Anna van Buerenplein 1
2595 DA Den Haag
P.O. Box 96800
2509 JE The Hague
The Netherlands

www.tno.nl

T +31 88 866 00 00

TNO report

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ICT Developments in Smart Industry Field labs

Date	Februari 10, 2017
Author(s)	Claire Stolwijk, Matthijs Punter
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Contents

1 Introduction

1.1 Objective

This report is intended as a contribution to the OECD project called Next Production Revolution on behalf of the Netherlands. The Next Production Revolution exams the impacts and policy implications of emerging production technologies. The focus of the Next Production Revolution project is on specific policy themes, including issues associated with digital technologies, industrial biotechnology, nanotechnology, new materials and 3D printing.

This report focuses on Smart Industry – the digitalization initiative for the Dutch industry. Based on a case study of the 10 priority 'field labs' for Smart Industry, the research provides insights into ICT developments for improving the overall competitiveness of the industry (see Figure 1).

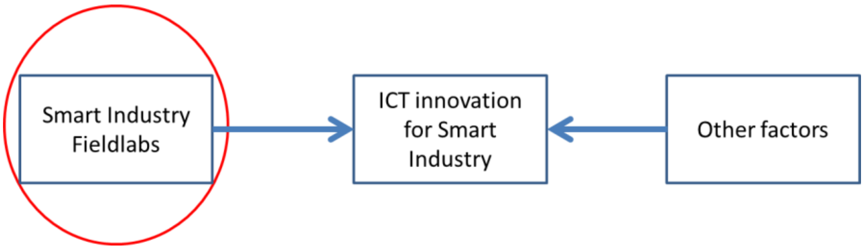

Figure 1 Focus of the research

This research:
- Provides insights into field labs as an organization form
- Gives an overview of the ICT development within field labs
- Will discuss the relationship between field labs and ICT development

The scope of our analysis is defined by the current set of 10 well known Smart Industry field labs. This set was chosen to address a broad range of (ICT) technologies, market domains and geographical regions. Industries range from the manufacturing industry to the creative industry and agriculture.

Based on the outcomes we will provide recommendations to field labs to speed-up ICT-innovations and their adoption – both within an industrial context.

1.2 Reading guide

- **Chapter 2** provides an overview of **conclusions and recommendations**.
- **Chapter 3** highlights the various components of the **research framework**: the role of field labs, the relevant ICT technologies for digitalization in industry and the technology readiness level to assess their evolution.
- **Chapter 4** provides insights in the **broader context** of this report: the objectives of the Smart Industry programme, the underlying action agenda and an overview of the field labs.
- **Chapter 5** provides an overview of the **findings** per technology and per field lab.

2 Conclusion and recommendations

2.1 The relation between field labs and ICT development

Based on this investigation of the 10 field labs we come to the following main conclusions:

- **Field labs are a useful collaboration form** for knowledge and risk sharing, required for the combination and application of ICT technologies. This is in line with previous research which argues that collaboration is an organizational driver to fosters the Smart Industry developments[1].
- The **10 field labs mainly apply ICT technologies on a high-TRL level.**
- Development of ICT technologies on a **medium-TRL level is limited in the 10 field labs**.
- Investigated field labs that do develop ICT technologies on medium-TRL are in most cases **funded by 'top sector' or other public funding with a strong R&D focus.**
- Field lab partners find internal cooperation useful but **cooperation between field labs is limited.** This relates to the fact that field labs differ a lot in terms of the technologies they develop and the sectors they focus on, which limits the relevance of a strong cooperation. This finding is in line with existing research that shows that a larger technological distance (difference in technological focus and knowledge) between cooperating partners results in less recognition of the value, assimilation and commercialization of the knowledge from partners[2,3].
- **Most business level innovations** (5 out of 6) **are addressed within the field labs** such as:
  1. Improving quality
  2. Flexibilization
  3. Value chain participation
  4. Customer intimacy
  5. High-value information
- There is **limited emphasis on the business level innovation "automation"** (within production processes).
- **Most enabling ICT innovations** (2 out of 3) **are addressed** by the field labs:
  1. Data driven innovations
  2. Network centric collaboration
- **There is less focus on the enabling ICT innovation "next generation of factory automation".**
- **Most ICT technologies** (5 out of 8) are covered within the field labs:
  1. Distributed Data Infrastructures
  2. Secure and trusted connectivity
  3. Semantic Interoperability
  4. Visualization and human machine interaction
  5. Digital designs and product data
- There is currently **less emphasis on the following three ICT technologies**:
  1. Industrial Internet of Things

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[1] Schuh, G., Potente, T., Varandani, R., Hausberg, C., & Fränken, B. (2014). Collaboration moves productivity to the next level. Procedia CIRP, 17, 3-8.
[2] Ahuja, G., & Katila, R. (2001). Technological acquisitions and the innovation performance of acquiring firms: A longitudinal study. *Strategic Management Journal, 22*(3), 197-220.
[3] Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly, 35*(1), 128-152.

2. Wireless communication technologies
3. Big data analytics

- **Standardization activities are out of scope** for most of the field labs.
- Even though ICT companies are involved in the field labs, there are very **few examples of ICT firms that develop/commercialize a new product/technology**. Most ICT companies focus on the marketing of their existing product offering.
- **Funding and commercialization are the most frequent bottleneck** for further progress of the field labs.

2.2 Recommendations for further ICT acceleration by field labs

Based on these conclusions we have the following recommendations for different stakeholders:

2.2.1 For the Programme Bureau Smart Industry

- For a good **portfolio management of the field lab topics** focus on one or more of the following topics when selecting new field labs:
  – ICT developments on medium TRL level to accelerate more fundamental and radical developments such as the use of blockchains in distributed data infrastructures or machine learning for data analytics.
  – The business level innovation ‘automation’ in manufacturing: the use of robots and other automated manufacturing equipment.
  – On the enabling ICT innovation ‘next generation of factory automation’: the new IT setup of the factory of the future.
  – One or more of the following ICT technologies:
    1. Internet of Things in an industrial context
    2. Wireless Communication Technologies
    3. Big Data analytics
- It should be noted that some **recently initiated new Smart Industry field labs** are not in the scope of this research. Their **ICT developments need to be analysed** as well to be able to say something about their TRL level and to get a complete picture of the field lab portfolio. 5G wireless communication technology is for instance part of one of the recently selected new field labs.

2.2.2 For policy makers in general

- **Stimulate the use of field labs** to fosters the Smart Industry developments.
- Public funding with a strong R&D focus from top sectors or other sources **might stimulate an increase in ICT developments on medium TRL-level** both within existing as well as in new field labs.
- **More funding contributes to support technology development in field labs.**

2.2.3 For the Smart Industry programme bureau in cooperation with individual field labs

- Increase cooperation between field labs by organizing **workshops** on content related ICT topics for experts. Increase cooperation between field labs in projects about data sharing.
- **Increase awareness on standardization** by the Smart Industry Standardization agenda and its follow up.
- **Stimulate standardization** by including potential standardisation developments of field labs as a use case in international platforms such as the Industrial Internet Consortium and the Industrial Data Space Association.

2.2.4 For the Smart Industry programme bureau in cooperation with their partners

- **Advice on scaling up and market introduction** is required. Specific advice should focus on business models and activities to generate income. This could be done by organizing a workshop on this topic followed by one on one discussions with the field labs.

3 Research method

3.1 Introduction

In this chapter we discuss the elements of the framework we used for our analysis.

The framework consist of three components aimed to:
1. Identify the role of field labs in ICT development (see section 3.2).
2. Provide an overview of relevant ICT-technologies for Smart Industry (see section 3.3).
3. Identify the TRL (Technology Readiness Level) of the innovations in each field lab as an indication of the development stage of ICT (see section 3.4).

The framework results in:
- 8 field lab related questions and
- 8 ICT related questions which we discussed with the field labs.

We use the outcome of the resulting analysis to:
- Identify which ICT-technologies are covered in each field lab
- Identify topics that are not covered in the field labs
- Identify bottlenecks related to ICT innovation in the field labs
- Identify related standardization activities
- Identify if field labs are an appropriate organization form to accelerate ICT innovations
- Based on these outcomes we will provide recommendations to field labs to speed-up the adoption of ICT-innovations in the industry.

3.2 Framework components: The role of field labs in ICT innovations

The single inventor who experimented in his backyard and brought technologies that changed our lives belong to the past. We now see that new technologies are developed by firms that are cooperating closely with other firms, academia, RTOs, the government and investors. A good example is the High Tech Campus in Eindhoven, with a lot of SMEs and large firms like ASML and Philips. Recent innovation policy pays extra attention to the role of such cooperation's. The focus in this report is on a specific cooperation form called field labs. *Field labs are practical environments in which companies and knowledge institutions develop, test and implement Smart Industry solutions. In addition, Field Labs strengthen connections with research, education and policy on a specific Smart Industry theme.* The role of field labs in the acceleration of technology development is often discussed in recent policy reports. Examples of this trend are the European 'Innovation Hubs', the German 'Mittelstand 4.0-Kompetenzzentren', and the Dutch 'Smart Industry field labs'.

The European Commission[4] has funded several of these initiatives. These initiatives share a common goal to create the conditions for long-term business success for the partners involved, including the support of SMEs and startups in their innovation activities.

[4] https://ec.europa.eu/digital-single-market/en/blog/digital-innovation-hubs-ict-2015

We want to address the role of field labs in the acceleration of ICT development. To investigate this role we focus on the following topics (formulated as questions that are discussed with the field labs):

1. What is the main focus of the field lab (does the field lab serve to accelerate ICT development or does the field lab only use ICT in relation to the development of other technologies)?
2. What is the advantage to develop ICT within the field lab (in terms of knowledge sharing, risk sharing, specific partners etc.)?
3. What are the disadvantages of developing ICT within the field lab?
4. Would other organizations forms (non-field lab related) better contribute to ICT development and why or why not?
5. Do you cooperate with other field labs (and in particular for ICT development)?
6. Are there ICT topics you prefer to develop outside the field lab and why (in the own organization)?
7. Do you cooperate with other related ICT initiatives (like other existing consortia)?
8. Are there specific resources, partners or other aspects that are relevant for the ICT development that are currently missing in the field lab?

3.3 Framework components: Relevant ICT innovations for Smart Industry

ICT innovations relevant for Smart Industry can be divided in the following two types of innovations (see Figure 2):

1. Business level innovations
2. Enabling ICT innovations for Smart Industry, driven by new ICT technologies

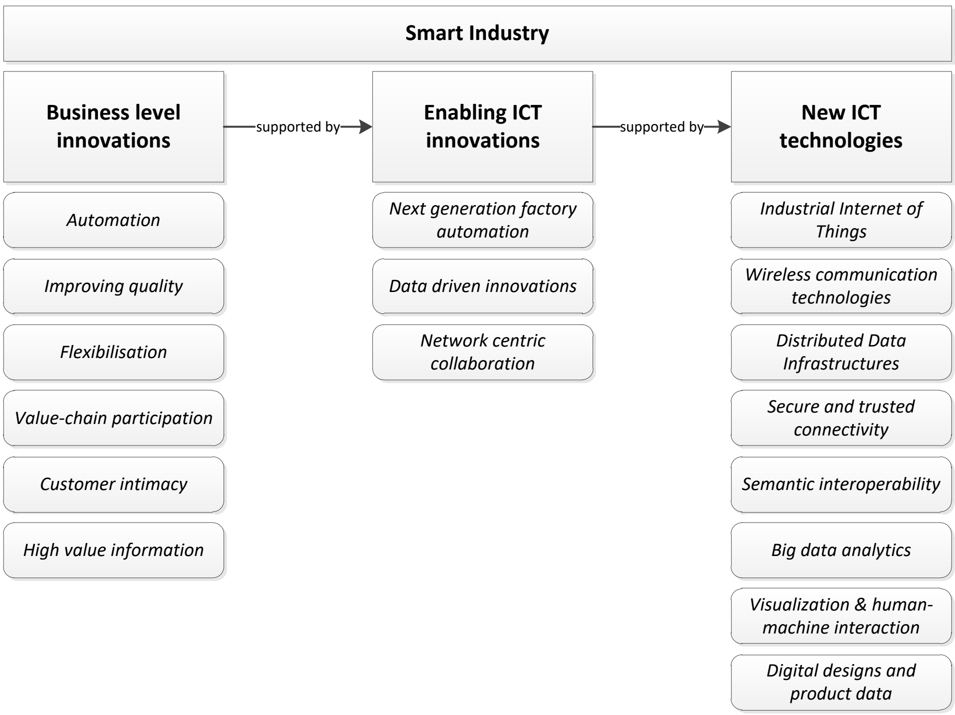

Figure 2 ICT innovations for Smart Industry

3.3.1 Business level innovations

The Dutch Smart Industry action plan identifies several business level innovations that can contribute to the overall competitiveness of the industry. These include:

- Automation: the increased use of robots and other automated manufacturing equipment.
- Improving quality: the ability to produce products without any defects and a lifetime involvement of a manufacturer with its product (for servicing and maintenance).
- Flexibilization: the ability to easily switch between products, allowing for the production of tailor-made goods.
- Value chain participation: increased collaboration in the supply chain, allowing for manufacturers to focus on specific production, service or design capabilities.
- Customer intimacy: tailor made production of unique products exactly specified according to the needs of the customer – ranging from personalized fashion to medical equipment.
- High value information: the usage of digital designs and big data analysis to improve products and processes.

3.3.2 Enabling ICT innovations

There are various underlying enabling technological innovations. In many cases these are combinations of:

- New production technologies such as robotics technologies and technologies for 3D printing
- Software and ICT technologies – the focus of this research: ICT plays an important role in controlling the production environment and allowing customers to work together. The power of software allows for new concepts such as value chain participation and tailoring products to the exact needs of the customer.

We have identified three generic ICT innovations in Smart Industry that relate to one or more of the business level innovations:

- Next generation factory automation: current factory automation systems are mostly geared towards high-volume/low-mix production with centralized control. The next generation of manufacturing environments will be characterized by cyberphysical systems: there will be more sensors (industrial 'internet of things') providing measurements and subsystems will have a higher level of intelligence (e.g. collaborative robots). The production environment will likely change from a high-volume/low-mix (large numbers of standardized products) to a high-mix/low volume (many customized products) setting as goods will be more tailored to a customer's needs. This requires much more flexibility in configuring and setting-up the production environment – and the underlying IT systems. Finally sensors are required to provide more and more accurate data. This is necessary for ensuring 'zero defect' production and long term maintenance.

- Data driven innovations: Sensors and connected devices will provide a wide range of new data. Data driven innovations are needed to use this data and turn it into valuable information. This information could be used to design new products, to optimize production processes or to facilitate the maintenance of existing products. Data driven innovations include the analysis of large volumes of data and the controlled sharing of this data between actors in a value network: data will likely cross organizational boundaries and new actors will emerge in the value chain. New service providers can for instance provide value-added services used by multiple customers or suppliers.

- Network centric collaboration: Increasingly businesses need to collaborate in the supply network. This ranges from collaborative design of new products to the improvement of supply chains by sharing production capabilities. This requires a 'plug & play' infrastructure for sharing data that is flexible, controlled and secure.

In the Table 1 we provide an overview of these enabling ICT innovations and how they link to the overall business level Smart Industry innovations.

	Enabling ICT innovations			**Other enabling technological innovations (non-ICT) - examples**
Business level innovations	*Next generation factory automation*	*Data driven innovation*	*Network centric collaboration*	
Automation	x			Robotics
Improving quality	x	x		High-precision equipment
Flexibilisation	x		x	Robotics, 3D printing
Value chain participation		x	x	
Customer intimacy		x	x	
High-value information		x	x	

Table 1 Overview of the enabling ICT innovations and their link to the overall business level Smart Industry innovations

3.3.3 *New ICT technologies*

Advances in the underlying technologies are driving the ICT-enabled innovations for industry. For instance: industrial internet of things capabilities are needed to support data driven innovation and big data analytics are needed for zero defect manufacturing in the factory IT-setup of the future.

To get a good understanding of the ICT innovations in the various field labs it is therefore also important to get an understanding of the advances of these underlying technologies: Field labs can be a platform for guiding these advances by providing requirements, providing a testbed for their development or to seek their large scale adoption.

Most technologies are used in multiple ICT innovations. For each technology we outline the current state of play and the (likely) future development.

- Industrial Internet of things: products and equipment will increasingly be equipped with smart sensors and communication devices for tracking and measurement purposes. Examples include smart sensors, embedded software and related communications equipment.
  - *Current state of play:* sensors are tightly integrated with the ICT-system that processes the data. For instance a dedicated PLC (digital controller) connected to a factory automation system.

  - *Future development:* sensors will be 'loosely' coupled and can be flexibly connected to multiple information systems. Internet-technology is used to connect to each sensor.

- Wireless communication technologies: new wireless communication technologies are needed to connect products and services.
  - *Current state of play*: Devices are equipped with local networking capabilities (e.g. Bluetooth, Zigbee or WiFi) to connect to systems in the vicinity or use a GSM/3G-network to communicate with remote organizations. New technologies such as LoRa provide long-range/low-power communication and provide low-bandwidth connectivity with remote organizations.
  - *Future development:* New 5G wireless communication technologies provide even more pervasive networking capabilities. Public (telco-operated) and private (company-network) networks will converge.

- Distributed data infrastructures: to share data in networks of organizations distributed data infrastructures are needed to find, distribute and retrieve data.
  - *Current state of play:* Data is shared through centralized community platforms where all organizations upload their data. New developments also include more decentralized approaches where each organization remains in control over its own data, e.g. by using 'connectors' to share data and 'data brokers' to provide a 'yellow-pages' to possible data providers and consumers.
  - *Future development:* Data infrastructures will increasingly become powered by cloud technologies. Through distributed ledgers (blockchains) data will be shared by everyone in a community without the need of a centralized infrastructure.

- Secure and trusted connectivity: to allow for the controlled sharing of data technologies are needed to limit access to data to trusted parties only.
  - *Current state of play:* Data is secured using public private key mechanisms and connected authorization and identity management tools.
  - *Future development*: Homomorphic encryption technology allows for the encrypted sharing of data. The receiver cannot decrypt the data but can perform certain algorithms on the data and see the result.

- Semantic interoperability: organizations need to be able to interpret each other's data. Technology is needed to facilitate this interoperability.
  - *Current state of play:* Organizations use EDI- or XML-based integration schemes to share data. Data is exchanged using standardized messages.
  - *Future development:* New advanced semantic web technologies allow for more easy sharing and interpretation of data as they not only include the syntax (layout) of the data, but also the meaning of the data and links to relevant other datasets.

- Big data analytics: analytics technology is needed to discover patterns and links in data. This can be used to make recommendations and provide new insights.
  - *Current state of play:* Business Intelligence technology is used to analyze datasets for statistical purposes.
  - *Future development:* New machine learning will be used to identify patterns in data and use these patterns for predictive and prescriptive analytics (providing recommendations to the user).

- Data visualization and human-machine interaction: with digital data becoming increasingly pervasive it is important to be able to allow people to work with it. This requires technology for visualization and human-machine interaction.
  - *Current state of play:* Tablets, touchscreens and similar connected devices and their underlying software.
  - *Future development:* More pervasive human-machine interactions, e.g. holographic projections or displays embedded in workplace tools.

- Digital designs and product data: increasingly production is driven by digital designs. Organizations use ICT to collaboratively work on these designs after which it is used by the production environment to steer the manufacturing process.
  - *Current state of play:* Product lifecycle management systems, product data management systems and CAD/CAM-tools.
  - *Future development:* Fully digital designs – organizations no longer share the final design document (e.g. PDF file), but also the underlying digital model (e.g. enhanced STEP-file). This digital model is used as an input for further designs and production.

In our analysis we will show which technologies are used/developed in each field lab, the role of standardization and the maturity of the technology (TRL; see the next section).

3.4 Framework components: Technology Readiness Levels of ICT innovations

In our analysis of the Dutch Smart Industry field labs we do not only investigate which technology domains are covered by each field lab, but we also used the principle of the ‘Technology Readiness Level’ to assess the stage of development. We used a simplified categorization of Figure 3:

- **Low** (TRL 1-4) – Invention and concept validation: a new technology is being developed. The field lab is used to validate the concept.
- **Medium** (TRL5-7) – Prototyping, incubation, pilots and demonstration: a new technology is being prototyped and demonstrated as part of the field lab.
- **High** (TRL8-9) – Market introduction and expansion: the field lab is used to introduce a new technology (that is already there) to the market. E.g. an ICT-technology that is already established in other markets and is now being introduced in the manufacturing-domain.

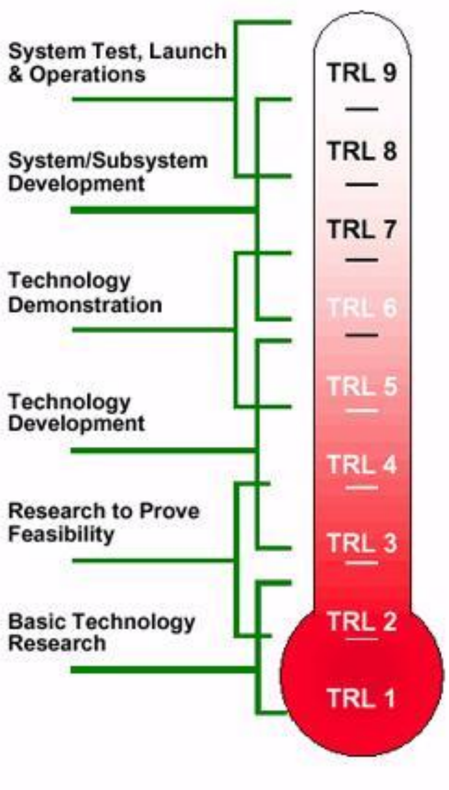

Figure 3: Technology Readiness Levels

Source: Nasa

Based on the relevant ICT innovations for Smart Industry and the technology readiness level we developed the following questions that are discussed with the field labs.

1. Do you recognize the enabling ICT innovations and ICT technologies in the overview we provided?
2. Which one is most relevant in your field lab?
3. Which ICT technologies are developed/or do you plan to develop within your field lab?
4. What is the current stage of the ICT development (R&D, scaling up, applications, close to the market/TRL)?
5. What are the most important bottlenecks related to your ICT development?
6. What are the needs to solve this in terms of funding resources etc.?
7. What is the role of standards in these ICT developments?
8. Do you develop/apply/combine standards (different domains) (with a main focus on ICT)?

4 Context of the case study

This chapter describes the empirical cases under study. In 4.1 the Smart Industry Programme will be described followed by the Action Agenda and the role of field labs in section 4.2. Section 4.3 describes the 10 field labs that are investigated.

4.1 Background of the Smart Industry Programme in the Netherlands

The Netherlands has a world-class industrial base. Numerous
Dutch firms are among the leaders in their markets. At the same time, unparalleled technological development is taking place: called Smart Industry or the fourth industrial revolution[5]. This development means far-reaching digitalization of industry. High demands are being placed on firms to adapt to this. Countries like Denmark, the US and China are examples of countries that are committed to this development. Different investigations and statistics indicate that ICT is the most important driver for a productivity increase[6]. Therefore, firms need to have the ambition to be at the forefront. The Action Agenda Smart Industry in the Netherlands supports these firms in this ambition. The Action Agenda is an enhancement of the top sector policy and the Technology Pact. The aim is to make the industry more competitive through faster and better utilization of ICT in combination with the manufacturing technologies.

4.2 Smart Industry Action Agenda

The Action Agenda uses the following three step approach[7]:

4.2.1 Capitalizing on existing knowledge

A lot is already possible based on existing technology and knowledge. Two things are required to convert knowledge into business. First, a large group of firms is aware of the need and opportunities but lacks the tools to make it work. These tools needs to be provided. Second, a large group of firms has insufficient insight into the digital revolution. It is important to involve this group and provide them more insights.

4.2.2 Accelerating in Field Labs

The main ambition of the Action Agenda is the creation of ecosystems - of firms and knowledge institutions - around the most important principles of Smart Industry. Such as the following business level innovations: *automation, zero defect manufacturing, flexible production, chain collaboration, customer intimacy* and *value creation* based on big data and on a number of core technologies such as 3D printing and robotics (see Figure 4). A lot of knowledge and expertise was already available at the start of the Smart Industry Programme, but in a fragmented way. Therefore, the Team Smart Industry chose a field labs approach. The field labs are

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[5] https://www.smartindustry.nl/site/assets/files/1740/smart-industry-action-agenda-summary.pdf
[6]https://www.smartindustry.nl/site/assets/files/1951/the_dutch_smart_industry_action_program_with_fieldlabs.pdf
[7] http://www.smartindustry.nl/site/assets/files/1740/smart-industry-action-agenda-summary.pdf

located in different regions of the Netherlands, and address various technologies and sectors .

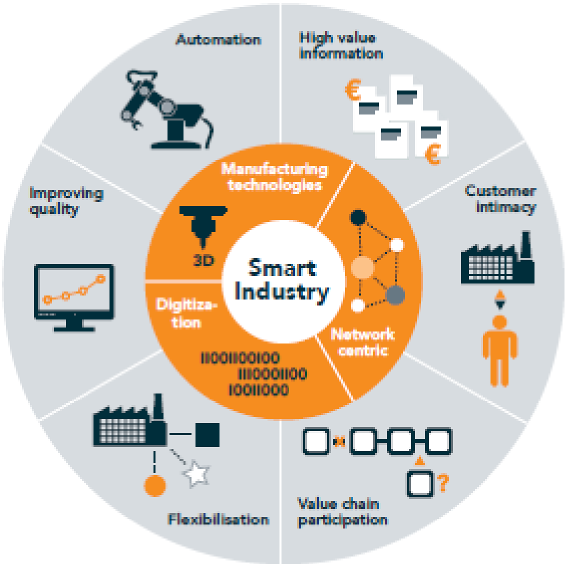

Figure 4 Business level innovations and core technologies for Smart Industry

Source: Action Agenda Smart Industry

4.2.3 Strengthening the foundation

To support the development toward a sustainable Smart Industry, the foundations need to be reinforced in the following three areas:

1. Knowledge

Capitalization of existing knowledge and acceleration of knowledge in field labs provide a lot in the short term. In the long term, it is essential to invest in new knowledge to face the competition.

2. Skills

The success of the firms is largely determined by the skills of their employees. That demands involvement of employees, another management style and new organizational designs. Many jobs will change and investments in digital skills are needed for staff at all levels. This requires training at schools and intensive cooperation between education and firms.

3. Parameters (ICT)

Parameters in the field of ICT and the legal area are needed for Smart Industry, since the core of Smart Industry is the connection between machines and firms in the chain via ICT, especially via internet. Organizing firms in chains, exchanging data, cybersecurity and the quality of the ICT infrastructure are all crucial.

4.3 Individual field lab cases

This chapter describes the content of the 10 field labs under study. It gives insights in the technologies and sectors of each of the field labs. Recent new field labs are out of the scope of this research (like the new field lab that focus on 5G).

4.3.1 Region of smart factories

The field lab “Region of Smart Factories” (RoSF) is a field lab based on a consortium of 25 companies (large and small) and knowledge institutes that jointly conduct research into a range of new technologies for the “Zero defect factory.” This consortium was established around the three main OEM companies (Philips, Fokker and CentraalStaal). The foundations of Smart Factories are first reinforced with the help of a scientific program, after which various firm clusters develop and implement new technologies in 10 pilot projects. Examples of these pilot projects include the use of new factory automation for ‘zero defect’ production of electric shavers, the use of new sensors for the production of optical lenses and the development of dashboards for data visualization.

4.3.2 CAMPIONE

Field lab CAMPIONE is a facility where innovators can work in a lab environment to predict maintenance. The field lab focus on the chemical and process industry. In this sector maintenance is currently corrective or preventive. With advanced sensors and data analytics premature maintenance and unnecessary shutdown of a factory can be prevented. The firms involved make part of their plant available for testing purposes. There are +/- 30 participants involved, such as FUJIFILM, Ericsson, Tata Steel and Sitech Services.

4.3.3 FreshTeq

Field lab FreshTeq offers - worldwide - local value chain solutions for sufficient healthy and fresh food for consumers in large cities. FreshTeq unites different actors such as seed breeder, grower, supplier, retailer and transport experts. Main focus of the field lab is on business intelligence and the development of growth support system (e.g. greenhouses). FreshTeq supports its partners in optimizing their performance through training and education. Relevant partners are the Demokwekerij, TU Delft, WUR, TNO, Greenport Horti Campus and InnovationQuarter.

4.3.4 The Garden

Field lab The Garden focuses on security in the implementation of Industry 4.0. The partners experiment with existing and (where necessary) new products and services for secure, real-time and reliable data and information exchange. In the area of security some new technologies are being tested for encryption and controlled data sharing. Secure data exchange is an important precondition for connections in the entire value chain. E-PLM (Extended Product Life Cycle Management) is an important use case and project of the Garden. The field lab has approximately 40 consortiums partners. These are industrial actors, universities and supporting organizations.

4.3.5 Smart Connected Supplier Network (SCSN)

Field lab Smart Connected Supplier Network focuses on the development of a networked high-tech supply chain for easier data sharing, to provide quick access to product and design data. The involved partners collaborate on the following topics:

- Easy data sharing.
- Reliable data sharing.
- Interpretation of shared data.

4.3.6 Flexible Manufacturing

Field lab Flexible Manufacturing works on the development of flexible and fully and partly automated small series production against low costs. The field lab focuses on the development of human-robot applications and other forms of next generation manufacturing automation, that contribute for instance to a decrease of the time required to programme robots. As a result the competitiveness of the manufacturing industry could be improved and jobs can be created. There are 9 consortium partners involved.

4.3.7 Smart Dairy Farming

Field lab Smart Dairy Farming develops a data hub (Data broker) and uses sensor technology. This helps the farmers to make the right choices for cow care. Proper care contributes to better health and longer life expectancy of these animals. The field lab provides an infrastructure for the farming sector. That means that a farmer has access to its own information and to the information of other parties.

4.3.8 Smart Bending Factory

Field lab Smart Bending Factory wants to become a worldwide innovation model for the metal sector, by developing small batches that are 25% cheaper and 5 times faster. The field lab develops the state of art factory for cutting and bending metal. Customers can order fully digitized products based on an environment for digital designs. The costs of these products are the same as if it was a product from a series of 500 pieces. There are 10 partners involved in the field lab.

4.3.9 Multi material 3D printing

Field lab Multi material 3D printing aims to develop entirely new value chains, based on the next generation 3D printing technologies and the associated data management systems. The field lab focuses on the realization of new innovative value chains in which mono and multi-material 3D printing plays a key role. Required technologies are ICT solutions for the management of large data streams and integrating 3D printing into existing production systems. Main sectors involved are the medical sector and the high tech industry. The field lab brings complementary knowledge organizations and industrial partners together.

4.3.10 Ultra-Personalized Products and Services (UPPS)

UPPS stands for Ultra Personalized Products and Services and is a result of new technologies such as 3D scanning, internet and smart sensors. Field labs UPPS uses these technologies to process the data in the product so that it is optimally matched to the user. UPPS can be divided into two categories. (1) Products in which personal data is obtained before use - such as 3D scans - and (2) products in which the data is obtained during use - such as temperature and heart rate sensors. Field lab UPPS focus on the health and fashions sectors. There are 10 consortium partners involved.

5 Results

5.1 Field labs as organization form

In this section we will highlight our key-finding with regards to the field lab as organization form for ICT development. The field lab case show that each field lab has its own way of implementing the Smart Industry concept and using it for ICT development. Every field lab is different and their solutions are tailor made. Each of the field labs already performed a lot of activities in terms of research activities, pilot activities etc. in a relative short time period since the start of the Smart Industry programme in 2014.

5.1.1 Field labs are useful to share knowledge, resources and risks

The results indicate that field labs are helpful to learn from each other and to share knowledge, resources and risks between complementary partners. The field lab representatives mention that sharing these things is crucial for ICT development as well as for other types of technology development. Field lab UPPS mention for instance that field labs are a good way to learn from each other. The field lab Smart Connected Supplier Network indicates that field labs are a good organisation form to provide a neutral platform for competing manufacturers. The stakeholders involved in the field labs see room for improvement. One of them mentioned that the commitment of partners could be increased and that field lab participants might take a more proactive role. It is also mentioned that cooperating in a field lab is time consuming and focusing on future developments is difficult, since business partners focus on the short term and the daily activities first.

5.1.2 Most respondents prefer a field lab as organization form

Most field labs participants prefer the field lab as organization form for their ICT and Smart Industry related development purposes. Except for field lab The Garden that indicates that defence applications are developed within another organization form. Field labs are a good solution to bring (complementary) partners together. The results indicate that the advantages of the this organization form are more important than the disadvantages (like the time it requires and the investments that needs to be made).

5.1.3 Limited cooperation between the current field labs

Some field labs exchange information or cooperate with each other on certain topics (like field lab Smart Connected Supplier Network and field lab the Garden), but there is in general not a very strong interaction. The cooperation between the field labs under study is limited. The main explanation for this is that field labs differ a lot in terms of the technologies they develop and the sectors they focus on, which limits the importance of a strong cooperation. Some field labs mention that a workshop for knowledge sharing between field labs would be helpful. Especially for field lab partners that focus on the technology development itself instead of the managers who have more frequent meetings with the other field labs. This was for instance mentioned by the field labs Flexible Manufacturing and Smart Bending Factory.

5.1.4 Field labs cooperate with other ICT initiatives outside the Netherlands
Field labs cooperate with foreign ICT initiatives. This happens more often than the cooperation between field labs in the Netherlands. Examples are cooperation in European projects (The Garden), cooperation with foreign research institutes (Flexible Manufacturing) or with for instance the German Industrial Data Space initiative (Smart Connected Supplier Network).

5.1.5 Field lab related bottlenecks
Bottlenecks with which field labs deal are insights on social innovation, finding the right business model (UPPS), attracting customers, finding good use cases (Flexible Manufacturing) and innovators in the ICT field (Smart Connected Supplier Network). Other field labs mention funding for further technology development as a problem.

5.2 Overview of ICT development within field labs

In this section we will highlight our key-finding with regards to ICT related developments in the various field labs. ICT is a very important technology and each of the field labs already performed a lot of activities in this area.

5.2.1 Main focus on high-TRL
Most field labs focus on ICT technologies with a relatively high TRL level. This means that they take existing/generic ICT solutions and (re-) use them or apply these technologies in an industrial context driven by the specific needs of the industrial end-users of the field lab. Even though ICT companies are involved in the field labs, there are very few examples of ICT companies using field labs to develop new technologies or product/service offerings.

The combination and application of these existing technologies can be seen as a form of incremental innovation. Incremental innovation is the most common and a very relevant form of innovation. This is in line with previous research on the Apple cases which indicate that incremental technological innovations can sometimes have more influence than radical ones[8].

Many field labs indicate that their key-aim is to facilitate the collaboration between the stakeholders in the field lab and align business and IT accordingly. For example: the field lab FreshTeq aims to provide an integrated ‘growth support systems’ proposition to the international market. To achieve this they are looking for international market opportunities and ways for the individual vendors to collaborate. In the current status of the field lab they aim to use the existing underlying (ICT) technologies to achieve the required integration.

There are very few field labs with a specific focus on medium level TRLs (as far is ICT is concerned). If this was to be the case the field lab would be used as a means to develop new ICT technologies by fundamentally innovating in industrial ICT technologies themselves or adapting ICT technologies from other domains for industrial use.

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[8] Rayna, T., & Striukova, L., (2009). The Curse of the First-Mover: When Incremental Innovation Leads to Radical Change, *International Journal of Collaborative Enterprise,* Vol. 1, No. 1, pp. 4–21.

Currently such medium level TRL developments are part of field labs that receive some form of ‘top sector’ or other public funding with a strong R&D focus. Examples include the use of semantic web technology in the Smart Connected Supplier Network field lab and the application of data analytics technology in the Smart Dairy Farming field lab.

5.2.2 Most business level innovations are covered by the field labs

The business level innovations are well addressed in the field labs.

The only business level innovation with little emphasis in the field labs is “automation” (the increased use of robotics and other automated manufacturing equipment). This relates to the fact that there is less focus on the next generation of factory automation in the field labs as might have been expected. The limited focus on the next generation of factory automation is discussed in section 5.2.4.

5.2.3 Main focus on data driven innovations & network centric collaboration

Where ICT plays an important role in a field lab the key focus is on either data driven innovations and network centric collaboration as key ICT innovations.

In data driven innovations the focus is on the sharing of data between stakeholders and using this data for a new business proposition. Often a third party such as a platform provider or ‘information value provider’ is involved to integrate the data and to perform certain analytics functions. For example:

- The Smart Dairy Farming field lab where sensor-data relating to the well-being of livestock is shared between farmers, equipment manufacturers and dairy companies through a so called ‘information broker’ (the Data hub).
- The CAMPIONE field lab where maintenance related data is shared between equipment manufacturers, service & maintenance companies and users of equipment. To do this an architecture called ‘Daisy’ is applied. This architecture was initially developed for offshore wind turbines and is now used in the chemical process industry.

In network centric collaboration the focus is on connecting the various stakeholders in a supply chain and supporting the exchange of designs, orders, logistics and product-usage data. For example:

- Field lab ‘The Garden’ focusing on extended product lifecycle management. This includes the sharing of designs and product data between an OEM and its suppliers to seek their involvement in the design and maintenance of a product.
- Smart Bending Factory, Multi material 3D printing and Ultra Personalised Products and Services (UPPS) focusing on the exchange of (3D) digital designs between customers and manufacturers in various contexts: metal cutting and bending, 3D printing and ultra-personalized products.

5.2.4 Limited focus on next generation of factory automation in the current field labs

There are some field labs which apply factory automation (e.g. the ‘zero defect’ pilot in RoSF). But very often this is in the context of seeking new business opportunities/collaborations for existing technology (e.g. the FreshTeq field lab) and not yet to enhance or develop the required underlying technologies. One could think of sensor technology (industrial ‘internet of things’) and subsystems with a much higher level of intelligence (e.g. the combination of big data analytics/machine learning and manufacturing execution systems (MES)).

Only the Flexible Manufacturing field lab has this topic in its scope to some extent. The aim of this field lab is to try and test new ways of controlling a flexible production cell which can easily switch between different products and which features a collaboration between robots/automated machinery and humans (e.g. to perform certain tests or to assemble certain sub-components).

That means that there is less focus on the next generation of factory automation as might have been expected.

5.2.5 Some ICT technologies are not yet covered in the current field labs

To support the three enabling ICT innovations (factory automation, data driven innovation and network centric collaboration) a range of enabling ICT technologies is needed. For a full overview of these technologies we refer to section 3.3.

Two ICT technologies are reasonably well covered by the current field labs, even though most of their usage is on a higher TRL level (focus on application of the technology and not on the development of the technology). This includes the development of distributed data infrastructures (for the sharing of data) and semantic interoperability (to facilitate the interpretation of data).

It should be noted that there is little emphasis on the following new ICT technologies in the 10 field labs at the moment:

- **Industrial Internet of Things**. This typically includes:
  - the usage of sensors in the production environment to support flexible and zero defect manufacturing
  - the usage of sensors in products in use to support new value added services and maintenance – both of which are very important from the perspective of ‘servitization’ of manufacturing.
- **Wireless communication technologies.** This typically includes the use of new protocols and technology to provide connectivity.
  - Commercial actors such as telecom operators are investing in technologies such as LoRa and narrowband LTE to support connecting to sensor devices. This development is however not yet included in any of the field labs.
  - Similarly there is no focus on the next generation of wireless connectivity as part of the development of 5G in the 10 field labs. The European Union puts a lot of emphasis on its development. The 5G PPP (public-private partnership) recommended that its development should be driven by verticals such as the (manufacturing) industry. This is however not yet covered in any of the field labs under investigation.
- **Big data analytics**. Even though numerous field labs focus on the exchange of data for data driven innovations and/or network centric collaboration little attention is paid to the role of future big data analytics technology in the current field labs. Most focus is on business intelligence and descriptive analytics: showing what has happened and providing recommendations accordingly. There is however a general trend towards machine learning and predictive and prescriptive analytics (‘this is expected to happen, this is the action you should take’). Such technology is likely needed for the next generation of predictive maintenance and zero defect manufacturing e.g. to identify trends and patterns.

5.2.6 Some field labs have potential for further standardization

In some field labs there are certain aspects which have a potential for further standardization (mostly by adapting or extending existing standards). This includes:

- The information broker concept as was developed in the Smart Dairy Farming field lab.
- Security requirements and frameworks which are part of the scope of field lab The Garden.
- The Daisy architecture for the sharing of maintenance related data (field lab Campione).
- Concepts for Flexible Manufacturing which relate to input and control mechanisms in a flexible production cell.

However, at present standardization is not at the core of any of the field labs. Most field labs indicate that they either apply or combine existing standards. There are no formal linkages to international standardization initiatives yet.

A possible approach could be to include these developments as a use case in international platforms such as the Industrial Internet Consortium and the Industrial Data Space Association. These consortia aim to develop new standardized frameworks for data sharing and network centric collaboration. Both consortia are driven by specific use cases. There are currently some links between the German Industrial Data Space Association and the Smart Connected Supplier Network field lab.

An overview of the ICT developments is presented in Table 2.

A Overview of findings per field lab

The table below highlights the various enabling ICT innovations and underlying ICT technologies and indicates their use in the various field labs. For each of the field labs and technologies several characteristics are highlighted in the table:
The **technology readiness level** (TRL). We differentiate between:
☑ - High TRL: Use of technology which is currently available on the market. The field lab applies this technology.
❋ - Medium TRL: Development of new technology or adaptation of existing technology for a new market/use case. The field lab is actively adapting or developing the technology.

The extent to which the field lab is **focused on the use of ICT**:

- Marked **GREY** – the technology is used as generic enabler: ICT is used to achieve the overall objective, but it is not considered to be part of the core developments of the field lab.
- Marked **BLACK** – the technology is considered to be at the heart of the field lab and is crucial to its success.

	Enabling ICT innovations			**ICT technologies**							
	Next generation factory automation	**Data driven innovation**	**Network centric collaboration**	**Industrial IoT**	**Wireless Communication Technologies**	**Distributed data infrastructures**	**Secure and trusted connectivity**	**Semantic Interoperability**	**Big data analytics**	**Visualization and human machine interaction**	**Digital designs and product data**
Region of smart factories	☑	☑	☑	☑	☑				☑	☑	☑
	The Region of Smart Factories field lab consists of various sub cases; as a result all enabling ICT innovations are applied to a certain extent.			Connected devices for consumer electronics; application of IoT in end-user products	Antenna development for wireless communication for consumer electronics and IoT applications				Analytics are used in the design process (to analyze designs) and to analyze production (to support zero defect) and to develop self-learning algorithm. Both are applied in a consumer electronics case.	Design of user friendly dashboard for both IoT end-user products and operators	Integration of CAD/CAM and PDM (product data) systems – used in a shipbuilding case for 'first time right' and in the metal-polymer-case for process optimization and virtual testing. The field lab calls this 'model based product design'
CAMPIONE		☑		☑		☑			☑		
		DAISY system for the exchange of maintenance related data		Application of IoT to monitor production equipment (Ericsson and other suppliers)		Architecture for sharing sensor data between vendors of industrial equipment and maintenance companies (DAISY architecture)			Data analysis to define maintenance requirements (business intelligence and analytics; dashboards/reporting)		

	Enabling ICT innovations			ICT technologies							
	Next generation factory automation	**Data driven innovation**	**Network centric collaboration**	**Industrial IoT**	**Wireless Communication Technologies**	**Distributed data infrastructures**	**Secure and trusted connectivity**	**Semantic Interoperability**	**Big data analytics**	**Visualization and human machine interaction**	**Digital designs and product data**
Freshteq	☑			☑							
	Growth support systems in the agricultural sector (e.g. greenhouses)			Connecting growth support systems of different vendors. These systems control the operation of greenhouses (climate, energy, robotics, etc.)							
The Garden			☑ ✱			☑	✱ ☑				
			Extended PLM solutions for collaboration between OEM and suppliers + technology for secure data sharing	The field lab the Garden performs experiments around the security aspects of Industrial IoT		Application of PLM portals for intercompany data sharing (product designs, product data) – focus on requirements and business processes	Advanced encryption and data protection technology for intercompany use without the need for centralized servers (Thales DPIF/Martello)		*The field lab performs experiments around security of the technology big data analytics*	*The field lab performs s experiments around security of the technology Visualization and HMI.*	*The field lab performs experiments around security of the Digital designs and product data aspects in the project Extended Product Life Cycle management*
									See: 'Secure and trusted connectivity'		

	Enabling ICT innovations			ICT technologies							
	Next generation factory automation	**Data driven innovation**	**Network centric collaboration**	**Industrial IoT**	**Wireless Communication Technologies**	**Distributed data infrastructures**	**Secure and trusted connectivity**	**Semantic Interoperability**	**Big data analytics**	**Visualization and human machine interaction**	**Digital designs and product data**
Smart Connected Supplier Network			☑ ✱ Connecting ERP/MRP systems of different suppliers			☑ Usage of cloud solutions for the exchange of procurement data (ERP/MRP) between companies – e.g. Tradecloud, Ariba, Supply Drive		✱ Semantic web technologies and the use of ontologies/domain models for easier interoperability (vs. existing EDI/XML systems)			

	Next generation factory automation	**Data driven innovation**	**Network centric collaboration**	**Industrial IoT**	**Wireless Communication Technologies**	**Distributed data infrastructures**	**Secure and trusted connectivity**	**Semantic Interoperability**	**Big data analytics**	**Visualization and human machine interaction**	**Digital designs and product data**
Flexible Manufacturing	✱ New technology for supporting production cells for flexible manufacturing							☑ Development of semantic models for smart production cells		✱ Human-machine interaction in semi-automated production - e.g. an operator working together with a robot with handling instructions being presented on a tablet	
Smart Dairy Farming		☑ ✱ Sharing of sensor data related to cows to optimize livestock conditions (health, milk production)				☑ ✱ Data broker for the trusted sharing of sensor data: the broker keeps track of data providers and data users. It allows for data governance by farmers (data owner)			✱ Application of data analytics technology: used to analyze data shared through the data broker.		

	Next generation factory automation	**Data driven innovation**	**Network centric collaboration**	**Industrial IoT**	**Wireless Communication Technologies**	**Distributed data infrastructures**	**Secure and trusted connectivity**	**Semantic Interoperability**	**Big data analytics**	**Visualization and human machine interaction**	**Digital designs and product data**
Smart Bending Factory	☑ Integration with the production environment (feeding digital designs to metal processing production equipment – cutting and bending)		☑ Online environment SOPHIA for digital designs, used to reduce the time to market for tailor-made sheet metal products								☑ SOPHIA web-tool for analyzing digital designs (design optimization, quotations, production preparation) – used for value chain integration.
Multimateriaal 3D printing	☑ Integrating multiple 3D printers in a production line, supporting different 3D printing technologies for different materials		☑ Digital designs for 3D printing are used as an input for the printing-line; the field lab uses market-standards for this.							☑ Improvement of input and control interfaces for 3D printers	☑ 3D models are used as input
Ultra Personalised Products and Services (UPPS)			☑ Sharing of digital designs							☑ Visualization of product designs	☑ Digital models of personalized products

	Next generation factory automation	Data driven innovation	Network centric collaboration	Industrial IoT	Wireless Communication Technologies	Distributed data infrastructures	Secure and trusted connectivity	Semantic Interoperability	Big data analytics	Visualization and human machine interaction	Digital designs and product data
Key findings	Some field labs have some developments in this area. It is at the core of the Flexible Manufacturing field lab, but only for a specific purpose.	Several field labs have data driven innovation in the core of their developments.	Various field labs focus on network centric collaboration, especially when it comes to the exchange of digital designs, PLM and supply chains.	There is currently no field lab (within the scope of this research) focusing on advancing the use of IoT in industry. Several field labs apply IoT on a high TRL level.	Only the Region of Smart Factories field lab addresses an aspect of wireless communication technologies (antennas). There is currently no field lab (within the scope of this research) with wireless communication technologies (5G, LoRa, etc.) as a core development.	Several field labs develop or apply distributed data infrastructures. These are mostly on a high TRL level.	Only the 'The Garden' field lab focuses on security.	Semantic interoperability is at the heart of the Smart Connected Supplier Network field lab.	There are few field labs applying or developing big data analytics technologies. The Region of Smart Factories applies big data analytics in a part of their cases-portfolio.	Some field labs focus on human-machine interaction. This relates to control interfaces and visualization of designs.	Several field labs use digital designs for collaboration and/or to steer production.