4**		**3**	**7**
UNIVERSITEIT UTRECHT			6		3	9
UNIVERSITEIT VAN AMSTERDAM			5			5
UNIVERSITEIT VAN TILBURG			1			1

UNIVERSITY MEDICAL CENTER UTRECHT (UMC)		2				2
UTRECHT SCHOOL OF GOVERNANCEUTRECHT SCHOOL OF GOVERNANCE					1	1
VRIJE UNIVERSITEIT AMSTERDAM					1	1
WAGENINGEN UNIVERSITEIT			2		2	4

APPENDIX 5 – SOCIETY THEME EU FUNDED PROJECTS

In the following table an overview is included of the organizations who have more than >5 projects in sustainable economy and social inclusion. The organizations which have more than 10 projects have been indicated in bold. In annex 2 a complete overview of all the organization is included

Partners	Sustainable economy	Social Inclusion	Total
BRIGHTON & HOVE CITY COUNCIL		5	5
BRITISH TRANSPORT POLICE		5	5
BRITISH URBAN REGENERATION ASSOCIATION (BURA)		5	5
FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V	3	4	7
FUNDACAO PARA A CIENCIA E A TECNOLOGIA	3	2	5
HERTFORDSHIRE COUNTY COUNCIL		5	5
KATHOLIEKE UNIVERSITEIT LEUVEN		7	7
KINGS COLLEGE LONDON	1	5	6
NEWCASTLE UNIVERSITY		8	8
NORGES FORSKNINGSRAD	3	2	5
QUEEN MARY UNIVERSITY OF LONDON	2	3	5
UNIVERSITAT AUTONOMA DE BARCELONA		5	5
UNIVERSITY COLLEGE LONDON		**10**	**10**
UNIVERSITY OF CAMBRIDGE	1	4	5
UNIVERSITY OF EDINBURGH	6	3	9
UNIVERSITY OF ESSEX		5	5
UNIVERSITY OF LEEDS	**4**	**12**	**16**
UNIVERSITY OF OXFORD		5	5
UNIVERSITY OF STRATHCLYDE		5	5

In the table below the Dutch organizations are included. Some are included in the table above as they have more than 5 projects, but in the table below all Dutch organization are included.

Partners	Sustinable economy	Social Inclusion	Total
ACADEMISCH ZIEKENHUIS GRONINGEN		1	1
EIGEN VERMOGEN VAN HET INSTITUUT VOOR LANDBOUW EN VISSERIJONDERZOEK	1		1
ERASMUS UNIVERSITAIR MEDISCH CENTRUM ROTTERDAM		1	1
ERASMUS UNIVERSITEIT ROTTERDAM	1		1
KONINKLIJKE PHILIPS ELECTRONICS N.V.		1	1
MINISTERIE VAN ECONOMISCHE ZAKEN	2		2
MINISTERIE VAN INFRASTRUCTUUR EN MILIEU	1		1
NEA TRANSPORTONDERZOEK EN - OPLEIDING BV		1	1
NEDERLANDSE ORGANISATIE VOOR WETENSCHAPPELIJK ONDERZOEK	1		1
PRINS LEOPOLD INSTITUUT VOOR TROPISCHE GENEESKUNDE		1	1
STICHTING DIENST LANDBOUWKUNDIG ONDERZOEK		1	1
STICHTING DR HILDA VERWEY-JONKER INSTITUUT		**2**	**2**
STICHTING ECHO, EXPERTISECENTRUM DIVERSITEITSBELEID		1	1
STICHTING KATHOLIEKE UNIVERSITEIT		1	1
STICHTING NATIONAAL MUSEUM VAN WERELDCULTUREN		1	1
STICHTING NHTV INTERNATIONALE HOGESCHOOL BREDA		1	1
STICHTING SMART HOMES		**2**	**2**
TECHNISCHE UNIVERSITEIT DELFT	1		1
TILBURG UNIVERSITY		1	1
UNILEVER CORPORATE RESEARCH	1		1
UNIVERSITEIT MAASTRICHT		**3**	**3**
UNIVERSITEIT VAN AMSTERDAM		**3**	**3**

APPENDIX 6 – PEOPLE THEME EU FUNDED PROJECTS

In the following table an overview is included of the organizations who have more than >5 projects in continuous learning, man-machine interaction, talent management and/or self-management. The organizations indicated in bold have more than 10 projects. In annex 2 a complete overview of all the organization is included

Partner	Continuous learning	Man-Machine Interaction	Talent management	Self-management	Total
ATOS SPAIN SA	1			4	5
CARDIFF UNIVERSITY	1			5	6
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	2	2		2	6
ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS	1			4	5
FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.	**2**	**1**		**10**	**13**
IBM			**1**	**10**	**11**
IMPERIAL COLLEGE LONDON	1	1		5	7
IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE	1	1		4	6
KAROLINSKA INSTITUTET				5	5
KING'S COLLEGE LONDON (KCL)				7	7
KUNGLIGA TEKNISKA HOEGSKOLAN	1			4	5
LANCASTER UNIVERSITY				7	7
MEDICAL RESEARCH COUNCIL				5	5
NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO				5	5
ORANGE SA				6	6
TELEFONICA INVESTIGACION Y DESARROLLO SA				6	6
THE STROKE ASSOCATION				5	5
THE UNIVERSITY OF MANCHESTER				7	7
UNIVERSIDAD POLITECNICA DE MADRID	1			4	5

UNIVERSITAT POLITECNICA DE CATALUNYA	1			5	6
UNIVERSITY COLLEGE LONDON (UCL)		1		6	7
UNIVERSITY OF ABERDEEN				7	7
UNIVERSITY OF BRISTOL			1	4	5
UNIVERSITY OF EDINBURGH				**15**	**15**
UNIVERSITY OF GLASGOW				**13**	**13**
UNIVERSITY OF MANCHESTER				8	8
UNIVERSITY OF SOUTHAMPTON	1			6	7
UNIVERSITY OF SURREY	1			5	6

In the table below the Dutch organizations are included. Some are included in the table above as they have more than 5 projects, but in the table below all Dutch organization are included.

Partner	**Continuous learning**	**Man-Machine Interaction**	**Talent management**	**Self-management**	**Total**
ACADEMISCH MEDISCH CENTRUM BIJ DE UNIVERSITEIT VAN AMSTERDAM				2	2
ACADEMISCH ZIEKENHUIS GRONINGEN				1	1
ACADEMISCH ZIEKENHUIS LEIDEN				2	2
ACCENTURE				1	1
BERENSCHOT GROEP BV				1	1
BIERMAN EGBERTUS PETRUS BARTHOLOMEUS				1	1
DELFT UNIVERSITY OF TECHNOLOGY (TU DELFT)				2	2
DEMO CONSULTANTS BV				1	1
GEMEENTE DEN HAAG				1	1
INNOVATION IQ BV				1	1
LEIDEN UNIVERSITY MEDICAL CENTRE				1	1
MATERIALISE NV				1	1
NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO				**5**	**5**
NETHERLANDS INSTITUTE FOR CATALYSIS RESE	1				1
PHILIPS ELECTRONICS NEDERLAND B.V.				2	2
PHILIPS MEDICAL SYSTEMS NEDERLAND BV				1	1

PRIME DATA B.V.				1	1
ROYAL NETHERLANDS ACADEMY ARTS SCI KNAW	1				1
SIRRIS HET COLLECTIEF CENTRUM VAN DE TECHNOLOGISCHE INDUSTRIE				1	1
STICHTING GGZ INGEEST				1	1
STICHTING KATHOLIEKE UNIVERSITEIT				1	1
STICHTING KATHOLIEKE UNIVERSITEIT BRABANT				1	1
STICHTING SBRCURNET				1	1
STICHTING TRIMBOS- INSTITUUT, NETHERLANDS INSTITUTE OF MENTAL HEALTH AND ADDICTION				1	1
STICHTING VU				1	1
STICHTING WAGENINGEN RESEARCH	1				1
STICHTING ZIEKENHUIS GELDERSE VALLEI				1	1
TECHNISCHE UNIVERSITEIT DELFT	**1**	**1**		**1**	**3**
TECHNISCHE UNIVERSITEIT EINDHOVEN				1	1
UNIVERSITEIT MAASTRICHT				1	1
UNIVERSITEIT TWENTE		1			1
UNIVERSITEIT VAN AMSTERDAM	2				2
ZORGGEMAK BV				1	1

APPENDIX 7 – OVERVIEW OF UNIVERSITIES AND ORGANISATIONS WHICH ARE HEAVILY INVOLVED IN SMART INDUSTRY EU FUNDED PROJECTS

Industry 4.0

Organization
AIRBUS
HAVITA BERLIN FRISCHGEMÜSE GMBH
FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.
INFINEON TECHNOLOGIES
ROBERT BOSCH GMBH
ROLLS-ROYCE PLC
TEKNOLOGIAN TUTKIMUSKESKUS VTT OY
THE MANUFACTURING TECHNOLOGY CENTRE LIMITED
UNIVERSITY COLLEGE LONDON
UNIVERSITY OF BIRMINGHAM
UNIVERSITY OF BRISTOL
UNIVERSITY OF CAMBRIDGE
UNIVERSITY OF SHEFFIELD

Business

Organization
AALBORG UNIVERSITET
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE - CNRS
COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
CONSIGLIO NAZIONALE DELLE RICERCHE
ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH
ENGINEERING - INGEGNERIA INFORMATICA SPA
ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS
FOUNDATION FOR RESEARCH AND TECHNOLOGY HELLAS
FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.
FUNDACION TECNALIA RESEARCH & INNOVATION
HAVITA BERLIN FRISCHGEMÜSE GMBH
IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE
KARLSRUHER INSTITUT FUER TECHNOLOGIE
KATHOLIEKE UNIVERSITEIT LEUVEN
KUNGLIGA TEKNISKA HÖGSKOLAN

LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE (UNIVERSITY OF LONDON)
NATIONAL TECHNICAL UNIVERSITY OF ATHENS
POLITECNICO DI MILANO
RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN
TECHNISCHE UNIVERSITEIT DELFT
TECHNISCHE UNIVERSITEIT EINDHOVEN
THE UNIVERSITY OF MANCHESTER
UNIVERSIDAD POLITECNICA DE MADRID
UNIVERSITY COLLEGE LONDON
UNIVERSITY OF BRISTOL
UNIVERSITY OF EDINBURGH
UNIVERSITY OF GLASGOW
UNIVERSITY OF LEEDS
UNIVERSITY OF OXFORD
UNIVERSITY OF SOUTHAMPTON
UNIVERSITY OF STRATHCLYDE
UNIVERSITY OF WARWICK

Society

Organization
UNIVERSITY COLLEGE LONDON
UNIVERSITY OF LEEDS

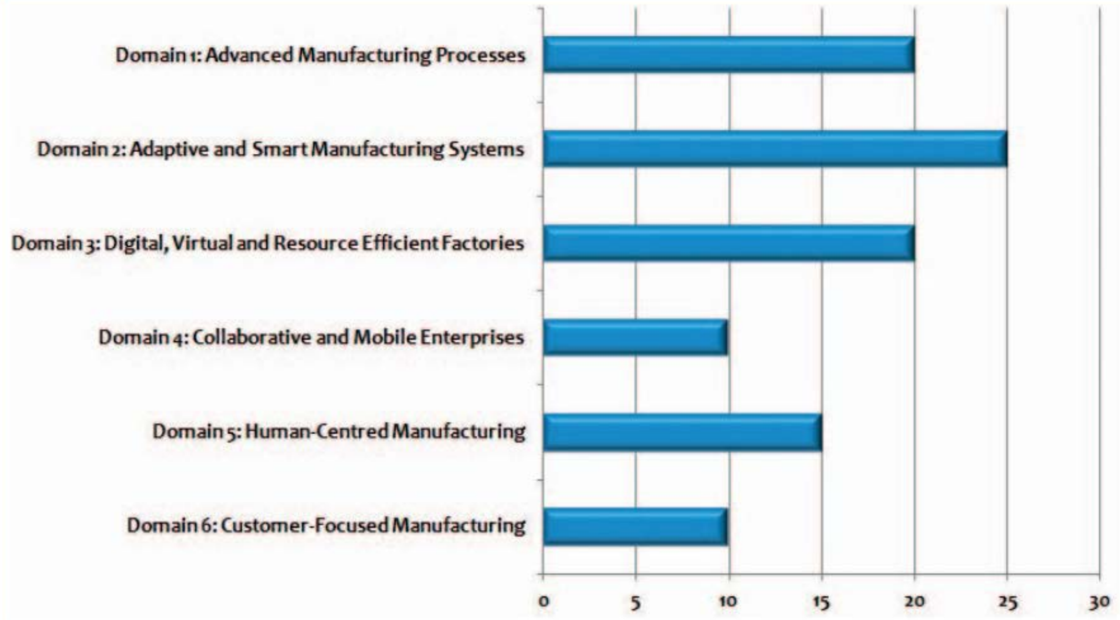
People

Organization
FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.
IBM
UNIVERSITY OF EDINBURGH
UNIVERSITY OF GLASGOW

APPENDIX 8 – FUNDING SCHEMES

H2020

If we look at the H2020 strategy in terms of Research & Development and the technical development of I4.0; the following indicative distribution of funds can be made:



Indicative public funding distribution among the roadmap domains (in %)

Generally speaking the Horizon2020 strategy is more focussed on industry and application, then on research itself. The calls (and thus the funding) for these project is more wide-spread then traditional research only oriented projects. However, almost all the projects will have a research related part in the project. Furthermore, there are different types of projects and calls to be found under H2020. These calls have a different focus which is mainly related to the TRL level of the project. The main calls are divided between:

- **Research and Innovation Actions (RIA) (TRL 1-4)**: RIA projects are collaborative research projects which can lead to the development of new knowledge or a new technology. The research projects have clearly defined challenges which are to be tackled. Projects must consist of a minimum of 3 partners from 3 Member States or Associated Countries.
- **Innovation Actions (IA) (TRL 5 – 9):** IA projects are closer-to-the-market activities which include prototyping, testing, demonstrating, piloting, scaling-up etc. for new or improved products, processes or services. Projects must consist of a minimum of 3 partners from 3 Member States or Associated Countries. The partners must be a mix of industry and academia.
- **Coordination and Support Action (CSA) (TRL < 2):** CSA projects are actions which can be described as accompanying measures. Funding for research and innovation are not covered by these actions. Measures include coordinator and networking of research and innovation projects, programs and policies. A project must have at a minimum 1 entity or a consortium

of partners from different countries dependent on the call. The project is open to industry and academia.

- **Fast Track to Innovation (FTI) (TRL 4 – 9):** Continuously open, innovator-driven calls which target innovation projects addressing any technology or societal challenge field. The pilot action will undergo an in-depth assessment half-way through Horizon 2020. Projects must consist of a consortium of industry, including SMEs, with a minimum of three and maximum of five partners and a maximum EU contribution of € 3 million per project.

In the next part of the chapter several calls are identified which could be interesting to the research questions formulated by BMS. With every call it is indicated what type of project is eligible, what the minimum requirements of the consortium are and what the expected impact is. The calls are a mix of technology oriented and societal oriented.

Marie Sklodowska-Curie Actions

Innovative Training Networks (ITN) support competitively selected joint research training and/or doctoral programmes, implemented by European partnerships of universities, research institutions, and non-academic organisations. The research training programmes provide experience outside academia, hence developing innovation and employability skills. ITNs include industrial doctorates, in which non-academic organisations have an equal role to universities in respect of the researcher's time and supervision, and joint doctoral degrees delivered by several universities. Furthermore, non-European organisations can participate as additional partners in ITNs, enabling doctoral-level candidates to gain experience outside Europe during their training. Deadline: 15th of January 2019.

Erasmus+ Program – strategic partnerships in higher education

Develop, test, adapt and implement innovative practices relating to:

- joint study programmes and joint curricula, intensive programmes and common modules – including emodules– between partnership members from different countries, disciplines and economic sectors (public/private), ensuring the relevance towards the needs of the labour market;
- project-based transnational collaboration between enterprises and students/staff at higher education institutions to study real life cases;
- pedagogical approaches and methodologies especially those delivering transversal competences, entrepreneurship mindset and creative thinking, including by introducing multi-, trans- and interdisciplinary approaches, building learning mobility more systematically into curricula ('embedded mobility') and through a better exploitation of ICT;
- the integration of a greater variety of study modes (distance, part-time, modular learning), notably through new forms of personalised learning, strategic use of open educational resources and virtual mobility and virtual learning platforms;

Strategic Partnerships are transnational projects designed to develop and share innovative practices and promote cooperation, peer learning, and exchanges of experiences in the fields of education, training, and youth.

Science with and for society program (SwafS)

This program has different calls related to the cooperation between science and society. It is expected that in the short term the development of partnerships between schools, local communities, Civil Society Organisations, universities and industry should contribute to a more scientifically interested and literate society and students with a better awareness of and interest in scientific careers. In the medium term the activities should provide citizens and future researchers with the tools and skills to make informed decisions and choices and in the long-term this action should contribute towards the ERA objectives of increasing the numbers of scientists and researchers in Europe. An interesting call could be: SwafS-16-2019 – Ethics of Innovation: the challenge of new interaction modes. Deadline: 2nd of April 2019.

TOPIC: Smart Anything Everywhere
Focus area: Digitising and transforming European industry and services (DT)
DT-ICT-01-2019: "Smart anything everywhere" stands for the next wave of products that integrate digital technology. The challenge is to accelerate the design, development and uptake of advanced digital technologies by European industry - especially SMEs and mid-caps - in products that include innovative electronic components, software and systems, and especially in sectors where digital technologies are underexploited. Deadline: 2nd of April 2019.

a. Innovation Actions SAE

As Phase 3 of Smart Anything Everywhere, this sub-topic calls for Digital Innovation Hubs that strengthen European SMEs and mid-caps by experimenting and testing with one or more of the following technologies, or by supporting them to manufacture these products. Projects should also support eco-system building for promising platforms developed in earlier R&I products.

b. Coordination and Support Activities SAE

The action will support the SAE network and help achieve broad coverage in technological, application, innovation, and geographic terms, and to link up with regional/national innovation initiatives, and other Digital Innovation Hubs. Its tasks and services shall include maintaining a single innovation portal, sharing of best practices, dissemination, brokering, leveraging further investment and training. For these support actions, close cooperation with ECSEL, and other CSAs funded under the Digitizing European Industry focus area is looked for.

INNOSUP
These calls are focused on SMEs but will necessitate universities and other partners to set up a competitive proposal. The topics which can be specifically relevant for Twente University are:

- INNOSUP-04-2019: Workplace innovation uptake by SMEs deadline 17/01/2019
- INNOSUP-07-2019: European Open Innovation network in advanced technologies deadline 01/08/2019
- INNOSUP-01-2018-2020: Cluster facilitated projects for new industrial value chains deadline first stage 03/04/2019, second stage 12/09/2019

All the topics can be found here: https://ec.europa.eu/easme/en/horizon-2020-innosup

Factory of the Future calls
Are more related to the technology development. Deadlines for calls of 2018 are for the end of February and are not relevant.

- For 2019, there are different calls, but this will not fit with University Twente ambitions. Consequently, it is not advised that BMS initiatives any project in this call but should join any consortium if an opportunity arises.
  - DT-FOF-05-2019: Open Innovation for collaborative production engineering (IA)
  - DT-FOF-06-2019: Refurbishment and re-manufacturing of large industrial equipment (IA)
  - DT-FOF-07-2020: Reliable and accurate assembly of micro parts (RIA)

        - DT-FOF-08-2019: Pilot lines for modular factories (IA)
        - DT-FOF-09-2020: Holistic energy-efficient factory management (IA)
        - DT-FOF-10-2020: Pilot lines for large-part high-precision manufacturing (IA 50%)
        - DT-FOF-11-2020: Quality control in smart manufacturing (IA)
        - DT-FOF-12-2019: Handling systems for flexible materials (RIA)
        - DT-NMBP-18-2019: Materials, manufacturing processes and devices for organic and large area electronics (IA)
        - DT-NMBP-19-2019: Advanced materials for additive manufacturing (IA)

- Sustainable process industry (SPIRE) are more related to process industries and are quite similar to FoF calls.
    - CE-SPIRE-03-2018: Energy and resource flexibility in highly energy intensive industries
    - DT-SPIRE-06-2019: Digital technologies for improved performance in cognitive production plants (IA)

Eureka clusters are also a possibility to get funding. Regular meetings with national Contact Points are a prerequisite to set up winning project within this scheme. PNO can help to guide Twente university through the process.

- SMART Eureka cluster https://www.smarteureka.com *(Advanced manufacturing program)*
- EURIPIDES Eureka cluster www.euripides-eureka.eu (*Smart Electronic systems)*
- ITEA Eureka cluster itea3.org (*Software-intensive Systems & Services)*

NWO Calls

The NWO program in the Netherlands is the national program for research. The NWO program will be remodelled in august of 2018 and will be centred on four categories. These categories are:

1. Talent
2. Open project financing
3. Open program financing
4. Strategic financing

For every category there will be several financing instruments. Examples include Veni, Vidi, Vici in the category talent. All the programs will be modular in form; meaning that there will be several phases for the different financing instruments (NWO, 2017). Open calls for NWO will be published on their website.

There are currently limited calls open under the old structure of the NWO. One call which could be interesting for I4.0 is:

- Duurzame Living Labs. Fase 1: Ontwikkelsubsidies voor consortiumvorming
  A small project, maximum €300.000, which support the development of a consortium around a living lab. The living lab will have to be in the area of transport/logistics. Deadline is the 27th of March 2018

Additional calls will be published throughout the year. The expectation is that after August 2018 most of the calls will be published as the new structure is then relevant.

Open Technologieprogramma
The Open Technologieprogramma is a call within the NWO program. The aim of the program is to support projects across the scientific spectrum. The projects are judged based on the scientific quality and utilization. There are no specific deadlines for this program as it is open year-round.

Perspectief programma
The “Perspectief programma” is a program within the STW. The aim of the program is to support projects that aim to realize economic and societal impact in the Netherlands. The programs are public-private research oriented. Connection to the topsector program in the Netherlands is a requirement. The current program is now in its third phase and only approved application from phase 1 and phase 2 can submit projects. However, the expectation is that this program will come back in Q3/Q4 of 2018. For more information see: http://www.stw.nl/nl/perspectief.

OPEN mind
Is an STW/NWO initiative which supports researcher with an idea which could potentially have a significant societal impact. The fund is €50.000 and the project duration is one year. Currently, there is no open call, but the expectation is that there will be one in November 2018. For more information on this program see: http://www.stw.nl/nl/content/open-mind.

Commit2data
Commit2data is a multi-year national research and innovation program. The program is based on public-private partnerships (PPP). Commit2data works together with NWO and TNO. Within research the focus will be on multi-year public-private partnerships between science and business. Within valorisation and dissemination, the focus will be on short-term projects with knowledge partners. With that, Commit2Data offers opportunities for science as well as for large companies, small and medium enterprises and the government (Big Data, sd).

On the website of Commit2data the relevant funding instruments are published. Currently, there are no open calls but the website is continuously updated. The calls are published here: https://www.dutchdigitaldelta.nl/big-data/instrumentarium

M.ERA-Net network
M.ERA-NET aims to be a suitable tool to respond to societal challenges and evolving technological advances. A series of innovative joint calls will be operated in a variable geometry approach. They will reflect the priorities, needs and challenges identified at national and European levels, thus opening an attractive and efficient tool for transnational RTD with low administrative efforts.

This will help to overcome barriers to enter transnational cooperation, in particular for SMEs. An interdisciplinary approach will enable knowledge transfer not only along the innovation chain, but also across application fields. There is currently no open call, but a new call is expected in Q4 of 2018. The calls are published here: https://m-era.net/joint-calls.

Interreg
The Interreg program is a European funding program for spatial and regional development. The projects under Interreg are always a cooperation between organizations from different member states. The Interreg program is divided into three programs. The programs have a different aim and focus.

The three programs are:
- Cooperation between border regions (Interreg A)

- Cooperation between regions in different countries (Interreg B);
- Cooperation interregional and European wide (Interreg C)

In the Netherlands there are four Interreg A programs, namely: Interreg Nederland-Vlaanderen, Interreg Deutschland-Nederland, Euregio Maas-Rijn (EMR) and 2 seas (Maritime). For the University of Twente the latter is interesting as they are within the region of the Interreg program. The Interreg Deutschland-Nederland does not work with calls and it is possible to submit a project idea throughout the year. There are some main characteristics to the project: it must be cross-border, there must be a lead partner and it has to contribute to the program goals. For more information on the requirements, see: https://www.deutschland-nederland.eu/nl/eigenes-projektstarten/.

The Interreg North West Europe, Interreg North See Region and Interreg Europe (VC) are the transnational and European wide cooperation programs. These programs work with different calls depending on the region. The programs support transnational project that focus on research, technical development and innovation, transition to low carbon emissions, protection of the environment and supporting of efficient use of natural resources and solving the bottlenecks in infrastructure and stimulating energy efficient transport. There must be at least three partners in a project, from different member states. The application procedure is in two phases. The first phase is submitting the project idea to the program secretariat. If the project idea is approved, then it must be further developed into a full project proposal. Currently, there are no calls, but they are expected in the coming months as the full Interreg program will run till 2020.

APPENDIX 9 – PROPOSAL MINOR INDUSTRY 4.0/SMART INDUSTRY

To translate the Industry 4.0/Smart Industry research done at our university into education a minor is a good start-up to explore the possibilities. Therefore this proposal is written as a discussion document.

At the UT a minor consist of 2 modules of 15 EC each. Different types of minors exist:

- HTHT-minors; 30 EC, bound by several rules, subjects in the 2 modules are related;
- Join-in minors; two modules of 15 EC each, no relation between modules necessary, more freedom in design and regulations than a HTHT-minor, very broad target group;
- In-depth minors; two modules of 15EC each, no relation between modules necessary, more specifically designed for deepening knowledge within a discipline.

Combinations of minor-modules possible; a join-in minor-module can be combined with an in-depth minor-module. For none of the related modules within a minor it is allowed to demand pre knowledge of the first module in a minor (also not for HTHT-minor). So it must always be possible to follow a module in a minor stand-alone.

In this proposal the assumption is made that there will be a module (15 EC) designed for a join-in minor.

The target group for this minor-module is broad: engineering, business and computer science students.

Content
Industry 4.0 started in industry, so this minor-module will focus on the industry.

General part
7,5 EC courses (divided over 3 main courses):

- Engineering
- Business
- Computer science

This part can be done in cooperation with Fraunhofer Institute.

Specialization part (7,5 EC)
Students working on an Industry 4.0/Smart Industry topic. These topics can be brought in by anyone related to Industry 4.0/Smart Industry research. The topics can differ per year, a yearly theme can be an option to take care of cross-fertilization between disciplines. When a group of 4 students is available the topic will continue. A specialization can consists of lectures to introduce, but the main part should be an assignment.

Possible topics:
Technology based

- Digital twin models

- IOT - sensors- communication protocols
- 3D printing
- Blockchain
- …

Business models based

- Life cycle business
- From supply chain to marketplaces
- Network driven businesses
- ….

APPENDIX 10 – OVERVIEW OF SMART INDUSTRY FIELDLABS

Name	Description
Ultra-personalised products and services	UPPS develops new methods to design and produce personalized products and services. Focused on the entire process; from data acquisition, concept development and scanning, to engineering and data processing for production.
Region of smart factories	Consortium of 40 companies from the Northern Netherlands (including Philips and Fokker) develops concepts for the Factory of the Future, with a focus on faultless production and 'First-Time-Right' product development. Program consists of 10 pilot projects, business development activities for technology suppliers, and the building of an eco-structure around Smart Manufacturing including education (Centre of Expertise) and shared facilities.
Smart dairy farming	Increasing the sustainability (health and production) and (economic) efficiency of dairy farming by collecting real-time data from dairy cows and sharing them in the chain.
Smart bending factory	State-of-the-art factory for laser cutting and bending of steel, fully controlled via the internet. Aim: to reduce 'total-cost-of-ownership' by 20% and 'time-to-market' 5 times faster.
The garden	Working together in the chain in a safe way. Security in Smart Industry with the first project EPLM (Extended Product Life Cycle Management).
Freshteq.nl	Technological innovation for greenhouse horticulture. Smart solutions for fully automated production, cultivation and distribution of fresh fruit and vegetables. Creating Fresh Food chains for cities and densely populated regions worldwide.
Multimateriaal 3D printen	Focuses on developing completely new value chains, based on the next generation of multi-material 3D printing technologies and the associated data management systems.
Smart connected supplier network	Fieldlab aims to make information exchange in the supply chain more efficient through standardization and interoperability, starting with ERP software.
Fieldlab campione	The aim of this first field lab in the process industry is to make maintenance 100% predictable. Condition Based Maintenance: sensors monitor the status of installations to accurately predict when maintenance is needed. The plant installations are better available, at a lower cost.
Flexible manufacturing	This field lab aims to make production processes more flexible with the use of, among other things, robotics, ICT and operator support systems. The easier, error-free and flexible production of large product mix in small series through shorter changeover times and zero programming.
Digital factory for composites	Facility for open cross-sectoral innovation and demo centre for automated and digital production of composites.
Automated composited and metal manufacturing & maintenance	Centre for the development of lightweight structural parts and associated manufacturing technologies and maintenance concepts in composite and metal. Focus is on automated

	processes (including robot-based composites manufacturing and metal additive manufacturing).
Ramlab	Develops knowledge in the field of metal 3D printing and certification of large parts for the port-related sector.
3D makers zone	Revolutionizing how things are made. 3D Makers Zone focuses on applied innovation for Smart Industry. We create innovative products and solutions for companies. We do this by applying innovation technologies with a strong focus on industrial 3D printing / Additive Manufacturing. Our practice environment also has several labs where IoT tech, blockchain, AR / VR and robotics are applied.
Smart welding factory	Flexible and fully automated production and 3D printing (WAAM) using welding robots, without programming time: 'first-time-right' and 'one-piece-flow'.
Praktijkcentrum voor precisielandbouw	Making data and measurement data accessible for (collective) use by agricultural companies, suppliers, processing industry and knowledge institutes. Providing demo and test facilities within the practice centre and on location.
De duurzaamheids fabriek	Smart Solutions maritime automation (Robotics), Smart Metrology and Smart Energy. Stimulating development, valorisation of innovations in maritime sector and energy transition. Facilitate the 'Lifelong development'
3D medical	The drastic improvement of personalized care through SMART technology such as 3DImaging and 3D printing. Collaboration with UMC Utrecht, ProtoSpace Foundation, and University of Applied Sciences of Utrecht.
Composieten onderhoud en reparatie	The aim is to fully automate maintenance of repair on composite parts, primary for aircrafts.
Thermoplastic composites Nederland (TPC NL)	Centre for both fundamental and applied research for production with thermoplastic composites. Main aspects are tape laying, compression moulding, insert moulding, recycling automation (robotics).
Fieldlab Camino	Ambition is 100% predictable maintenance of infrastructural works. Work is being done in 2 clusters: Rail and Water, and new clusters in the field of Smart Energy and Tunnels are under development. Within the clusters, parties such as Prorail, Rijkswaterstaat and Vechtstromen water board work together with technology parties to develop new solutions in the field of Smart Maintenance.
Fieldlab Smash	Ambition is 100% predictable maintenance. Condition based Maintenance in shipbuilding. Collect and analyse real-time information about the state of the ship in order to be able to carry out maintenance on time and prevent downtime
Smart base	A testing ground for the development of a 'Smart Base' for Defense. The Defense organization is going to experiment in collaboration with the innovative business community to come up with solutions in the areas of protection, energy, water and 'support & services'.
Fieldlab 5G	5G makes Noord-Groningen the test ground for 5G mobile internet. Entrepreneurs and non-profit organizations work together with experts to test applications of 5G.

Industrial robotics	Develops certified training in robot programming and robot control at MBO and HBO level. Offers the possibility to develop and experiment with new technologies and applications.
Technologies added	The first Shared Smart Factory with a shared production location for Smart Manufacturing, incubators and service providers in the field. In addition, it provides in-house facilities for Stenden University of Applied Sciences and other knowledge and training institutes.
Dutch optics centre	Dutch Optics Centre brings together knowledge and research capacity to support Dutch companies. Together we develop the next generation of optical instruments to contribute to global challenges
Robohouse	Facility and innovation program to further develop robotics in the Netherlands. Focus is on adoption acceleration of 'state-of-the-art' robotics solutions for organizations.
High tech software competence centre	Consortium of 20+ high tech software companies around virtual prototyping & design, model-based software and data analytics & services. Show how ground-breaking innovative software contributes to more efficient, flexible and qualitatively better development and production of hardware.
Blocklab	Blocklab is working on a decentralized future. Together with engineers, developers and supply chain partners from the Logistics and energy sector, it develops blockchain usecases that bring about radical changes in chains, grids and market models.
Dutch growth factories	Innovation cluster to accelerate the digital transformation of manufacturing companies into new markets. Aim: to develop and scale up production processes of 50 scale ups, SMEs and multinationals in 2025.
Techport	The Fieldlab Techport has the ambition to link real-time data from factory installations to production data and quality data and thus realize a complete integration of data - and thus control - in the process industry: result; 100% predictable maintenance of installations and optimum use of production resources with maximum output at minimum cost.

APPENDIX 11 – OVERVIEW OF SMART INDUSTRY JOURNALS AND CONFERENCE

Please find below the complete list of most cited journals and conference proceedings in which most of the I4.0 research has been published. Most of these are also shown in the citation analysis map from Error! Reference source not found. **(Section 0).**

Legend:
J – journal
CP – conference proceedings
CPS – conference proceedings series
BS – book series (peer reviewed)

Type	Name
CPS	ACM International Conference Proceeding Series
BS	Advances in Transdisciplinary Engineering (IOP Press)
J	Aiche Journal (Wiley)
CP	Annals of DAAAM and Proceedings of the International Daaam Symposium
CP	ASME 2017 12th International Manufacturing Science and Engineering Conference, MSEC 2017 Collocated With the JSME/ASME 2017 6th International Conference on Materials and Processing
J	At-automatisierungstechnik (De Gruyter)
CP	CEUR Workshop Proceedings
CP	Challenges for Technology Innovation: An Agenda for the Future - Proceedings of the International Conference on Sustainable Smart Manufacturing, S2m 2016
J	Chinese Journal of Mechanical Engineering (English Edition) (Springer)
CPS	CIRP Annals - Manufacturing Technology
J	Computers and Chemical Engineering (Elsevier)
J	Computers in Industry (Elsevier)
CP	ICSMA 2008 - International Conference on Smart Manufacturing Application
CP	IECON Proceedings (Industrial Electronics Conference)
J	IEEE Access (IEEE)
CP	IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)
CP	IEEE International Conference on Industrial Informatics (INDIN)
J	IEEE Transactions on Industrial Informatics (IEEE)
CPS	IFAC-papersonline
J	International Journal of Advanced Manufacturing Technology (Springer)
J	International Journal of Computer Integrated Manufacturing (Taylor & Francis Online)
J	International Journal of Precision Engineering and Manufacturing - Green Technology (Springer)
J	International Journal of Production Research (Taylor & Francis Online)
CPS	IOP Conference Series: Materials Science and Engineering
J	Journal of Cleaner Production (Elsevier)
J	Journal of Manufacturing Systems (Elsevier)

J	Journal of Security and Sustainability Issues (Entrepreneurship and Sustainability Center)
CPS	Lecture Notes in Informatics (LNI), Proceedings - Series of the Gesellschaft Fur Informatik (GI)
J	Manufacturing Letters (Elsevier)
CPS	Procedia CIRP
CPS	Procedia Computer Science
CPS	Procedia Engineering
CPS	Procedia Manufacturing
CP	Proceedings of International Conference on Computers and Industrial Engineering (CIE)
CP	Proceedings of SPIE - the International Society for Optical Engineering
CP	Proceedings of the ASME Design Engineering Technical Conference
CP	Proceedings of the IEEE International Conference on Industrial Technology
CP	Proceedings of the Summer School Francesco Turco
J	Robotics and Computer-integrated Manufacturing (Elsevier)
J	Sensors (Switzerland) (MDPI)
J	Sustainability (Switzerland) (MDPI)

APPENDIX 12 – QUERY FOR BMS RESEARCH

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APPENDIX 13 – STATE-OF-THE-ART RESEARCH FOR INDUSTRY 4.0, BUSINESS AND SUSTAINABILITY[24]

Big data analytics:

Xu, L. D., et al. (2014). "Internet of things in industries: A survey."
Internet of Things (IoT) has provided a promising opportunity to build powerful industrial systems and applications by leveraging the growing ubiquity of radio-frequency identification (RFID), and wireless, mobile, and sensor devices.

Today, a commonly accepted definition for IoT is a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'Things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network [2].

SOA for IoT: Sensing layer, Networking layer, Service layer, Interface layer.
Key enabling technologies: Identification and Tracking Technologies, Communication Technologies in IoT, Networks Involved in IoT, Service Management in IoT.
Key IoT Applications in industries: Healthcare service industry, FSC, mining production, transportation and logistics, firefighting.

As a complex cyber-physical system, IoT integrates various devices equipped with sensing, identification, processing, communication, and networking capabilities. In particular, sensors and actuators are getting increasingly powerful, less expensive and smaller, which makes their use ubiquitous.

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6714496

Al-Fuqaha, A., et al. (2015). "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications."

The IoT is enabled by the latest developments in RFID, smart sensors, communication technologies, and Internet protocols. The basic premise is to have smart sensors collaborate directly without human involvement to deliver a new class of applications. The current revolution in Internet, mobile, and machine-to-machine (M2M) technologies can be seen as the first phase of the IoT. In the coming years, the IoT is expected to bridge diverse technologies to enable new applications by connecting physical objects together in support of intelligent decision making.

IoT can play a remarkable role and improve the quality of our lives. These applications include transportation, healthcare, industrial automation, and emergency response to natural and man-made disasters where human decision making is difficult.

The IoT transforms these objects from being traditional to smart by exploiting its underlying technologies such as ubiquitous and pervasive computing, embedded devices, communication technologies, sensor networks, Internet protocols and applications.

Architecture standardization can be seen as a backbone for the IoT to create a competitive environment for companies to deliver quality products.

[24] Partial results (will be updated soon with a complete overview)

IoT Architecture: Objects Layer, Object Abstraction Layer, Service Management Layer, Application Layer, Business Layer.
IoT Elements: Identification, Sensing, Communication, Computation, Services, Semantics.
IoT Common Standards: Application Protocols, Service Discovery Protocols, Infrastructure Protocols, Other Influential Protocols.
IoT Challenges: Availability, Reliability, Mobility, Performance, Management, Scalability, Interoperability, Security and Privacy.
Relations IoT: Big Data Analytics in Support of the IoT, Cloud Computing for the IoT, Fog Computing in Support of the IoT.
Application use-cases: Nursing Home Patient Monitoring System, Monitoring and Mitigation of Eating Disorders, In-Door Navigation System for the Blind and Visually Impaired People.
Service Analytic Use-Cases: Efficient Estimation of the Number of Unique IP Addresses, Tracking the Frequency of Service Usage by a Given IP.

Low-weight efficient communication between sensing devices and interoperability between different communication mechanisms are critical problems of IoT.

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Boyd, D. and K. Crawford (2012). "Critical questions for big data: Provocations for a cultural, technological, and scholarly phenomenon."
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84861974217&doi=10.1080%2f1369118X.2012.678878&origin=inward&txGid=c283a519f3b5969e1c7b537e4bfe6a27

Chen, H., et al. (2012). "Business intelligence and analytics: From big data to big impact."
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84916597404&origin=inward&txGid=27be6aa593862d8bae44dae0fd3bd44b

McAfee, A. and E. Brynjolfsson (2012). "Big data: the management revolution."
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84871857828&origin=inward&txGid=3055f4ed120172b090124fd0e432a6f1

Circular Economy:

Geng, Y., et al. (2012). "Towards a national circular economy indicator system in China: An evaluation and critical analysis."

China is the first country to release nationally focused CE indicators so that objective and credible information on the status of CE implementation can be recognized.

We show that certain benefits can be gained, but substantive revision is also needed due to the lack of a comprehensive set of sustainability indicators which should include social, business indicators, urban/industrial symbiosis, absolute material/energy reduction, and prevention-oriented indicators. Concerns related to barriers on implementation are also presented.

CE is based on the 'win-win' philosophy that a healthy economy and environmental health can co-exist

A variety of benefits, including economic, environmental and social ones, can be gained through the implementation of such indicators. However, some problems exist, such as lack of social indicators, urban/industrial symbiosis, prevention-oriented indicators and absolute energy/material reduction indicators, as well as barriers to implementation.

We do acknowledge that the indicators can be used for benchmarking, improvement of environmental performance at multiple levels, identification of problem areas, cost-benefit analyses, policy direction, business investment decisions, and many other applications.

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Ghisellini, P., et al. (2016). "A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems."

The ultimate goal of promoting CE is the decoupling of environmental pressure from economic growth. The implementation of CE worldwide still seems in the early stages, mainly focused on recycle rather than reuse.

Sustainable development requires balanced and simultaneous consideration of the economic, environmental, technological and social aspects of an investigated economy, sector, or individual industrial process as well as of the interaction among all these aspects.

Although the implementation of CE worldwide is still at an early stage of development, CE provides a reliable framework towards radically improving the present business model towards preventive and regenerative eco-industrial development as well as increased wellbeing based on recovered environmental integrity. H

With reference to the so-called Odum and Odum's pulsing paradigm, with long time-scale oscillating waves of growth and descent, it seems evident that the same policies and strategies that apply to growth phases may not be the best options in transition and descent stages. As a consequence, CE is not an appropriate tool for growth-oriented economic systems (i.e. cannot be claimed to support further economic growth), where efficiency is not the "winning card" and the rebound effect and market competition are likely to diminish the potential benefits of increased efficiency.

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Mirabella, N., et al. (2014). "Current options for the valorization of food manufacturing waste: A review."

The authors present feasibility and constraints of applying industrial symbiosis in recovering waste from food processing, focusing on recycling (excluding energy recovery) of the solid and liquid waste from food processing industry.

The large amount of waste produced by the food industry, in addition to being a great loss of valuable materials, also raises serious management problems, both from the economic and environmental point of view. Many of these residues, however, have the potential to be reused into other production systems, trough e.g. bio-refineries.

The review of the literature about food waste recovery and industrial symbiosis in the food industry showed that the majority of the studies focus on restricted examples and pilot-scale laboratory experiences, while only few cases contain data about economic and technical feasibility on existing full-scale studies.

It is clear that the promotion of industrial symbiosis in the food industry is possible only upon assessment of available technologies and of materials potential in terms of quality and quantity. Indeed, in order to promote an industrial symbiosis among companies, feasibility studies are essential to classify the type and amount of wastes and to identify which industrial sector/activity might transform and use them

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Tukker, A. (2015). "Product services for a resource-efficient and circular economy - A review."

Since the 1990s, Product Service Systems (PSS) have been heralded as one of the most effective instruments for moving society towards a resource-efficient, circular economy and creating a much needed 'resource revolution'.

Business and environmental (dis)advantages of PSS. Here, recent literature e mainly case study research e simply seems to confirm the findings of the pre-2006 literature.

PSS is not the sustainability panacea. Renting, leasing and sharing can have environmental benefits since, in principle, the same service level can be achieved with the use of fewer artefacts. However, leased products tend to be used less carefully than products that are owned, and rented, leased or shared products may be returned earlier to the service provider in comparison to the lifetime of a product sold in the traditional manner. Furthermore, the added value of PSS in terms of comfort, convenience and the experience of ownership, particularly in a B2C context, might be lower than that of a corresponding product. Consumers simply value owning things and having control over artefacts, issues that seem less relevant in a B2B context.

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Chertow, M. and J. Ehrenfeld (2012). "Organizing Self-Organizing Systems: Toward a Theory of Industrial Symbiosis."
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84858614472&doi=10.1111%2fj.1530-9290.2011.00450.x&origin=inward&txGid=7494faf5ddaa4724ec8ce78c5ff3bb47

Closed loop supply chain:

Govindan, K., et al. (2015). "Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future."

Ilgin, M. A. and S. M. Gupta (2010). "Environmentally conscious manufacturing and product recovery (ECMPRO): A review of the state of the art."

Pishvaee, M. S., et al. (2011). "A robust optimization approach to closed-loop supply chain network design under uncertainty."

Link: https://ac.els-cdn.com/S0307904X10002623/1-s2.0-S0307904X10002623-main.pdf?_tid=26038ddd-6496-4941-9b1a-10ced8a65730&acdnat=1520245576_7bdf3eeeb20c48a630336c2299d8855d

Pishvaee, M. S. and S. A. Torabi (2010). "A possibilistic programming approach for closed-loop supply chain network design under uncertainty."

The significance of accounting for uncertainty and risk in such networks (closed-loop supply chain networks) spurs an interest to develop appropriate decision making tools to cope with uncertain and imprecise parameters in closed-loop supply chain network design problems.

The proposed model integrates the network design decisions in both forward and reverse supply chain networks, and also incorporates the strategic network design decisions along with tactical material flow ones to avoid the sub-optimalities led from separated design in both parts.

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Seuring, S. (2013). "A review of modeling approaches for sustainable supply chain management."

While different kinds of models are applied, it is evident that the social side of sustainability is not taken into account. On the environmental side, life-cycle assessment based approaches and impact criteria clearly dominate. On the modelling side there are three dominant approaches: equilibrium models, multicriteria decision making and analytical hierarchy process.

It is evident that the environmental dimension clearly dominates and social aspects are widely ignored or interpreted in an unusual manner. Life-cycle assessment type studies and respective data form the backbone of the environmental debate in the papers, while cost minimization still seems to dominate the economic dimension.

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Co-creation in smart industries:
Ghanbari, A., et al. (2017). "Business Development in the Internet of Things: A Matter of Vertical Cooperation."

The potential of the Internet of Things lies in the interaction among industries working together toward value co-creation. Firms need to look beyond their internal business models and explore cooperative perspectives to define new business opportunities. We look into the relevance of vertical cooperation in the area of IoT and highlight the need to develop new value networks that leverage this cooperation and enable the creation of new business models.

Business relationships: Cooperation, Competition, Coopetition, Coexistence.

When discussing business opportunities in the IoT, firms need to collaborate and be aware of novel network-centric business models.

Companies will need to define their own business models, but in connection with the value network. They will need to understand how to define a business model that is aligned with the value created by the value network in the IoT ecosystem.

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7842424&tag=1

Kaihara, T., et al. (2015). A proposal of value co-creative production with IoT-based thinking factory concept for tailor-made rubber products.
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84952056823&doi=10.1007%2f978-3-319-22759-7_8&origin=inward&txGid=5af1e87e24c8350a8412307291ff2047

Kudo, H. and B. Granier (2016). Citizen co-designed and co-produced smart city: Japanese Smart city projects for "quality of life" and "resilience".
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84976402683&doi=10.1145%2f2910019.2910103&origin=inward&txGid=8d2346819f4d8f719141de1e5d03e24a

Matschoss, K., et al. (2015). "Pioneering customers as change agents for new energy efficiency services—an empirical study in the Finnish electricity markets."
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84942365393&doi=10.1007%2fs12053-014-9300-8&origin=inward&txGid=735938fd7af3bc0fc20cf6801b21c70b

van Geenhuizen, M. and P. Nijkamp (2012). "Knowledge virtualization and local connectedness among young globalized high-tech companies."

Smart high-tech companies are characterized by knowledge intensity and open innovation, and even when these companies emerge in spatial clusters or in dense urban places, they may utilize knowledge networks on a global scale. There is, however, not much insight into the factors that shape global knowledge networks, the role of virtualization therein, and the impact of global knowledge sourcing on local connectedness.

The outcomes suggest coexistent use of both mainly local and mainly global knowledge networks in city-regions, and losing local connectedness by some of the globalized companies, particularly those involved in co-creation of products with global customers and those acting as learning partners of global multinational corporations.

Due to remaining relationships with the local university or local company of origin, local connectedness has increased despite strong support from virtualization in global innovation practices.

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Cyber Physical Systems:
Lee, J., et al. (2015). "A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems."

Recent advances in manufacturing industry has paved way for a systematical deployment of Cyber-Physical Systems (CPS), within which information from all related perspectives is closely monitored and synchronized between the physical factory floor and the cyber computational space. Moreover, by utilizing advanced information analytics, networked machines will be able to perform more efficiently, collaboratively and resiliently.

With recent developments that have resulted in higher availability and affordability of sensors, data acquisition systems and computer networks, the competitive nature of today’s industry forces more factories to move toward implementing high-tech methodologies.

5C architecture: Smart connection, Data-t-information conversion, Cyber, Cognition, Configuration.

This paper presents a 5C architecture for Cyber-Physical Systems in Industry 4.0 manufacturing systems. It provides a viable and practical guideline for manufacturing industry to implement CPS for better product quality and system reliability with more intelligent and resilient manufacturing equipment.

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Mo, Y., et al. (2012). "Cyber-physical security of a smart grid infrastructure."

We argue that the “smart” grid, replacing its incredibly successful and reliable predecessor, poses a series of new security challenges, among others, that require novel approaches to the field of cyber security.
The tight coupling between information and communication technologies and physical systems introduces new security concerns, requiring a rethinking of the commonly used objectives and methods. Existing security

approaches are either inapplicable, not viable, insufficiently scalable, incompatible, or simply inadequate to address the challenges posed by highly complex environments such as the smart grid.

Grid: generation, transmission, distribution, consumption.

The smart grid enables a drastic cost reduction for both power generation and consumption. Dynamic pricing and distributed generation with local generators can significantly reduce the electricity bill.

Cyber Security Requirements: Confidentiality, Integrity, Availability.
Attack Model: Attack Entry Points, Adversary Actions.
Countermeasures: Key Management, Secure Communication Architecture, System and Device Security.

On the one hand, the increased complexity will require more effort from the adversary to understand the system, but on the other hand, this increased complexity also introduces numerous opportunities for exploitation.
System-theoretic approaches are nondeterministic as compared to information security

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6016202

Rajkumar, R., et al. (2010). Cyber-physical systems: The next computing revolution.
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-77956217277&doi=10.1145%2f1837274.1837461&origin=inward&txGid=e2c51a6f94162770517ac0f4179dee2e

Rao, L., et al. (2010). Minimizing electricity cost: Optimization of distributed internet data centers in a multi-electricity-market environment.

While most existing research focuses on reducing power consumptions of IDCs, the power management problem for minimizing the total electricity cost has been overlooked. This is an important problem faced by service providers, especially in the current multi-electricity market, where the price of electricity may exhibit time and location diversities.

Through extensive evaluations based on real life Google IDC data and associated electricity price, we show the efficacy of the proposed method as well as total electricity cost reduction.

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5461933

Sridhar, S., et al. (2012). "Cyber-physical system security for the electric power grid."

The development of a trustworthy smart grid requires a deeper understanding of potential impacts resulting from successful cyber attacks. Estimating feasible attack impact requires an evaluation of the grid's dependency on its cyber infrastructure and its ability to tolerate potential failures. A further exploration of the cyber–physical relationships within the smart grid and a specific review of possible attack vectors is necessary to determine the adequacy of cybersecurity efforts.

The U.S. Department of Energy (DOE) has identified seven properties required for the smart grid to meet future demands [1]. These requirements include attack resistance, selfhealing, consumer motivation, power quality, generation and storage accommodation, enabling markets, and asset optimization.

A reliable smart grid requires a layered protection approach consisting of a cyber infrastructure which limits adversary access and resilient power applications that are able to function appropriately during an attack.

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6032699

Digital and cloud manufacturing

Bari, M. F., et al. (2013). "Data center network virtualization: A survey."

With the growth of data volumes and variety of Internet applications, data centers (DCs) have become an efficient and promising infrastructure for supporting data storage, and providing the platform for the deployment of diversified network services and applications (e.g., video streaming, cloud computing). These applications and services often impose multifarious resource demands (storage, compute power, bandwidth, latency) on the underlying infrastructure. Existing data center architectures lack the flexibility to effectively support these applications, which results in poor support of QoS, deployability, manageability, and defence against security attacks. Data center network virtualization is a promising solution to address these problems.

Traditional TCP/IP protocol stack limitations: No performance isolation, Increased security risks, Poor application deployability, Limited management flexibility, No support for network innovation.

Virtualization is a promising technology for designing scalable and easily deployable data centers that flexibly meet the needs of tenant applications while reducing infrastructure cost, improving management flexibility, and decreasing energy consumption.

Designing smart-edge networks, providing strict performance guarantees, devising effective business and pricing models, ensuring security and programmability, supporting multi-tiered and multi-sited data center infrastructures, implementing flexible provisioning and management interfaces between tenants and providers, and developing efficient tools for managing virtualized data centers are important directions for future research.

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6308765

Demirkan, H. and D. Delen (2013). "Leveraging the capabilities of service-oriented decision support systems: Putting analytics and big data in cloud."

Using service-oriented decision support systems (DSS in cloud) is one of the major trends for many organizations in hopes of becoming more agile.

For many companies (especially small and medium size), the pay-as-you-go service-oriented computing model (cloud computing), with having someone else worrying about maintaining the hardware and software are becoming very attractive.

Service-oriented DSS: Data-as-a-service (DaaS), Information-as-a-service (information on demand) (IaaS), Analytics-as-a-service (AaaS).

When we define data, information and analytics we see that the traditional measurement mechanisms do not work efficiently. Organizations may care about service accuracy and quality in addition to the cost and delivery time. Service-oriented DSS (DSS in cloud) proposes scale, scope and speed economies. Basically, reduction in unit service costs due to increase in operational size (scale), reduction in unit service costs due to increase in number of services being developed and provided (scope) and reduction in unit costs due to increase in number of services put through supply/demand chain (speed).

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Gubbi, J., et al. (2013). "Internet of Things (IoT): A vision, architectural elements, and future directions."

Ubiquitous sensing enabled by Wireless Sensor Network (WSN) technologies cuts across many areas of modern day living. This offers the ability to measure, infer and understand environmental indicators, from delicate ecologies and natural resources to urban environments.

IoT elements: Radio Frequency Identification (RFID), Wireless Sensor Networks (WSN), Adressing schemes, Data storage and analytics, Visualization.
Applications: Personal and home, Enterprise, Utilities, Mobile.
Open challenges and future directions: Architecture, Energy efficient sensing, Secure reprogrammable networks and privacy, Quality of service, New protocols, Participatory sensing, Data mining, GIS based visualization, Cloud computing, International activities.

Presented here is a user-centric cloud based model for approaching this goal through the interaction of private and public clouds. In this manner, the needs of the end-user are brought to the fore. Allowing for the necessary flexibility to meet the diverse and sometimes competing needs of different sectors, we propose a framework enabled by a scalable cloud to provide the capacity to utilize the IoT. The framework allows networking, computation, storage and visualization themes separate thereby allowing independent growth in every sector but complementing each other in a shared environment.

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Ren, Y., et al. (2015). "Mutual verifiable provable data auditing in public cloud storage."
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84928106743&doi=10.6138%2fJIT.2015.16.2.20140918&origin=inward&txGid=9aae2052d249cb975afd5dec805a7844

Xiao, Z., et al. (2013). "Dynamic resource allocation using virtual machines for cloud computing environment."

We have presented the design, implementation, and evaluation of a resource management system for cloud computing services. Our system multiplexes virtual to physical resources adaptively based on the changing demand. We use the skewness metric to combine VMs with different resource characteristics appropriately so that the capacities of servers are well utilized. Our algorithm achieves both overload avoidance and green computing for systems with multi-resource constraints.

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6311403

Digital Business Ecosystems

Battistella, C., et al. (2013). "Methodology of business ecosystems network analysis: A case study in telecom italia future centre."

The paper shows how it is possible to systematically study the structure and fluxes of a business ecosystem. The main problems of other modelling languages for firm interactions that MOBENA tries to overcome are that (1) the methodologies tailored for BEs are very few, the others neglect interdependences or focus only on tangible or intangible aspects, and (2) they limit potential for strategic analysis and they do not take in a future-perspective.

Understanding ecosystems requires understanding how it evolves by monitoring evolutionary trends. It is thus important that companies establish monitoring processes for their ecosystem, both from a static and dynamic point of view, and analyse BEs by investigating how the relationships and the dynamics can potentially positively and/or negatively impact their businesses.

Tools that help to systematically characterize the BE and analyse the potential impact of different business decisions on each entity in the network are essential for improving business design.

The MOBENA methodology permitted to study the business models for new products and services, hypothesizing different business models and identifying pro and cons for each one.
Building the methodology presented two main difficulties and limits: the standardization (the methodology is structured in order to collect the common aspects for all typologies of ecosystems but also to have a certain grade of flexibility to analyse their specific characteristics) and the data and information availability and retrieval.

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Dong, H. and F. K. Hussain (2011). "Focused crawling for automatic service discovery, annotation, and classification in industrial Digital Ecosystems."

Digital Ecosystems make use of Service Factories for service entities' publishing, classification, and management. However, before the emergence of Digital Ecosystems, there existed ubiquitous and heterogeneous service information in the Business Ecosystems environment. Therefore, dealing with the pre-existing service information becomes a crucial issue in Digital Ecosystems.

We have designed a conceptual framework for a semantic focused crawler, which combines the speciality of ontology-based metadata classification from the ontology based focused crawlers and the speciality of metadata abstraction from the metadata abstraction crawlers, in order to achieve the goal of automatic service discovery, annotation, and classification in the Digital Ecosystems environment.

From the experiments, we have drawn two conclusions:
The increase of the threshold value can reduce the amount of associated and nonrelevant metadata, and 2) the relatively higher threshold values can benefit the overall performance of the crawler.

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5475251

Gretzel, U., et al. (2015). "Conceptual foundations for understanding smart tourism ecosystems."

It further draws on conceptualizations of smart technologies, smart cities and smart tourism to envision new ways in which value is created, exchanged and consumed in the smart tourism ecosystem (STE).

Boley and Chang (2007) list four critical elements of ecosystems: (1) interaction/engagement; (2) balance; (3) loosely coupled actors with shared goals; and, (4) self-organization. This means that in ecosystems individual agents or groups of agents proactively form symbiotic relationships to increase individual benefits and to achieve shared goals.

No further summary: Paper is just stating opinions of different authors on the subject, not formulating a conclusion nor giving the represented text structure.

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Hanna, R., et al. (2011). "We're all connected: The power of the social media ecosystem."

Companies and organizations are looking to online social marketing programs and campaigns an effort to reach consumers where they 'live' online. However, the challenge facing many companies is that although they recognize the need to be active in social media, they do not truly understand how to do it effectively, what performance indicators they should be measuring, and how they should measure them. Further, as companies develop social media strategies, platforms such as YouTube, Facebook, and Twitter are too often treated as stand-alone elements rather than part of an integrated system.

''Consumers increasingly use digital media not just to research products and services, but to engage the companies they buy from, as well as other consumers who may have valuable insights.''

Dramatic developments in interactive digital media are revolutionizing marketing, and social media has fundamentally altered marketing's ecosystem of influence.

It is no longer enough to merely incorporate social media as standalone elements of a marketing plan. Companies need to consider both social and traditional media as part of an ecosystem whereby all elements work together toward a common objective.

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Woodard, C. J., et al. (2013). "Design capital and design moves: The logic of digital business strategy."
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84876877345&origin=inward&txGid=fcba6bb4a4b6308c46903fb28a8c0a9b

Digital Strategy
Bharadwaj, A., et al. (2013). "Digital business strategy: Toward a next generation of insights."

Key themes to guide our thinking on digital business strategy and help provide a framework to define the next generation of insights: the scope of digital business strategy, the scale of digital business strategy, the speed of digital business strategy and the sources of business value creation and capture in digital business strategy.

The themes and their fields to which we should pay particular attention:
Scope of Digital Business Strategy: Digital Business Strategy Transcends Traditional Functional and Process Silos, Digital Business Strategy Includes Digitization of Products and Services and the Information Around Them, Digital Business Strategy Extends the Scope Beyond Firm Boundaries and Supply Chains to Dynamic Ecosystems That Cross Traditional Industry Boundaries.
Scale of Digital Business Strategy: Rapid Digital Scale Up/Down as Strategic Dynamic Capability, Network Effects Within Multisided Platforms Create Rapid Scale Potential.
Scale with Digital Business Strategy Will Increasingly Take Place under Conditions of Information Abundance: Scale Through Alliances and Partnerships.
Speed of Digital Business Strategy: Speed of Product Launches, Speed of Decision Making,
The Speed of Supply Chain Orchestration, Speed of Network Formation and Adaptation.
Sources of Value Creation and Capture: Increased Value from Information, Value Creation from Multisided Business Models, Value Capture through Coordinated Business Models in Networks, Value Appropriation through Control of Digital Industry Architecture.

The main thesis of both our paper and the overall special issue on "Digital Business Strategy: Toward a New Generation of Insights" is that the time is right to shift our thinking about IT, not as a functional-level response, but as a fundamental driver of business value creation and capture. Digital technologies shape the new business infrastructure and influence the new organizational logic and patterns of coordination within and across firms.

Link: file:///C:/Users/BVerheijen/Downloads/si_dbs_introduction.pdf

Hanna, R., et al. (2011). "We're all connected: The power of the social media ecosystem."

See Digital Business Ecosystems.

Link: https://ac.els-cdn.com/S0007681311000243/1-s2.0-S0007681311000243-main.pdf?_tid=05c4debc-97b1-432f-aebe-5388937e9802&acdnat=1520208341_9d058a75279c5d2f65b443a92b553ed8

Mohsenian-Rad, A. H., et al. (2010). "Autonomous demand-side management based on game-theoretic energy consumption scheduling for the future smart grid."

The proposed distributed demand-side energy management strategy requires each user to simply apply its best response strategy to the current total load and tariffs in the power distribution system.

Simulation results confirm that the proposed approach can reduce the peak-to-average ratio of the total energy demand, the total energy costs, as well as each user's individual daily electricity charges.

DSM programs include conservation and energy efficiency programs, fuel substitution programs, demand response programs, and residential or commercial load management programs. Residential load management programs usually aim at one or both of the following design objectives: reducing consumption and shifting consumption.

Approaches to residential load management: direct load control, smart pricing (real-time pricing)

The smart meters with ECS functions interact automatically by running a distributed algorithm to find the optimal energy consumption schedule for each user. The optimization objective is to minimize the energy cost in the system.
The system models is represented by the following factors: power system, energy cost and residential load control.
Problem formulation: peak-to-average ratio minimization & Energy cost minimization.

Simulation results confirm that the proposed distributed demand-side management strategy can reduce the PAR, the energy cost, and each user's daily electricity charges.

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5628271

Neirotti, P., et al. (2014). "Current trends in smart city initiatives: Some stylised facts."

This explores the diffusion of smart initiatives via an empirical study aimed at investigating the ratio of domains covered by a city's best practices to the total of potential domains of smart initiatives and at understanding the role that various economic, urban, demographic, and geographical variables might have in influencing the planning approach to create a smarter city. Results reveal that the evolution patterns of a SC highly depend on its local context factors. In particular, economic development and structural urban variables are likely to influence a city's digital path, the geographical location to affect the SC strategy, and density of population, with its associated congestion problems, might an important component to determine the routes for the SC implementation.

To this end, six main domains and the associated sub-domains of SC deployment have been classified (i.e.: natural resources and energy, transport and mobility, buildings, living, government, as well as economy and people) and a CI has been defined as the ratio of domains covered by a city's best practices to the total of the potential domains or sub-domains.

The results of this study have revealed that there is no unique global definition of SC, and that the current trends and evolution patterns of any individual SC depend to a great extent on the local context factors. City policy makers are therefore urged to try to understand these factors in order to shape appropriate strategies for their SCs.

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Yoo, Y., et al. (2010). "The new organizing logic of digital innovation: An agenda for information systems research."

Not Available: https://www.scopus.com/record/display.uri?eid=2-s2.0-78650630327&doi=10.1287%2fisre.1100.0322&origin=inward&txGid=01faa9a98c80723f6175076ab7e308cc

Industry 4.0

Drath, R. and A. Horch (2014). "Industrie 4.0: Hit or hype? [Industry Forum]."

The term Industrie 4.0 refers to the fourth industrial revolution and is often understood as the application of the generic concept of cyberphysical systems (CPSs) [5]–[7] to industrial production systems (cyberphysical production systems).

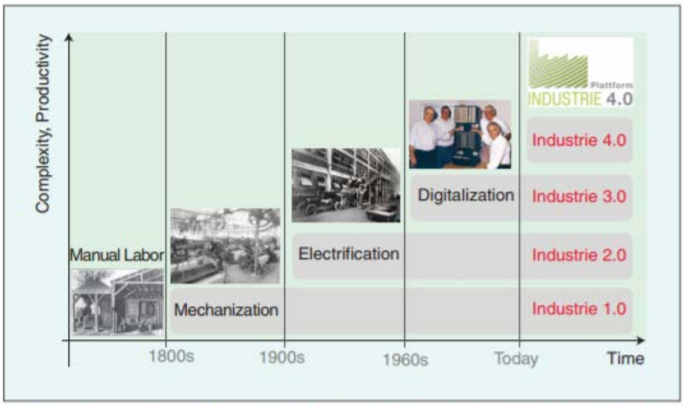

FIGURE 1 – An overview of the four industrial revolutions. Note that production flexibility was highest when manual labor dominated production. Flexibility is one of the main drivers behind Industrie 4.0. [Images courtesy of Archive City of Murg, Germany, http://commons.wikimedia.org/wiki/File:Aline1913.jpg, and Control Engineering Asia (www.ceasiamag.com).]

A CPS requires three levels: ■ the physical objects (in this example, the traffic lights and cars) ■ data models of the mentioned physical objects in a network infrastructure ■ services based on the available data.

Industrial requirements: Investment protection, stability, data privacy, cybersecurity.

For Industrie 4.0, the term revolution does not refer to the technical realization but to the ability to meet today's as well as future challenges.

Industrie 4.0 is the triad of physical objects, their virtual representation and services, and applications on top of those.

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Lasi, H., et al. (2014). "Industry 4.0." Business and Information Systems Engineering
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-84926457128&doi=10.1007%2fs12599-014-0334-4&origin=inward&txGid=2e35df31541e0bc294f6cf5662c6f060

Lee, J., et al. (2015). "A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems."

See Cyber-Physical Systems.

Link: https://ac.els-cdn.com/S221384631400025X/1-s2.0-S221384631400025X-main.pdf?_tid=2bf9d169-391a-4380-98ca-67f613707a8e&acdnat=1520245562_33e80b88c0ee8979e1806ec7d46f5527

Lee, J., et al. (2014). Service innovation and smart analytics for Industry 4.0 and big data environment.

Today, in an Industry 4.0 factory, machines are connected as a collaborative community. Such evolution requires the utilization of advance-prediction tools, so that data can be systematically processed into information to explain uncertainties, and thereby make more "informed" decisions. Cyber-Physical System-based manufacturing and service innovations are two inevitable trends and challenges for manufacturing industries.

Transformation from today's status into more intelligent machines requires further advancement in the science by tackling several fundamental issues. Categorized: Manager and Operator Interaction, Machine Fleet, Product and Process Quality, Big Data and Cloud, Sensor and Controller Network.

The prognostics-monitoring system is a trend of the smart manufacturing and industrial big data environment. There are many areas that are foreseen to have an impact with the advent of the fourth industrial revolution, which four key impact areas emerge:
• Machine health prediction reduces the machine downtime, and the prognostics information will support the ERP system to optimize manufacturing management, maintenance scheduling, and guarantee machine safety.
• The information flow among the production line, business management level, and supply chain management make the industrial management more transparent and organized.
• The new trend of industry will reduce labour costs and provide a better working environment.
Eventually, it will reduce the cost by energy-saving, optimized maintenance scheduling and supply chain management.

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Monostori, L. (2014). Cyber-physical production systems: Roots, expectations and R&D challenges.

Cyber-Physical Production Systems (CPPSs), relying on the newest and foreseeable further developments of computer science, information and communication technologies on the one hand, and of manufacturing science and technology, on the other, may lead to the 4th Industrial Revolution, frequently noted as Industry 4.0.

Industrial production of the future will be characterized by the strong individualization of products under the conditions of highly flexible (large series) production, the extensive integration of customers and business partners in business and value-added processes, and the linking of production and high-quality services leading to so-called hybrid products.

R&D challenges: Context-adaptive and (at least partially) autonomous systems, Cooperative production systems, Identification and prediction of dynamical systems, Robust scheduling, Fusion of real and virtual systems, Human-machine (including human-robot) symbiosis.

There are mutual influences in regards to the parallel development of computer science and information and communication technologies on one hand, and of manufacturing on the other.

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IoT Infrastructure:

Bi, Z., et al. (2014). "Internet of things for enterprise systems of modern manufacturing."

A complex system has a large number of design variables and decision-making requires real-time data collected from machines, processes, and business environments. Enterprise systems (ESs) are used to support data acquisition, communication, and all decision-making activities.

Core Components and Enabling Technologies IT infrastructure: Ubiquitous Computing, RFID, Wireless Sensor Networks, Cloud Computing.

IoT For Modern Manufacturing:

- IoT Infrastructure for Enterprises.
- Features of Next-Generation Enterprises:
  - Decentralized Decision-Making
  - Flat and Dynamic Organization: Massive data, Heterogeneous environment, Agility and adaptability, reconfigurable capabilities.
- Features of IoT for Manufacturing Applications:
  - Integrated Networks of RFIDs and WSNs
  - Dynamics
  - Cloud computing
  - Human and Things
  - Merging IoT in ESs

However, the application of IoT in ESs are at its infant stage, more researches are in demand in the areas such as modularized and semantic integration, standardization, and the development of enabling technologies for safe, reliable, and effective communication and decision-making.

It has concluded that the limitations of ESs are: 1) static IT architecture incapable of dealing with all types of changes and uncertainties; 2) unbalanced flexibility of hardware and software systems; 3) rigid and confined boundaries of an enterprise with the barriers for virtue collaboration; and 4) the lack of the considerations on system sustainability

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Jin, J., et al. (2014). "An information framework for creating a smart city through internet of things."

Increasing population density in urban centers demands adequate provision of services and infrastructure to meet the needs of city inhabitants, encompassing residents, workers, and visitors. The utilization of information and communications technologies to achieve this objective presents an opportunity for the development of smart cities, where city management and citizens are given access to a wealth of real-time information about the urban environment upon which to base decisions, actions, and future planning.

IoT Infrastructure for Smar City:

- Network-Centric IoT: Sensing Paradigm, Addressing Scheme, Connectivity Model, QoS Mechanism.
- Cloud-Centric IoT:
- Data-Centric IoT: Data Collection, Data Processing and Management, Data Interpretation.

Design of Network Architecture:

Autonomous Network Architecture: Architecture Description, Application – Automatic Parking Management, QoS.
Ubiquitous Network Architecture: Architecture Description, Application – Structural Health Monitoring, Application – Traffic Congestion and Impact Monitoring, QoS.
Application-Layer Overlay Network Architecture: Architecture Description, Application – Combined Noise Mapping and Video Monitoring, Qos.

Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6702523

Mainetti, L., et al. (2011). Evolution of wireless sensor networks towards the Internet of Things: A survey.
Not available: https://www.scopus.com/record/display.uri?eid=2-s2.0-81455142290&origin=inward&txGid=9b8b89c1f76db59cab2438f5c140f06f

Perera, C., et al. (2014). "Sensing as a service model for smart cities supported by Internet of Things."
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Sicari, S., et al. (2015). "Security, privacy and trust in Internet of things: The road ahead."

Internet of Things (IoT) is characterized by heterogeneous technologies, which concur to the provisioning of innovative services in various application domains. In this scenario, the satisfaction of security and privacy requirements plays a fundamental role. Such requirements include data confidentiality and authentication, access control within the IoT network, privacy and trust among users and things, and the enforcement of security and privacy policies. Traditional security countermeasures cannot be directly applied to IoT technologies due to the different standards and communication stacks involved. Moreover, the high number of interconnected devices arises scalability issues; therefore a flexible infrastructure is needed able to deal with security threats in such a dynamic environment.

Note that adaptation and self-healing play a key role in IoT infrastructures, which must be able to face normal and unexpected changes of the target environment.

The real spreading of IoT services requires customized security and privacy levels to be guaranteed.

More in details, a unified vision regarding the insurance of security and privacy requirements in such an heterogeneous environment, involving different technologies and communication standards is still missing.

Suitable solutions need to be designed and deployed, which are independent from the exploited platform and able to guarantee: confidentiality, access control, and privacy for users and things, trustworthiness among devices and users, compliance with defined security and privacy policies. Research efforts are also required to face the integration of IoT and communication technologies in a secure middleware, able to cope with the defined protection constraints.

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