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Towards a new era in manufacturing

Final report of VTT's For Industry spearhead programme

Edited by Jaakko Paasi

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Preface

VTT Technical Research Centre of Finland Ltd launched at the beginning of 2015 a spearhead programme called ***For Industry*** that aimed at boosting the competitiveness of the Finnish manufacturing industry. The For Industry programme differed from many earlier programmes through the strongly multidisciplinary nature of the programme. In addition to technological aspects, the programme included a strong focus on business aspects. The work in the programme was divided into six modules from which three had a technological base and three a business research base. The modules were called: Manufacturing Ecosystem, Business Models, Digital Engineering, Automation & Robotics, Industrial Internet, and Decision Making in a Complex World.

This VTT Technology report summarises the main results, highlights, achieved in the For Industry spearhead programme. The approach of the report, however, is not only to look backwards, but also to give visions for the future of manufacturing. We are in the middle of a new industrial revolution, a rapid transformation **towards a new era in manufacturing**, and that is why we are emphasising the future visions from all the perspectives of manufacturing that were included in the For Industry programme. Although the spearhead programme was closed at the end of 2016, VTT's work for the manufacturing industry will continue. The For Industry programme created a new multidisciplinary platform producing research results that could be further developed into new businesses in Finnish industry.

The report is structured in accordance with the modules of For Industry, each module forming its own chapter. Each chapter contains an overview article on the topic and a few articles focusing on specific research results written by researchers. The contents of the chapters were moderated by the leaders of the For Industry modules: Senior Scientist, Tiina Apilo, in the module Manufacturing Ecosystems, Principal Scientist, Jaakko Paasi, in the module Business Models, Research Team Leader, Juha Kortelainen, in the module Digital Engineering, Principal Scientist, Tapio Heikkilä, in the module Automation & Robotics, Research Team Leader, Mikael Haag, in the module Industrial Internet, and Principal Scientist, Eija Kaasinen, in the module Decision Making in a Complex World. The introductory chapter of the report was written by the head of the For Industry programme, Business Development Manager, Risto Kuivanen. Finally, the concluding remarks were given by Vice President of Research, Kalle Kantola.

In addition to the authors of this final report, there were tens of other people involved in the programme work in roles of researchers, assistants and supervisors, either at module or at programme level, etc. Among all of them, the role of Executive Vice President, Erja Turunen, as an initiator and key supervisor of the For Industry programme must be highlighted.

Tampere, January 27, 2017

Jaakko Paasi
Chief Editor of report

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1. Introduction

1.1 Overview of For Industry spearhead programme

Risto Kuivanen
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1.1.1 Introduction

The preparation of the For Industry spearhead programme started at the end of 2013. During that time historical structural change was ongoing in Finnish industry. The technology industry had lost 40 000 jobs since 2008. An international finance crisis was one of the key factors for this. Large brand owners had moved their production facilities to China, India and Eastern Europe, and suddenly very effective supplier networks were without hosts. The structure of the industry was not ready for the change. A majority of the small- and medium-size companies (SME) did not have alternative customers or their own products to be able to survive. Only about 20% of the SMEs had their own products and only 12% their own exports. This was a significantly lower number, compared to the main competitors, like Sweden and Germany. (Rikama, 2016; Teknologiateollisuus, 2016.) The lack of products and customers was an essential missing element, but one of the reasons for this was also lack of competitiveness. The productivity was too low and the price per produced unit was too high.

The technology industry was still the most important export sector in Finland, being responsible for over 50 percent of the export and 80 percent of the R&D investments. It employed directly 290 000 and indirectly 700 000 persons, which was 26% of the total workforce (Tilastokeskus, 2014). During the same time, the investments into production automation decreased dramatically.

In industrialized countries robotics increased during 2014 by 29%, which meant 229 000 new robots. The growth was strongest in Asia. The programme: ”Made in China 2025” was encouraging companies to invest in robotics. China became the biggest robot market area in the world. Because of the really large number of employees, China cannot be seen on the statistic in Figure 1.

The Finnish Robotics Industry Association reported that the number of industrial robots had decreased to a level placing Finland at position ten in the statistics

(2014), which was lower than ever (see Figure 1). Finland had been one of the most robotized countries in the world since industrial robots started to become more common in the early 70's. According to the Finnish Robotics Association, the average robot lifetime in the industry is 15 years. This means that 400 robots are "retired" every year in the Finnish industry. The number of new investments did not cover even that. The same phenomenon occurred in all machine tool sectors. This meant that Finland's manufacturing capability and competitiveness was weakening rapidly.

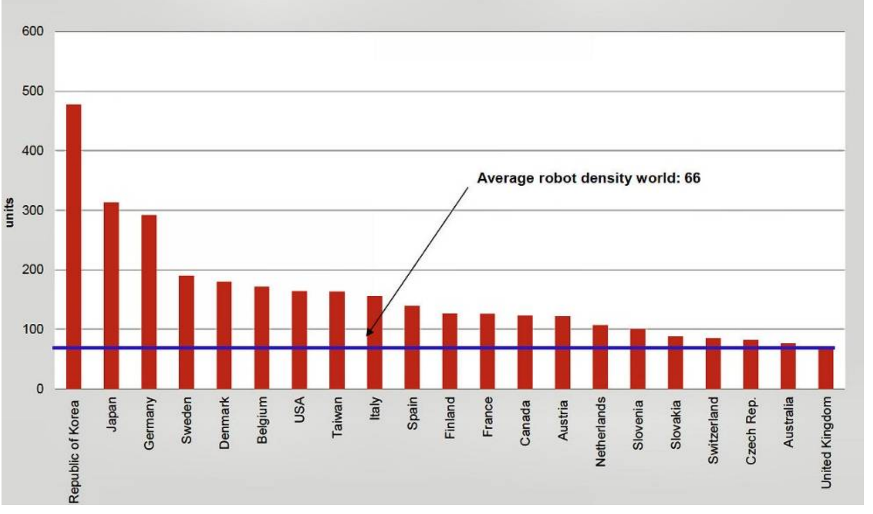

Figure 1. Robot statistic 2014. Number of industrial robots per 10000 employees in the manufacturing industry (Suomen Robotiikkayhdistys).

1.1.2 Success factors of manufacturing SMEs

VTT made a survey using Fonecta ProFinder data service classification based on its company register data (Fonecta) and financial statements data from 2011 to 2013 (Suomen Asiakastieto). The survey data contained 166 Finnish manufacturing companies that employed from 50 to 250 persons. The survey pointed out that, according to the financial data, the biggest share of manufacturing SMEs were actually doing quite well. The finding was that even though the companies were profitable, they did not experience so much growth during this time period (see Figure 2). Perhaps growth was seen as a risk by the businesses that were doing well. Only a minor part of the companies, the aces, were growing, profitable and had a good financial standing. It was essential to recognize the key factors for success in these cases. This motivated programme planning to concentrate on strengthening the positive success factors of manufacturing SMEs.

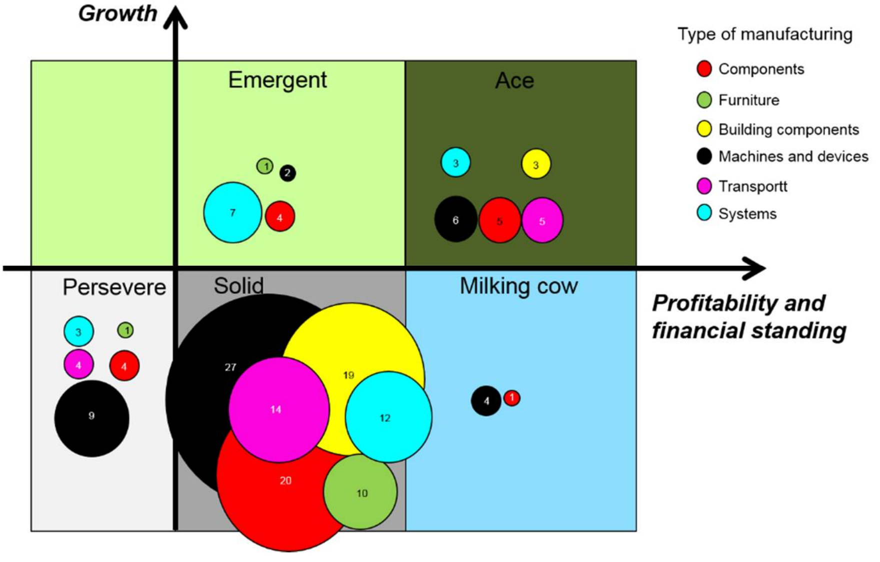

Figure 2. Growth and profitability of small- and medium-size manufacturing companies.

The question was, what factors create a successful manufacturing company in this changing environment and how is it possible to support the companies with the means of research? The For Industry programme started to clarify the factors with discussions and literature. Eleven factors were identified (see Figure 3). Three very important factors are listed below:

- Specialization and differentiation
- Excellent products and services
- Efficient production

For a small company, it is essential to act in a business segment, where the competitive edge is something more than just price. The company must specialize, perhaps even in a small niche area, in which the bigger companies are not interested. In specialized business there is still a need to differ from competitors. In the manufacturing industry this means high quality, demanding manufacturing methods, or longer life time than competitors, etc.

It is not possible to be a successful company if the products are not on track. Without good products there is no manufacturing either. So, a lot of efforts need to go into the products. Today, products normally are connected to services, where the business logic is wider and the development channel towards excellent products is clearer.

There are some opinions that manufacturing location is not important, because it in many cases represents a very low share of the total price of the product. It is also obvious that if there is no manufacturing relatively close to the design, the design will go closer to manufacturing. The manufacturing industry has high importance to society, because it gives jobs not only to the highly educated, but to a wide variety of professions. It also makes it possible to export results of the whole value chain which made the product possible. This means that productivity becomes essential. The price of the produced unit must be competitive, although not necessarily the lowest price. In the manufacturing sector productivity has been increasing for a long time mainly due to technology. It can be estimated that if the share of labour in the unit price is less than 15%, the place of manufacturing is not important; all the other competitive edges are. Sometimes it is important for the manufacturing location to be close to its markets, although sometimes this is not important, for example for products with long life cycles. The robotics and automation are the keys for increasing the competitiveness of manufacturing even in high-cost countries.

Figure 3. Success factors of SMEs in the manufacturing sector.

The next success factors for SMEs are:

- Digital solutions
- Industrial Internet solutions
- New business models.

Automation and robotics are of course digital solutions, but today the possibilities to utilize digitalization are much wider. The data can be collected from any phases of product lifetime or production. It can be processed and changed into knowledge, and utilized in the continuous improvement or bigger technological leaps and business. The industrial Internet provides totally new tools for this and even changes business models.

For the successful business also the next topics must be taken into account:

- Partners and alliances
- Risk management
- Asset management
- Sales and marketing

Partners and alliances make it possible for SMEs to offer bigger projects to customers. It is essential in export, but also with all businesses. In the best cases, a group of companies or an alliance can productize their offering and create added value together. This co-creation makes the development work cheaper and makes it possible to integrate state-of-the-art research knowledge into the products. These two things may create a winning consortium for SMEs in the export market.

SMEs often forget risk management at many levels of their activities. It is common that too many topics depend on one person. This makes the whole business fragile. It is also common that even high investments are not fully utilized, which makes the business less profitable. Sales and marketing often requires special efforts and resources in SMEs.

1.1.3 Structure of the programme

In Chapter 1.1.2 set of factors was presented as the basis for programme planning. The aim of the programme was formulated to be:

- To implement “2020 models” for a successful manufacturing industry
- To support competitiveness of SMEs by developing, transferring and implementing new technologies
- To create killer competencies to VTT’s growth areas for supporting the companies.

Targeted outputs for these were:

- A return to profitable businesses in the manufacturing industry
- Finland as the most robotized country in the EU by 2020
- As a part of the Finnish ecosystem, to change the SME share of export from 15 to 25% and share of R&D from turnover from 2.2 to 3.5%
- More SME specialised in their own products, manufacturing or to act as a development partner
- Implementation of advanced technologies such as Industrial internet, embedded system, additive manufacturing (AM)
- VTT’s For Industry is a well-known R&D platform in Europe

The programme focused on key technologies that would make new solutions available for the Finnish industry to maintain domestic manufacturing as well as to create new products and services for international markets. These key technologies include the industrial Internet, additive manufacturing, automation, robotics and embedded intelligence. In addition to technology, For Industry focuses on how to create successful businesses from new technology. These considerations include studies on business ecosystems, business models and decision making in complex business environments. Special emphasis on the For Industry programme is given to increasing the competitiveness of Finnish manufacturing SMEs.

The For Industry programme was divided into six modules. Three of them represented technologies and three other areas business and business environment. Modules of the project were:

1. Manufacturing ecosystem
2. New manufacturing industry business models
3. Digital engineering
4. Productivity: Automation & Robotics
5. Industrial Internet
6. Decision making in complex world

This report gives detailed descriptions of the key development projects and actions under these topics. Each module will be described briefly in the beginning of the section. The programme concentrated on SMEs, but it is obvious that large companies are needed as brand owners and engines with many of the development actions.

1.1.4 References

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2. Manufacturing Ecosystems

2.1 Research cooperation with manufacturing SMEs

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Digitalization and the rapidly changing business environment challenge SMEs and research institutes to develop a cooperative development mode in the manufacturing industry. Creation of new operational models and tools for cooperation were in focus in the Manufacturing ecosystem module in the For Industry spearhead programme.

2.1.1 Introduction

SMEs – *small- and medium-sized enterprises* – play a crucial role in economic growth and job creation in Finland. The majority, approximately 99%, of Finnish companies are SMEs. It is evident that SMEs are increasingly recognized as welfare and job engines for Finland. However, due to the large scale of different SMEs in the manufacturing sector, there is considerable heterogeneity among them. The growth-oriented, middle-sized companies operate in global markets and take care of their future competitiveness by renewing their business models according to customer experiences and being technology forerunners. But then there are SMEs, which focus all their resources and attention only on everyday operational issues. These companies have not gone through the global financial crisis of 2008 and manufacturing globalization consequences. Between these aforementioned two groups of companies lies the third group of SMEs, which have customers for their products and services, some development resources and rather good technology knowledge. These companies need only encouragement, inspiring examples and networks to become future international players.

Many of SMEs tend to treat technology as a contingency, something that only needs to be dealt with if it cannot be avoided. Digitalization challenges these companies in the manufacturing sector. They need to seize the industrial Internet and other digitalization opportunities to be competitive also in the future. Due to the lack of economic scale in R&D, to more difficult access to information and the lack of other critical resources as special competencies, SMEs need to collaborate to complement their scarce internal resources.

The module *Manufacturing ecosystem* objective in the For Industry spearhead programme is the following: SMEs see VTT as a valuable partner, who understands their future technology and business needs. To achieve the objectives three tasks were planned: creating an extensive and well-managed customer base and long-term partnerships with SMEs, establishing a status as an attractive innovation partner for SMEs, and launching the For Industry platform. In the following subchapter the shape that the For Industry platform has taken is presented, and further, new methods and approaches that have been developed and tested to achieve the main objective are discussed.

2.1.2 New approaches to support SMEs

The idea of a manufacturing industry platform took the shape of a knowledge centre. VTT and Tampere University of Technology (TUT) pooled their resources and knowledge to SMACC – *Smart Machines and Manufacturing Centre*. SMACC focuses on the digital transformation challenges of manufacturing in SMEs in cooperative development between SMEs and research institutes. The basis for SMACC combines VTT's and TUT's strong scientific knowledge and international research.

The main idea of the SMACC operation model is to change the development approach from technology push to business pull. This will be done via selected theme areas, which all have the potential to provide a productivity leap for a SME. In a wider scope it is a question of creating a new type of innovation ecosystem integrating knowledge and business ecosystems with new co-creation models. A business ecosystem focusing on customer value creation is set as base for case creation and knowledge ecosystem operations will be adapted according to it.

Strong and extensive cooperation between VTT and TUT in the mechanical engineering area enables new operational model success. A "Quick and dirty" experiment culture is characteristic of both knowledge centre operational model development and its SME specific co-creation projects. The leading idea is that the latest scientific knowledge will be available for all SMEs in a fast and efficient way – initiated from the business value creation point of view.

To serve manufacturing SMEs, VTT and SMACC have developed a few concepts and approaches. You can see objectives and short descriptions of these tools in Table 1.

Table 1. Tools and methods to increase VTT and SMEs co-operation.

Tool/method	Objectives	Description
SME under-standing	Increase researchers' under-standing of SME business	SME visit series, SME project lessons learnt workshops, SME classification exercise, SME 472 study
Apprentice model for marketing and sales	Train young sales-oriented researchers	Senior and junior researchers devel-oped and piloted apprentice model for SME marketing and sales
SME windows	Serve SMEs fast with concrete solutions based on research, support competitiveness of SMEs by implementing new technologies, prepare separate single company or parallel development and research projects	Operational model for activating SMEs: theme workshops and project planning go-development
SME newslet-ter	Inform SMEs about seminars and blog posts and dissemi-nate research results	Manufacturing SME-focused newslet-ter approximately four times/year
For Industry blog	Disseminate research results focusing on SME manager audience in manufacturing industry	Researchers write readable blog posts about their business and technology research
H2020 SME task force	Horizon 2020 SME Instrument proposal	Helping SMEs to prepare high-quality Horizon SME Instrument (Phase1 or Phase2) proposal with strong business idea
SMACC Think Tank	Identifying of SME's key assets and development targets for digitalisation	One-day workshop for one company or group of companies.
SMACC Flywheel	Fast solution through agile product or production devel-opment project	Speeded up project for product and production development. Participants may include several companies shar-ing similar needs.
SMACC Hack	New perspectives from profes-sionals and students to SME's challenges	Hackathon-type workshop, where students and professionals solve SME's business and digitalisation challenges

Following SME windows, SMACC Think Tank and SMACC Flywheel concepts are introduced.

SME windows is an operational model (see Figure 1), planned to provide concrete solutions to SMEs based on VTT research. The name *SME Windows* means that these topics are presented in a web theme page in a period of four weeks. During this time span SMEs are invited to participate in a theme workshop. In the theme workshop researchers introduce main topics related to the current theme. After these introductory presentations, all participants, SME people, VTT KAMs and researchers discuss interesting theme areas and try to find common interesting areas for future co-development.

The original idea to develop the *SME Windows* concept came from a concern that SMEs do not fully utilise VTT's research power and at the same time VTT researchers have ready solutions based on research projects conducted with big companies. Although, many of these research results are very applicable also in the SME context. To make an applied development project cost efficient for SMEs, the *SME Windows* workshop agenda is made to support co-operation and peer learning. So, SMEs can find other companies interested in solving similar technological and or business challenges.

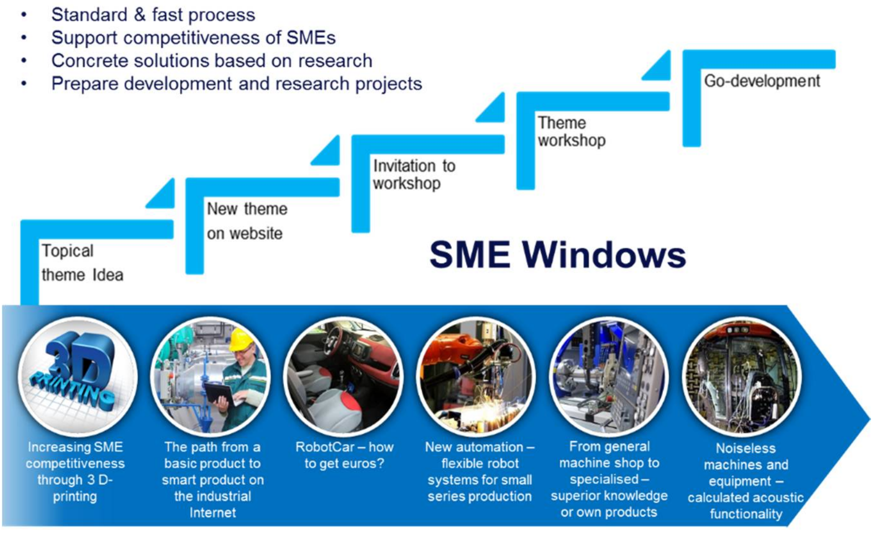

Figure 1. SME Windows operation model.

SMACC Think Tank is a productised ideation workshop for identifying SME's key assets and development targets in the area of digitalisation (see Figure 2). As an outcome, the SME receives a description of the significance and current performance levels of its key assets and any needs for improvement. The ideation day, *SMACC Think Tank,* can be executed either company-specifically or as a joint workshop for a group of SMEs.

The *SMACC Think Tank* workshop starts with a world café style discussion, where four roll-ups represent the cafés: Digital design & modelling, Digital manufacturing, Digital business and Digital services. These cafés are hosted by one facilitator for each. The facilitator keeps the discussion going, brings up examples of leading solutions and technology possibilities and also takes notes on the most important issues. The participants fill out an evaluation formula in each café as a self-test of digitalisation. After the break, the whole workshop group together check the evaluation results and prioritize the list of common development needs.

The workshop concept is developed to tackle SMEs' information needs regarding digitalisation and to help them answer the question "What does digitalisation mean to our company?" Further, after the *SMACC Think Tank* workshop the SME knows what their development need is and what kind of help and support they can get during their digitalisation journey. At the same time, business and technology researchers get a holistic picture of digitalisation in Finnish manufacturing SMEs.

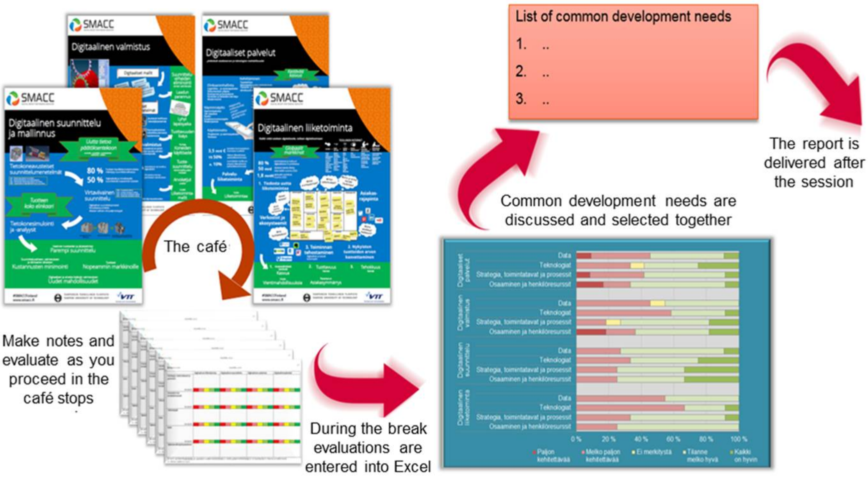

Figure 2. SMACC Think Tank workshop.

SMACC Flywheel is swift development model for products and production (see Figure 3). It combines several approaches and agile design methods to speed up traditional development work. The phases of the development process are followed through within a period of three months. Participants may include several companies (4–6) sharing similar needs or the *SMACC Flywheel* can be tailored for one SME. For example, the approach fits well for testing of new automation solutions, searching for industrial internet solutions, networked operational model development and searching for new material for specific uses.

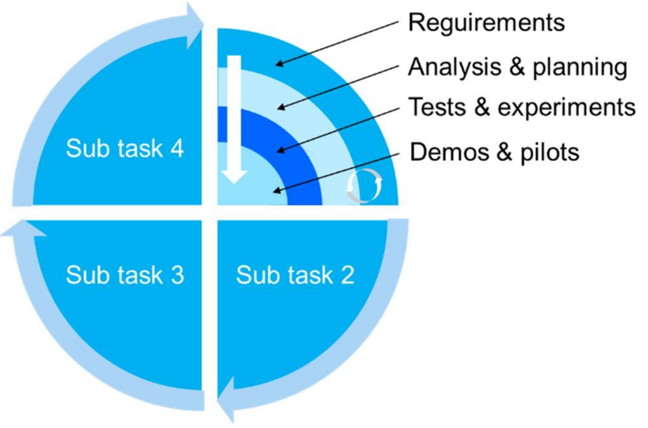

Figure 3. SMACC Flywheel.

2.1.3 Future visions

The economic growth and employment of Finland are highly dependent on the success of the manufacturing export industry also in the future. For that, it is essential to one of the leading players in implementing digital solutions and business models. Future smart products and services are created in the new industrial ecosystem. Robotisation, flexible automation and artificial intelligence offer opportunities for enhanced production. We are ready to be the frontrunner in next-generation manufacturing and service business with high innovation capabilities and a skilled work force. The foregoing is how one of five of VTTs strategy lighthouses, *Industrial renewal – innovation empowering industry*, describes the future manufacturing industry in Finland.

Next questions are how this vision can be realized and what is the role of SMEs in that vision. Figure 4 points out five aspects needing consideration, when we are talking about the capabilities for an SME to grow and to be a real international company. We can refer to these aspects as future success gears. The success gears are preliminary remarks from an ongoing study: Roadmap of smart manufacturing SME industry.

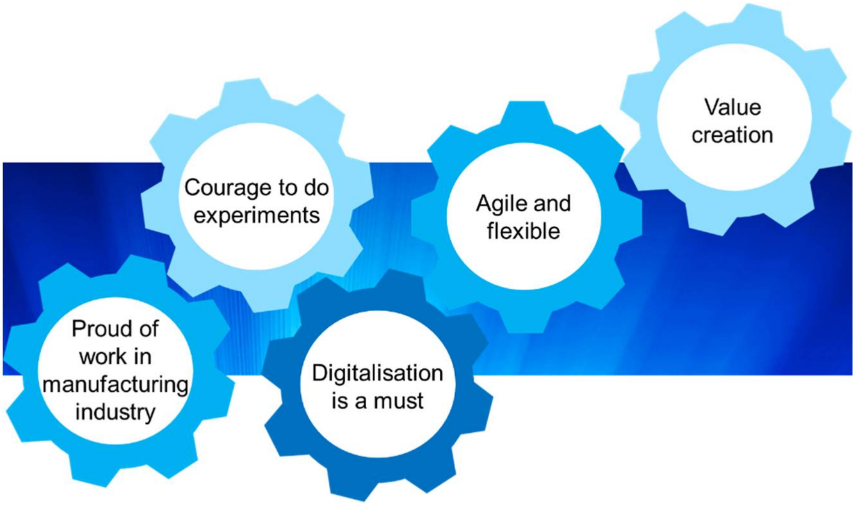

Figure 4. Future five success gears.

The ***Proud of work in manufacturing industry*** success gear covers three levels. Firstly, on the industry level there is a need to communicate what the manufacturing industry really can be. The industry needs more associations with topics like new technologies, circular economy, artificial intelligence and fancy products rather than dirty old engineering workshops, lay-offs and pollutants. Secondly, at the employee level, it is important not only for the job satisfaction point of view but also company success, that employees' innovation capabilities and problem solving capacity are utilised in full. Especially young generations value their work's meaning and workplace atmosphere more than money and position. So finally, the third level, where it is important to be proud, is young people's own choice of education. They choose their next education offered from a variety of possibilities. A desirable education is demanding and often also difficult to achieve. From the SME point of view, it is remarkable that students are much more interested in entrepreneurship and working at small companies nowadays than before.

The message of the ***Courage to do experiments*** success gear's is that SMEs have to make decisions much faster than before because of global competition, new technologies and structural changes of the manufacturing industry. A three-year planning time span or conducting the same business in the same way as in years before is no longer possible. But a SME CEO cannot know what business, technology or market is the right choice before trying. Experiments and learning from these experiments are what is needed in the path of a digitalisation journey as well as in an internationalisation path. But, SMEs do not need to execute these decisions alone, when the decision to go is made, there are plenty of good partners and networks to join. Additionally, different kinds of peer groups and peer networks can help a CEO evaluate various alternatives during a decision phase.

Agile and flexible production is characteristic of Finnish manufacturing companies' producing smaller series of products. There are already flexible automation and robot solutions available, which ensures that small series can be manufactured cost efficiently also tomorrow. But, mass customisation, close relationships with customers and international markets challenge old production capacity thinking. Together with network partners and multiply skilled employees, new flexibility requirements are able to be managed and led. Future leadership is open, customer-oriented, flexible and decisions will be made under uncertainty.

Digitalisation is a must. 2016 was a breakthrough year for digitalization among Finnish manufacturing SMEs. A year before most of the managers did not understand what digitalization could mean to their company. Today there are good examples of new digital service businesses, examples of automation solutions and even 3D printing. Creating data, collecting data, analysing data and conducting service business by utilizing data are things what the most companies need to explore carefully as a source of new business opportunities. The rest of the companies, need at least to utilize digitalization for improving their own operational and production process efficiency.

Value creation – how well a company understand a customer's business (BtoB) and user experience, and how well it turns that understanding into business, is the main issue in the end. For SMEs manufacturing for the international market, international customers and new business models mean a need for new knowledge and resources for business development, sales and marketing.

In Finland is a strong tradition of engineering work and lot of ICT knowledge. Further, there is a high level of pride in production quality, high-tech products, highly skilled workforce and straightforward leadership. In the interviews of roadmap work we heard often how the next generation helps to fulfil the manufacturing industry's vision with their open attitude toward networking, internationalisation, digitalisation and risk taking. But, the world will not wait for the next generation to take the reins in Finnish companies.

2.1.4 Further reading

For Industry blog http://vttforindustry.com/

SMACC – Smart Machines and Manufacturing Centre http://smacc.fi/

VTT Lighthouses http://www.vttresearch.com/about-us/strategy/vtt-lighthouses

3. Business Models

3.1 Business models in the future of manufacturing

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This chapter gives an overview on the topic of business models: what business models mean, and why the topic is highly important and current for the manufacturing industry. The role of digitalisation in novel business models is described, and the main results of the module work are reviewed in the chapter. Finally, visions of key factors shaping the future business of manufacturing are discussed in order to help manufacturing companies to be prepared for the future.

3.1.1 Introduction

In the past, an outstanding technological manufacturing solution or the introduction of an exceptional product was often sufficient for the success of a manufacturing company. In some cases it was sufficient simply to offer a standard manufacturing capacity to survive. In today´s globalised and digitalised business environment, to name just a few of the present driving forces of change, the competitive advantages of yesterday are often eroded and, what is left for a manufacturing company, is hard competition without any special competitive advantage. This is the situation for hundreds of SMEs and larger companies only in Finland, to say nothing of manufacturing companies in other countries.

The renewal of a manufacturing company's business may often require updating its technological capability, but that is seldom adequate. What is needed for success is to change the business model of a company. We have learnt from success stories, such as the Kone Corporation, where they have extended their business from selling elevators to also include the maintenance and service of elevators. We have also learnt how Sandvik Mining and Construction extended their business by starting to offer autonomous mining systems (instead of individual equipment), including specific technology and elements from several suppliers, with Sandvik acting as the integrator of the system. More radical is the business model change of the aircraft engine manufacturer, Rolls-Royce, where they started to sell flying hours to airlines instead of engines. In this performance-based business model Rolls-Royce retains ownership of engines but, on the other hand, engages airlines in maintenance services. These are examples of changes in business models that have brought competitive advantage to the company in today's markets.

The examples above are for large companies, but changes in business models are as relevant to SMEs as to large companies in order to be successful in markets. This is why the business model perspective is highly important for the renewal of the manufacturing industry at large.

In this overview chapter, I will explain what a business model is all about, describe what the role of digitalisation is in the business model renewal, review the main results produced in the module during the For Industry programme, and, finally, share some perspectives about how to be successful in the manufacturing business beyond 2020.

3.1.2 What is a business model?

The term 'business model' is defined and understood in the literature less unambiguously than many other key terms of management. There is a consensus that a business model describes how a company creates and captures value. Where the opinions about the term diverge is in to what depth and width the business model describes all that.

In the thinking that we have adopted at VTT, the business design of a company takes place at three levels (Osterwalder, 2004):

- strategic planning level,
- business model level,
- implementation level.

Strategy defines the business areas where the company wants to be good, the competitive advantage through which the company will do better than its rivals, and the future objectives of the company. A business model is a more detailed manifestation of the chosen strategy, a description of how a company's business runs. It defines briefly the value proposition (i.e. the offering), customers, value network and profit mechanism. The business model is then implemented through the organisation, processes and practices of a company.

A customer-centric way to present the main dimensions of a business model is given in Figure 1 (modified from Gassman et al., 2014). Targeted customers (to whom?) are in the centre, i.e. customers whose needs will be satisfied by the value proposition (what?). The value proposition defines the company's offerings (products and services). These two are external dimensions of a business model. The other two at the base represent internal dimensions of the model: the value network (how?) and profit mechanism (why?). The dimension 'value network' describes how the value proposition is created and delivered to customers. It also describes internal and external resources and capabilities needed in order to do that. The dimension 'profit mechanism' clarifies why the business model generates profit. It includes aspects such as cost structures and revenue-generating mechanisms.

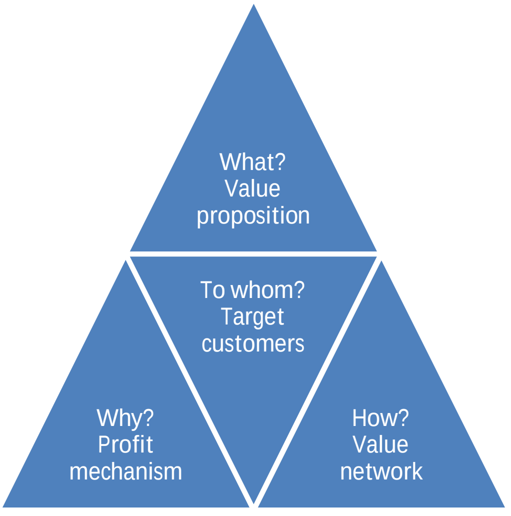

Figure 1. Main dimensions of a business model.

In practical business model creation, a business model of a company is often blueprinted and visualised in a table, such as the Business Model Canvas by Osterwalder and Pigneur (2010).

Most manufacturing companies are good at creating value for customers. This is the work that typically takes place in the technology domain. What is often challenging for a manufacturing company is to capture high enough portion of the created value. This is something that takes place at the business model domain. If the profits are not at a satisfactory level, a company should make changes at least in two dimensions of its business model. Changes only in one dimension (for example, through changes in product or in process) typically give competitive advantage to the company for only a short time.

A business model can be offering dependent, which means that there can be a few business models in a company. For example, Kone does not offer elevator solutions and their service by using the same business model. Furthermore, business models could be market dependent. For example, a business model that works in Europe will seldom work in Asia without modifications.

3.1.3 Digitalisation and business models

Digitalisation is one of the main drivers that has already changed and will continue to change society. Digitalisation can be defined as the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business. Digital business means here a business where physical and digital worlds have been blurred (Gartner, 2016).

Digitalisation, by definition, connects the technology and business model. This fact has not been realised by most people in industry. When speaking about digitalisation, the focus of manufacturing people is too often solely on how to use digital technology in their products and processes. In a holistic view to digitalisation one should, in addition to technology, think about the data and information that the digital technology in the products, services and processes create. And finally, how to create and capture value using the new information either by business models totally new for a company or by changing an existing business model. Without this holistic vision on digitalisation, the use of digital technology may stay in the technological domain and its impact on the business and company profits may remain unclear. In the worst situation, digitalisation is seen only as a cost factor. The holistic view presented in Figure 2 is a result of a multidisciplinary workshop at VTT with researchers from three spearhead programmes of VTT: For Industry, ProIoT and Bioeconomy.

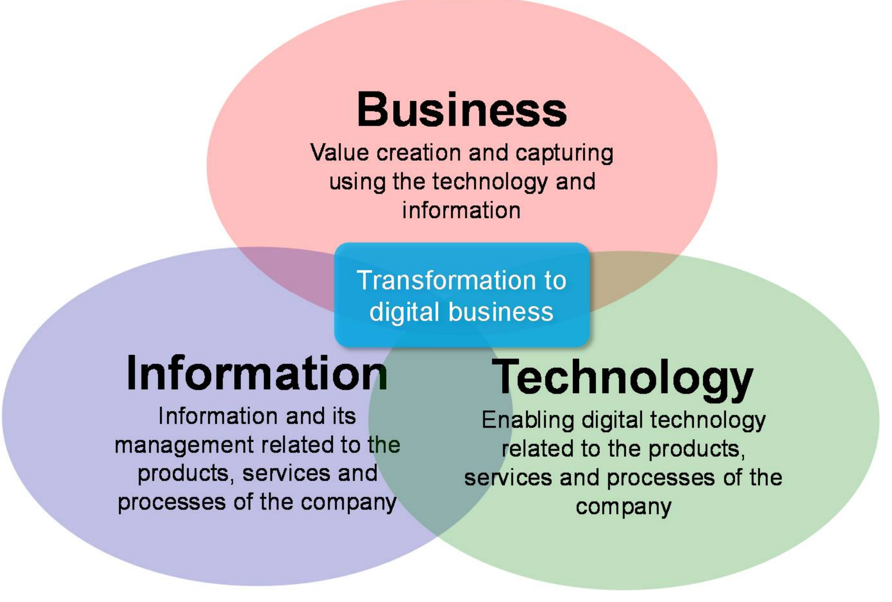

Figure 2. Holistic view of digitalisation.

Digitalisation may influence all four main dimensions of a business model. A company could attract totally new markets because physical presence in the market is less important than in the past. It could create new value propositions using the data produced by its products. The change in the value proposition could be incremental, based on new features in an existing product or service, or a radically new data-based service. Through digitalization a manufacturing company could shorten its value chain and have direct contact with end-users and in this way to capture more value or to offer customisation as a new business model. By digitalisation a company could often reduce its cost structure.

The methods given above are just a few examples of hundreds of ways in which a company could change its business model, competitiveness, and profitability with the help of digital technology. The best opportunities for a positive impact can be gained when the company aims at radical changes in, at least two dimensions of the business model instead of incremental improvements only in one dimension. In the former case the company may become a game changer in its field of business.

3.1.4 Review of main results

A business model integrates technological and economical perspectives. Perhaps that is why creative business model thinking is not so easy: one may be an expert in product, service or process development, or an expert in economy and business management, but you need both technological and economical thinking in order to make an innovative and successful business model. Often business model development needs to be accompanied by R&D where technological and business aspects are integrated. That is why we started the 'Business models' research work in the For Industry module by studying real R&D and new business development cases that had led to success and which included both technological and business aspects during the R&D phase.

We learnt from the studied cases a few success factors that were common in almost every case. The studied cases were performed in a multidisciplinary team which went over an organisational boundary in one way or another, i.e. it included members from the company that was responsible for the work, experts from one or more research institutes or universities, and experts from one or more supplier companies. The total financial volume of the work was typically large, in the million-euro range. The work, however, was almost always divided into much smaller parts, i.e. there was a framework plan (sometimes called as a development programme) but the actual R&D work was executed in a series of small projects with volumes of a few tens of thousands of euros. This way of managing the large development programme brought agility and flexibility to the realisation of the R&D and business development work, while the large framework plan gave the goals, guidance and supported commitment of all parties for the daily work.

The contractual relations between the company and its suppliers and research institutes were in the studied cases based on subcontracting. We knew, however, from earlier research that subcontracting is a powerful way of collaboration in the context of R&D and business development only when the sourced solutions, etc., would represent a standard level of knowledge (Paasi et al. 2013). If a high degree of innovation is needed in collaboration, some other formal model of collaboration could better encourage suppliers and research institutes to give their best effort to the joint work. That is why we started to develop a new Finnish model for co-creation that would encourage all actors to innovate and give their best effort to R&D and new business development. The fact that the studied cases had been successful did not mean that their outcomes have been optimal. In today's business with strong competition, one should aim for optimum results.

The alliance model of collaboration was recently used in large construction projects with great success. In the alliance model all the actors of the project are 'on the same side of table', on the contrary in the subcontracting model the principal and the suppliers stay on opposite sides of table. In the alliance model, all the actors will share both the benefits and risks of the work in a way jointly agreed in the alliance contract. In the For Industry Business Models we started to develop a model for the co-creation of new business by applying the basic principles of alliance models. The model is presented in the subsequent Chapter 3.2 of the report. The results of the work are waiting for piloting in a real new business development case.

Another development task in the module 'Business models' was related to digital transformation in companies. We developed, in collaboration with VTT's ProIoT spearhead programme, a test for the evaluation of digimaturity of a company, where we went beyond technological aspects and looked at the holistic picture of digitalisation (Fig. 2). In the maturity test we paid attention to six dimensions that are relevant in digitalisation. The dimensions are: strategy, business model, customer interface, people and culture, organisation and processes, and information technology. The test is presented in more detail in Chapter 3.3 of the report. The test is available for use at https://digimaturity.vtt.fi.

The last research work to be reviewed in this chapter is the For Industry scenario work 'Successful business at Finnish manufacturing companies beyond 2020' (Paasi & Wessberg, 2015), where the main target was to provide guidance to the manufacturing SMEs in preparing for the future. The future target year of the study was 2025. The questions that guided the work were: What will be the future markets (i.e. the business opportunities) for Finnish manufacturing SMEs? What kinds of products will probably be needed? What kinds of business models will create success?

The foresight study resulted in four scenarios that could be characterized by two word-pairs: global-local and growth-scarcity. In the word-pairs, the global-local refers to manufacturing processes: whether they are happening in global or local value chains. It also refers to markets, where the trend of globalization will continue or where the trend will turn into strong local markets. The word pair growth-scarcity refers to the drivers of business: whether the business will be driven by economic growth or by the scarcity of non-renewable raw materials or other resources. The four scenarios were: 1. global-growth, 2. local-growth, 3. global-scarcity, and 4. local-scarcity. The scenarios will be presented in more detail in Chapter 3.4 of the report. Here, in the following section, I will shortly review key factors shaping the future in the manufacturing industry, because each successful new business model of a manufacturing company should take into account some or all of these factors.

3.1.5 Future visions

Key factors shaping the future of the manufacturing industry are represented in Figure 3 using a multi-level perspective model where society is divided into three levels: landscape, regime, and niche (Paasi & Wessberg, 2015).

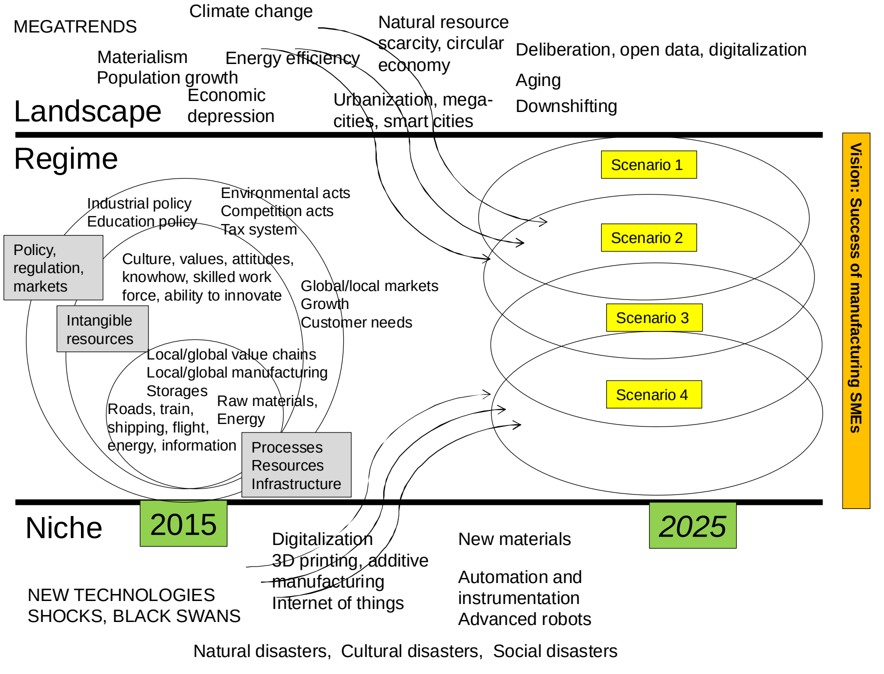

Figure 3. Key factors shaping the future of manufacturing industry.

Landscape encompasses the level of significant big societal moves; megatrends such as climate change, urbanization and aging. In the context of manufacturing, a materialistic way of living as well as population growth, for instance, ensures the demand for products. At the same time, the scarcity of non-renewable natural resources will create challenges for the manufacturing industry. Energy efficiency and renewable energy business will play important roles in the future. Urbanisation will increase the meaning of megacities and the construction industry. These are examples of megatrends that will shape the future.

Regime describes the system with its actors, institutes, resources, processes and ways of operating. Regime can be divided into physical resources and processes; intangible resources; and political, regulative and market aspects. Regime states whether the manufacturing is happening in global or local value chains by using global or local resources. For example, in the current regime the design of products may take place in global value chains, but the manufacturing of heavy products is often local. On the other hand, light and low-cost mass produced products can be transported around the world for global markets. The same applies for the manufacturing of very innovative high-end products. Infrastructure and its performance are important elements of regime. Intangible resources encompass, for instance, skilled, cost-efficient and innovative labour. In markets, it is foreseen that it will be important to react quickly to changes in market needs. Moreover, cyber security, as well as security in general, are foreseen to be essential elements of successful business making.

Niche is for issues that may challenge and shape the present regime in a disruptive manner. The niche level of society includes new technologies, local experiments, shocks and black swans. For example, digitalisation, automation, advanced robotics, additive manufacturing (3D printing) are foreseen to shape the existing system. The level may include special products which challenge the mainstream markets at the regime level. Severe natural, cultural or social disasters, such as earth-quakes, terrorism or wars, which will highly confuse the system, may also occur.

When the regime is in a state of change, all the levels flow in the same direction; landscape creates push and niche creates potential or shocks to the system change. Landscape represents slow-affecting megatrends, while the niche level factors may cause abrupt changes. Scenarios 1–4 will describe the potential new regimes. In the For Industry scenario work, the scenarios were global-growth, local-growth, global-scarcity, and local-scarcity.

The vision for the new regime of society would depend largely on whether the current trend of globalization and free trade will continue or will protectionism strengthen in several regions of the world. At the moment (the situation in early 2017), it seems that protectionism is entering back into global politics. Then the key question is, how strong will it become? Will it mean just increased customs duties, or will that mean some stronger restrictions on the flow of raw materials and goods across the borders of countries and unions? The latter would mean a major change in the regime. It could mean, for example, that the export of Finnish products outside Europe may become much more difficult than today. It could mean challenges to getting some raw materials and electronic components currently imported from Russia, China or elsewhere in Asia. It may also mean that many commodities, currently produced in Asia, would have to be produced in Europe, like the situation was 30–50 years ago before the start of globalisation. The latter thing (i.e. replacement of imports) may not be a bad vision for Finnish manufacturing SMEs, since it could open up many new business opportunities for manufacturing companies.

The future world beyond 2020 will, to some extent, be different from our current world of 2017. Therefore, manufacturing business models that are working today, may no longer create successful business beyond 2020. Accordingly, a manufacturing company should be prepared for the future, but the question is how to do that?

First, most people tend to think that transformation from one regime to another is a slow process that takes a few decades. If the transformation is mainly driven by landscape factors (see Figure 3), the transformation really is a slow process.

With slow changes, companies have a good amount of time to react to changes and adapt their strategies and business models to meet the requirements of a new regime. At the niche level, however, there are shock factors, such as major disasters or a flow of masses of refugees that may cause an abrupt systemic change from the present regime to a very different one. In such a case, a manufacturing company should be strategically ready to rapidly adapt or change is business model (or models) to fit for the needs of a new regime.

Second, although successful business models may not be the same in each potential future regime, there are a few success factors that appear in each scenario that go beyond 2020. Effective use of natural resources and circular economy are important in the future worlds and may give a competitive advantage to the companies that utilize these strategies. But above all is the effective implementation of digitalisation at all levels of business, from technology to business processes. It is the most important single success factors in future business models of manufacturing companies, but it does not alone bring a competitive advantage. The competitive advantage of a company has to be built on that.

Third, manufacturing of high-value-added products from Finnish raw materials will be one of the key success factors for Finnish companies in the future. This does not mean that each manufacturing SME should have their own product and use only Finnish raw materials. However, having an own product is something to be considered by many manufacturing SMEs. An own product, however, is not alone sufficient for success. How well the product concept has been designed and by which business model it has been launched to markets would be crucially important for success.

3.1.6 Conclusions

The transformation towards the 2020 business environment is already underway. During this time the transition may not be a slow process, like it often has been in the past, but an abrupt one. History has shown that abrupt changes offer good business opportunities for those who have proactively prepared to react rapidly to the changes, while those who have not, lose out in the competition. Because the business environment beyond 2020 will differ from that in 2017, we could conclude by saying that the competitiveness of the manufacturing industry comes from how fast it can react to the changes in markets and build new business models in order to create and capture high enough value in the markets.

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3.2 Alliancing for business development

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A major change is taking place in the way many challenging investment projects are implemented. Strict division of labour between the key players of a project with delimited scopes of liabilities has been substituted by a more collaborative practice where the players integrate versatile expertise into the development of the project solution relatively early and bear the risks of the project jointly, i.e. form a project alliance. It enables the parties to reach better results in many cases. This section looks, first, at such a change in the construction industry to introduce the key features of alliancing. Second, the text ponders whether analogous integrated effort by companies and R&D organizations would benefit the development of new businesses based on novel technology and that is the main purpose of this review.

3.2.1 The challenge with traditional project practices

A common method to carry out investment projects is to let the designer complete the design documents that are then put out to contractors for bids. Such systems do not fully utilise the know-how of the various parties while a relatively early fixed solution and price disallow continuous project development. Constructability and cost awareness of designers is inadequate. Unknowns left in plans result in contingencies and make the tenders expensive to the owner. Deviations and interpretations of change orders during construction also tend to increase conflicts of interest and adversarial behaviour in projects and be a hindrance to success.

The challenge remains even if the competence of designers and contractors is utilized synergistically by requesting candidate teams to complete design proposals. The costly proposal compilation and fast competition phase does not allow the parties to develop proper solutions and there is no time to determine the compliance of alternatives with requirements and regulations. More time and co-operation is needed for development but it would be too costly with numerous candidate teams. The aforementioned challenge related to the fixed price is also met in these cases.

The uncertainty related to demanding projects highlights the problems of traditional project delivery systems. Technological development also brings opportunities and makes projects increasingly complex underlining the need for new practices.

3.2.2 The change to joint development

Project alliance is a project delivery method typically based on a multi-party contract between the key actors in a project where the parties (Lahdenperä, 2009; DIT, 2015):

- assume joint responsibility for its design and construction to be implemented through a joint organization that includes the owner, the designer(s) and the contractor(s); and
- share risks related to the project and observe the open-books practice and unanimous decision making.

The basic idea is that an operational model where risk is borne jointly and reward is shared on the basis of the success of the entire project makes the parties consider each other's views better and collaborate more efficiently for the best of the project. The method also allows combining a wide range of expertise needed to foster innovation and to make demanding ventures successful. That, again, necessitates early selection of the actors, which does not enable the use of price criterion in a conventional way. Instead, the selection is mainly based on a thorough review of team capabilities and prices are to be negotiated within the project consortium as a part of the development.

The selected service providers enter into a 'development agreement' with the owner for the design of the project and to set the project's target cost and plan the incentive system. Thereafter the actual 'implementation agreement is signed, but only if the parties are able to agree on the project solution and the owner considers the target cost level, etc., reasonable. The performance in relation to the target cost and other key performance indicators of the incentive system determines the payment to the service providers eventually (Figure 1). However, if the parties are not able to agree on the target cost at the end of development phase, the owner is free to terminate the contract.

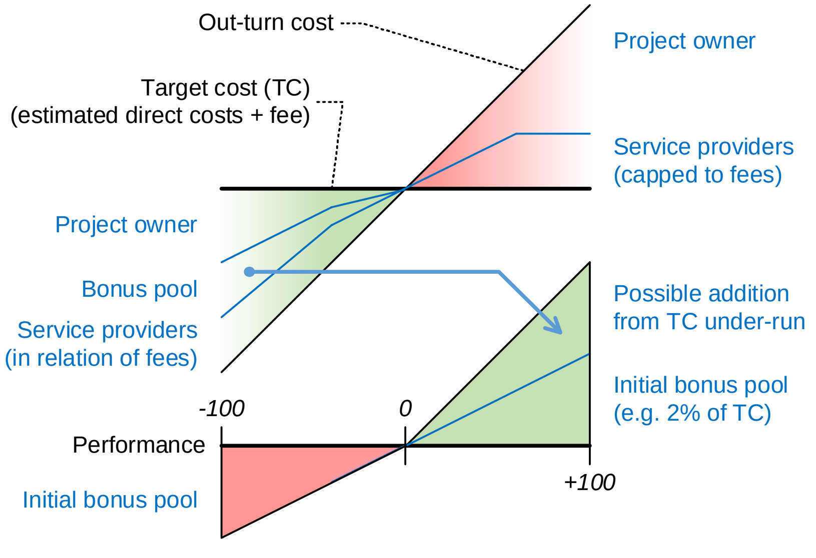

Figure 1. Joint risk-bearing and determination of payment to service providers in a project alliance: cost performance in terms of TC under/over-run forms the base that is adjusted on the basis of the performance in accordance with other criteria.

3.2.3 Experiences from alliancing

The trustful collaboration between alliance partners has resulted in excellent performance in general. The first projects of this type were successfully realized in the oil and gas sector about two decades ago which made the construction and real estate industries adopt and further develop project alliancing. This took place in Australia where hundreds of projects have been implemented by using the system. Little by little its use extended to other countries with different applications and under different names.

VTT has always been active in the development of new project delivery systems. Correspondingly, alliance experiences from Australia were discovered and reported to the predecessors of the Finnish Transport Agency (FTA) by VTT. This made the parties invite more members from the industry to participate in co-operation and to launch a joint project for the introduction of alliancing in Finland some ten years ago (Lahdenperä, 2009). Subsequently the procurement of the first alliance project started in 2010 and since then the FTA has utilised the model in a few projects. Besides, tens of alliance projects have been launched by other Finnish project owners as a consequence of the aforementioned groundwork.

The FTA's landmark project, by now, is the Tampere lakeshore road tunnel. The development phase of the project took a year and during that a large number of development ideas were born and implemented resulting in a 10% cost saving, although some of the ideas were implemented mainly due to their positive value effects (Alliance Executive Team, 2014; cf. Figure 2). Such innovativeness would have been unlikely if a disintegrated project delivery system had been applied (Lahdenperä, 2016) and the generation of joint interest had been ignored. Besides, none of the performance indicators used in the project were negative at the time of project completion and it is rather clear that the good performance in the implementation phase is thanks to the incentive system used.

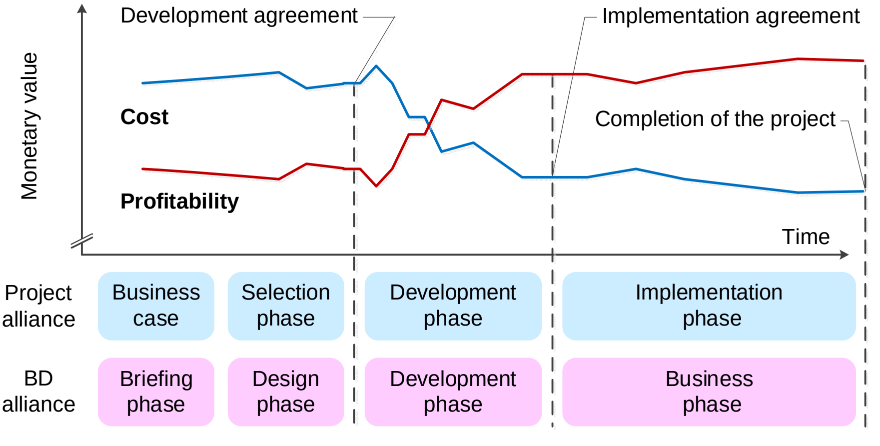

Figure 2. Cost and profitability in the course of a project: from estimate to out-turn.

3.2.4 Alliances for innovation and business development

The success of the application of project alliancing in project-based industries pose the question of whether joint risk bearing offers a potential solution also for more efficient introduction and commercialisation of new technology. This kind of project often requires the integration of expertise of various parties and joint risk bearing should align the interest of the parties to collaborate effectively for the common good. It is not a question of a pure principal-contractor relationship but a kind of joint ownership of the business endeavour since the payment to developers is determined partly on the basis of the success of targeted business. Hence, a new kind of cost and benefit sharing through the alliance model could enable finding the balance between self-interests of involved actors and enhance their working together.

Such a ‘business development alliance’ (BDA) would convert the cost-oriented joint risk bearing system of Figure 1 into one focussing on the profitability of the ensuing business. The cost issues of project realisation extend to cost of development and profit attained thereafter. Qualitative key performance indicators are likely to be of relevance here as well (e.g. time to market, service reliability). Correspondingly, it can now be expected that the cost decrease trend often reported in the case of joint development projects, like project alliancing (Figure 2; in blue), may now be flipped up-side down to describe potential increase in expected profitability (in red). Launch of a new business involves uncertainty and, therefore, the models that have proved their functioning in challenging, risky projects might offer a solution for more successful new businesses as well.

3.2.5 Key features of a business development alliance

A Business Development Alliance (BDA) is an alliance for the development of a new business and it is clear that different business cases call for different solutions. However, by definition, a BDA applies the core principles of project alliancing such as transparent collaboration and joint organisation, joint-risk bearing and joint decision making by the parties to the contract. Trust is a key element as in all collaborative settings.

A BDA contract may involve multiple actors. The key roles are idea owner, commercialiser, developer (R&D organisation in this case), and financer. The key aspects of each role are as follows:

- The idea owner is likely to be the initiator of the joint work with necessary background knowledge and/or network position.
- The commercialiser is a main party, since it is the one that will hold the end customer relationships.
- The resources and competences of the developer enable more efficient process or more innovative and profitable solutions.
- The financer provides capital for the initiation and may have a say in the cost and profit sharing arrangements due to the risk it assumes.

- The co-operation company may be one who contributes to the development and has partial ownership of the results, for instance, a right to utilise them in a place other than the primary business market.

In addition to these actors other co-operators may exist, but this depends on what parties are to be involved. Based on their capabilities, interests and network positions, each of the alliance members may also have more than one of the aforementioned or other relevant roles. There may also be changes in roles and in the composition of the development consortia during the process.

Also incentive arrangements and key performance indicators are likely to be case specific. It cannot be anticipated whether time to market, public image, production or maintenance cost, service reliability, or something else is a key in general. The unique customer value is created by different means in different cases. Suitability to product mix, extension of applicability, scalability or positive/negative externalities may also be of importance in some cases.

3.2.6 Joint process of a BDA

Although the BDA process is not similar in all applications, key phases are in line with the general innovation process from the fuzzy-front end of opportunity identification to commercialisation (Paasi et al., 2012). Arguments can be found that suggest the following four phases are distinguished in the process in accordance with the outline of Figure 3:

- **Briefing**: Identified market potential for innovation is the starting point for briefing which covers the necessary first informal steps to start formal co-operation. Key players from the viewpoint of application are to be found if the team is not in existence due the preceding joint R&D, for instance. The aim is to identify and agree on the customer needs, potential technological solution and a business concept. On those bases the team estimates the resources needed and determine a budget in order to be able to decide whether to enter in a formal co-creation process or give up the idea.
- **Design**: In the design phase it is a question of focussed work for the advancement of the preliminary plan or business concept to a more concrete business model under the guidance of a formal contract and agreed finances. Yet, it does not cover all the development, but the necessary amount of work needed to determine what should be done in order to be able to start the business (regarding opportunities, development needs, interest groups, markets, etc.). When this has been done the parties are able to plan appropriate risk sharing and incentives for the subsequent phases and decide whether to start the development phase or kill the work.
- **Development**: A major part of the co-creation for business is likely to be done in the development phase including the concretization of customer benefits, creation of market, and development and design of the service. In addition to the actual business solution the work should result in a plan of operationalization, i.e. a business plan. In this phase, transparency of cost

and other information and joint decision making are common to the preceding design phase, but now the joint risk bearing, target cost practice and related incentives/penalty clauses determined in the design phase are in use. Eventually it is time to decide whether to step into the business.

- **Business**: The launch of a business is the target of the entire process and it is the way to seize the benefits from the preceding co-creation investment. The commercialiser is in a key position in the business phase while the developer, for instance, steps aside. The developer is, however, involved as a joint business owner in accordance with the joint risk-bearing principles agreed on in the earlier phases of the process; they extend to the business phase. Naturally, this is the case only for a certain, pre-agreed time span as appropriate. Yet, the collaborators may, of course, decide to start a new co-creation cycle according to the described process.

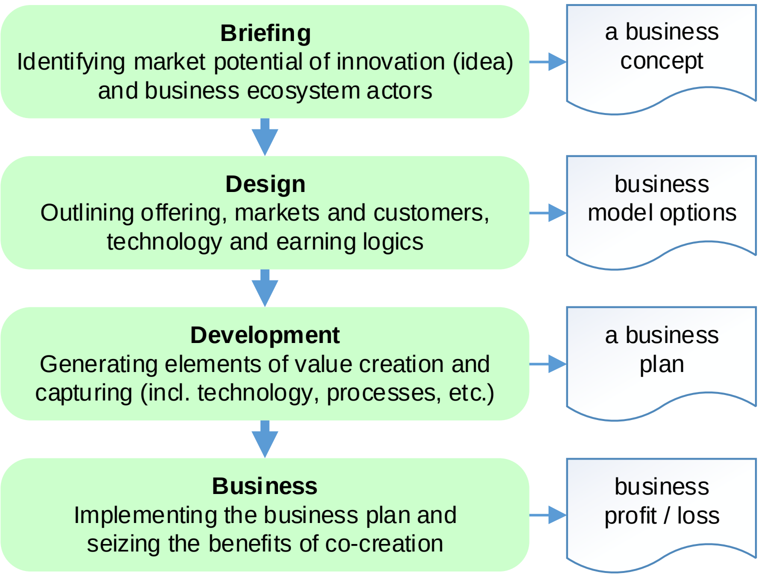

Figure 3. Phases of a BDA process and their main outcomes.

3.2.7 Conclusions

In this paper the potential for project alliancing for the creation and development of new business is discussed. It is suggested that the presented concept of Business Development Alliance (BDA) would offer a productive solution for cases where the impact of multiple parties is needed for the business creation, the targeted business is highly attractive and rewarding, but the development phase is demanding and includes high risk. Conventional principal-contractor assignments are not likely to provide optimal results while a joint enterprise may not be of interest to development organisations, for instance. The BDA is aimed at filling the gap between the extremes by providing a virtual enterprise by contract as appropriate in each case.

Benefits of the collaborative practices of alliancing have been proved in many challenging investment projects. The concept of alliancing is ready to be piloted in a new field: in business development.

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3.3 VTT Model of Digimaturity

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Digitalisation is today a common buzzword. Business directors are struggling to comprehend what it will mean for their industries. The only certain fact is that digitalisation is coming whether you are ready or not. The generic VTT Model of Digimaturity helps in understanding and structuring the concept of digitalisation. Additionally, it gives an estimate of organisations' current capabilities and maturity as well as general directions toward a desired maturity level. The VTT Digimaturity web tool can be found here: http://digimaturity.vtt.fi

3.3.1 Introduction

Digitalisation is recognised as one of the major trends that will change society and business in the near future. It is said to disrupt businesses, but some people say that it is same old thing with a new name. However, the concept of digitalisation is unclear and often vaguely defined. Nevertheless, it is sure that the scale and complexity of digital technology-based changes in business is on a new level, and we have only seen traces of it so far. Spotify and Netflix are examples of digitalisation-enabled new business models, more recent ones being Uber and AirBnB. Digitalisation has also changed the business models in the manufacturing industry, e.g. Xerox's pay-per-copy model for selling office equipment and Michelin's fleet management solution for selling truck tires per kilometre driven.

Organisations try to comprehend what digitalisation means for them, and what actions they should take in order to prepare for the digitalised future. For example, while existing processes can be made more efficient using new technologies, digitalisation also opens the door for innovative business models, many of which involve services in addition to product-based business, or even instead of it. Thus, most companies have found that challenging because digitalisation affects so many objects: besides information technology, also strategy and business model, products and services, internal and external processes, organisation and culture of a company, etc. It is no wonder that directors and managers may ask where they should direct their digitalisation actions and how in order to spend their resources effectively? The topmost question should be how to make a profitable business in a world where digitalisation is one of the greatest megatrends?

VTT has developed a web tool to help directors and managers in digitalisation efforts of organisations. The tool will guide managers to consider all dimensions that are important in digitalisation, to support development actions in the organizations, and to make benchmarking to other organisations: in short, to assess the digital maturity of an organisation.

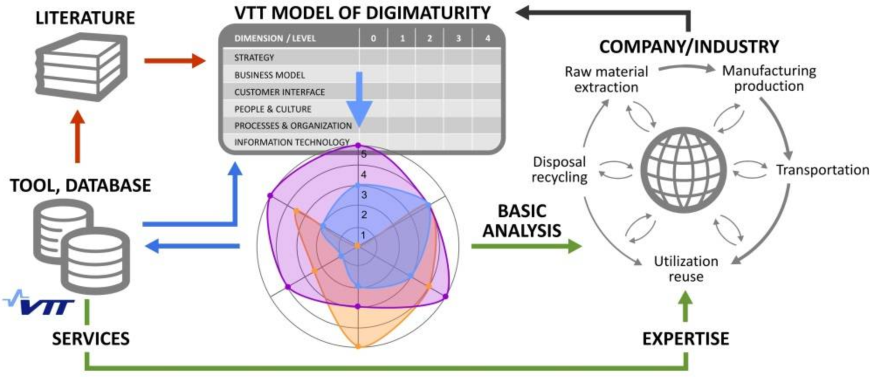

Figure 1. Research approach and purpose of the digitalisation maturity model.

The VTT Model of Digimaturity (VMoD) has several purposes, manifestations, functionalities and benefits. Firstly, the VMoD can be used as a free-of-charge self-service web tool, which produces a basic analysis for a company. It gives a baseline of current digitalisation capabilities and maturities in six main dimensions which can be used for recognising the most important and urgent development targets depending on nature of the business and size of the company. It also helps in understanding and structuring the ambiguous concept of digitalisation. Ideally, especially in larger companies, persons from several functions such as engineering design, production, sales, marketing, service, IT, management, etc., and several organisation levels, e.g. senior management, mid-management, officers, blue-collars would fill-in the web tool questionnaire in order to get different perspectives of maturity and digitalisation. In the long run the VMoD web tool will produce data for a VTT database that can be used in order to compare, for instance, different companies in the same industries, same size, same location, etc. From the scientific perspective, the digimaturity model produces data and knowledge that contributes to a body of knowledge related to many disciplines.

The baseline of digital maturity is a valuable piece of knowledge for the decision makers and digitalisation leaders in companies. However, further understanding and concretisation is required in order to allocate the development resources and activities so that the best possible impact and value can be created. This concretisation phase may depend on industry domain. Thus, a generic model is probably not suitable, but extended digimaturity models for different target areas are needed as well as industry- and technology-specific expertise. VTT offers, in addition to technology development and competences, services such as roadmapping, business modelling, training, benchmarking, and process modelling, and definition of digitalisation prerequisites for companies in order to help them in the journey of digitalisation. Furthermore, VTT has developed a model for tackling digital transformation in a company; introduced in Parviainen et al. (2017). The developed Digimaturity VMoD web tool is beneficial when positioning the company towards digitalisation.

3.3.2 Research framework

In the context of the VTT Model of Digimaturity, the definition of Sommarberg (2016) for the concept of digitalisation is suitable: "The use of digital technologies to create value for a firm". Furthermore, the concept of disruption is often connected to digitalisation and according to Sommarberg (2016) it can be defined as "the paradigm change in rules concerning how value is created in business". Thus, the digitalisation is fundamentally much more than digital technology. It is connected to digital transformation towards new business models, new revenues, new value creation that requires new organisation designs, processes, culture, risk tolerance and essentially good leadership. According to Tihinen and Kääriäinen (2016*) digital transformation is defined as a change to models of working, roles and business offerings, occasioned by the adoption of digital technologies by an organisation or its operating environment*. This refers to changes at process, organisational, business and societal levels*. It involves a change in leadership, different thinking, the encouragement of innovation and new business models, the incorporation of digitisation of assets and an increased use of technology to improve the experience of the organisation's employees, customers, suppliers, partners and stakeholders.* From the technical perspective, digitalisation utilises the processes of changing analogical data into a digital form (Sommarberg, 2016), but it does not mean just converting existing data into digital form, but creating new processes as well.

Concerning digitalisation, the notion of maturity means two slightly different things. Firstly, it refers to organisation readiness for digitalisation. It means an organisation's capability, willingness (mindset) to change its function, processes, organisation and capability to effectively adopt new technology. Secondly, maturity refers to an organisation's performance based on digital technology. Therefore, digimaturity is built as a systemic combination of business, technology and socio-technical totality. The balance between development of business and information technology is essential.

Maturity models have a long history and many models can be found in the literature directed to various topics. Recently, for example, several maturity models have been proposed in the area of Business Process Management (Tarhan et al., 2016) and PLM implementations (Silventoinen et al., 2013). However, based on our literature survey, maturity models with the proposed wide digitalisation scope being tightly linked to business perspective are lacking.

The research approach was constructive and iterative. The created Digimaturity model is a synthesis of literature and empirical experiences from industry (see Figure 1). For a start, concepts and models were drawn from the literature and synthesised as the six main dimensions introduced in the following table (Table 1):

Table 1. Main dimensions of VTT's Digimaturity model.

Dimension	Description
Strategy	A strategy is an organisation's plan for pursuing its mission and achieving objectives.
Business model	A business model is an architectural-level description of an organisation and its business functions: it describes the value proposition, key customer segments, way to reach customers and manage customer relationships, define key functions and resources needed to implement them, to identify key partners, to understand the cost structure and to determine the earnings logic.
Customer interface	A customer interface refers to those activities in which we are dealing with a customer, such as: marketing, sales, delivery, customer service.
Organisation and processes	The traditional structure diagram of the organisation describes the tasks of the members of the organization, division of labour, and reporting relationships. Processes consist of a series of operations related to each other or that are interactive. Each operation involves the tasks, roles, responsibilities, timelines and deliverables. In digitalisation, processes are primarily concerned with the processing of information and data in digital form.
People and culture	The term people refers to human resources: people are understood as either an individual or a group, which affects the performance of the organisation. Culture refers to the importance of the attitudes and behaviour for the organisation's performance.
Information technology	Information technology (IT) broadly refers to digital editing, transmission, storage, searching and presentation of data or information. IT covers the use of any computers, storage, networking and other physical devices, infrastructure and processes to create, process, store, secure and exchange all forms of digital data.

After dimensions setting, the maturity levels were defined and described as claims on the tool. The evaluation of the developed model was done iteratively with a pilot version of the tool. The model was first discussed internally in workshops at VTT. Then it was introduced to selected companies in order to get external feedback before releasing the public web tool. The process is continuous and iterative, i.e. the model will be fine-tuned based on the feedback from users.

3.3.3 VTT Model of Digimaturity

The web tool was developed for a self-assessment tool for organisations; the gathered information is saved on the database for further research and benchmarking purposes. The tool includes the steps of registration, self-assessment data entry and the result diagram display with their own and reference data.

The input includes 4–5 questions of each of the six dimensions, mostly one basic question about the dimension and the rest focusing on digitalisation of the dimension viewpoint. The self-assessment is done by selecting the most suitable option of the presented alternatives. The result diagram shows an organisation's own data and reference values. The results diagram includes also a comparison to all companies in the database. VTT can also make more thorough comparisons based on branch, turnover or personnel.

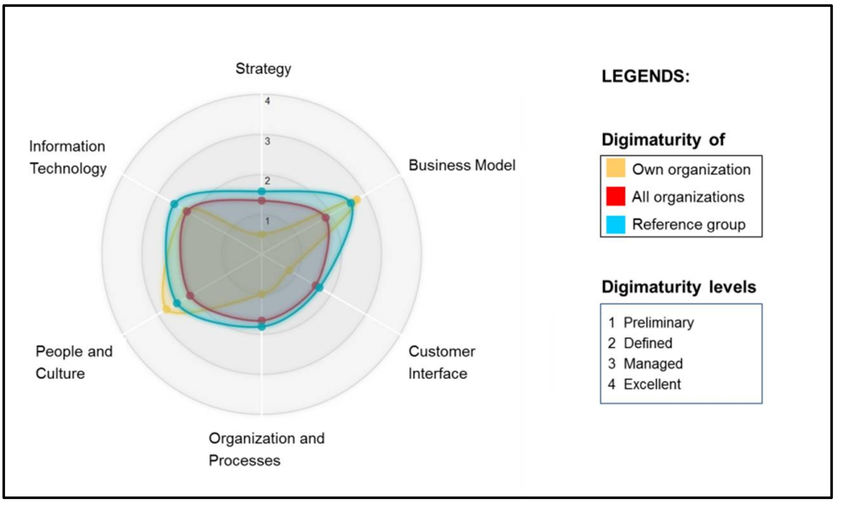

Figure 2. The result diagram of the VTT Digimaturity web tool. The diagram shows digital maturity of the organisation and reference values of all organisations or a selected reference group (based on branch, turnover and number of employees).

During the development phase, new ways for usage were invented. The tool can also be used as a baseline for common understanding of the digitalisation level in an organisation. When starting a digitalisation project, people from different functions should fill-in their views, and then especially potential differences can be discussed and common views formed as a baseline for development actions.

This also creates a need for defining and/or developing the system as benchmarking database data could then include several inputs from one company, i.e. a benchmarking database and workshop tool should then be separated.

The tool was first tested and commented on within VTT, which led to many modifications mainly to the formulations to make them more understandable and less ambiguous. In the second phase, feedback was asked from a few selected organizations. The overall feedback so far has been good; there is need for such a tool and the dimensions and questions were stated to be clear and relevant.

3.3.4 Conclusions

Companies need to clarify what digitalisation means in their business, and to understand how they should proceed in the journey of digitalisation. The VMoD tool can be used to analyse the current maturity status in respect to readiness and performance based on information technology. The maturity is assessed in six main dimensions including strategy, business model, customer interface, processes & organisation, people & culture, and information technology. As information technology is just one of the six dimensions, VMoD emphasises how new value is created, what kind of business models are needed, and how they transform the processes, organisations, culture, etc. The VMoD is manifested as a web-based tool which gives a visual estimation of a company's maturity based on answers given to questions related to the six dimensions. Besides the web tool, an extended maturity model, together with expert knowledge, will support development work in companies. Possible expert services include, for instance, roadmapping, business modelling and process design. Companies can also compare and benchmark their maturity with other companies, for instance, in the same industry. The VMoD enables companies to quickly perceive their baseline situation as well as their strength and weakness areas. It is important to realize that capabilities of digitalisation must be built on top of basic enablers, and the development must be balanced between business demands and technology enablers. In future work the model will be iteratively developed based on the experiences and feedback from companies concerning, for instance, understandability of the concepts, terminology and questions, possibly missing aspects of the model, etc. The model will also be discussed in the scientific community and compared to the success of other maturity models.

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3.4 Successful business at Finnish manufacturing companies beyond 2020 – Four scenarios

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The target of the work was to develop scenarios for future ways of doing successful business in Finnish manufacturing SME companies. The scenario and business model work was done in a participatory foresight process. Four scenarios and potential business models in the contexts of these scenario worlds were created together with companies and researchers.

3.4.1 Introduction

The manufacturing industry has, in a global sense, enjoyed a long era of growth. It has provided the machinery, tools, and materials to build modern infrastructures, transportation and housing. It has produced goods to help the daily life of citizens, etc. Manufacturing has always also included a range of activities in addition to production, such as different kinds of services.

Over the past decades, the manufacturing ecosystem has globalised. Design, sourcing of materials and components, and the manufacturing of products takes place more and more often in global value chains. Also, markets for the products have become global. As a result of the globalisation and growth, people around the world are used to considering global growth as a self-evident scenario of the future. Most foresight reports that consider the future of manufacturing take global operations and the continuation of economic growth as the starting point of their future studies without considering alternative scenarios. At the same time, however, a series of changes in the environment creates uncertainty: consequences of climate change, large catastrophic events, wars, etc. What if global growth will not be the driver in the manufacturing industry in the next decade(s)?

From a technology standpoint, we are, in all likelihood, currently at the centre of the fastest revolution that the industrialised world has even seen: the digital revolution. Digitalisation will to some extent shape all activities within societies. In the manufacturing industry, it means new ways to design products and manufacturing, operationalising manufacturing, new forms of intelligence (such as big data and the Internet of things), etc. Digitalisation also will affect the business processes of the industry. We foresee drastic changes in the logistic business value chain from a manufacturer to end-users and consumers. eBusiness is already here. What else will come?

What has been written above suggests that we should be prepared for the future and potential, even with radical changes in the business environment. In the manufacturing industry, we have been used to fairly slow changes in technologies and markets, but that situation may change. We may well foresee disruptive changes both in technologies and markets as well as material and workforce resources within the next few years. Foresight and scenario work will help in this development.

3.4.2 Method for scenario and business model building

The target of the work was to develop scenarios for future ways of doing successful business at Finnish manufacturing companies. A special emphasis was given to SMEs. The target year of scenarios was set to 2025. Questions that guided the work were: What will the potential radical changes be? Which kind of business models would create success? What will the future markets be for Finnish manufacturing SMEs? What kinds of products will probably be needed?

The scenario work was conducted in 2015 by using the methodology of participatory foresight. The foresight process was divided into five phases:

1) Literature study and identification of key factors
2) Generation of four future worlds
3) Identification of business models into the future worlds
4) Analysis of generated data
5) Reporting the scenarios

In Phase 1, recent foreign and domestic foresight reports for the manufacturing industry were studied and key factors of the sector were identified and analysed. In Phase 2, four scenario preforms for alternative futures were generated, based on the results of Phase 1. These scenario preforms were further developed in Phase 3 by identifying potential business models in the four different future worlds. The scenarios preformed were completed in Phase 4, where the generated data was analysed. The analysis is reported in Paasi and Wessberg (2015), which expresses Phase 5.

In order to tackle successful business expectations in the future, we created potential success business models for each scenario. In the sketching of the business models, we focused on four aspects:

1. What is the offering?
2. What are target markets/customers, i.e. to whom?
3. What are required capabilities to produce the offering, i.e. how/with whom?
4. What is the earning logic in the business model (i.e. how to earn money?)

In total, 37 persons were involved in this future study, of which 11 were representatives of manufacturing SMEs (entrepreneurs, CEOs, other executives). SME involvement was particularly strong in Phase 3, Identification of business models in the future worlds, where the SME representatives actually drove the work with researchers being in facilitating and supporting roles. Consequently, the business environment analysis and business opportunity identification in the scenarios of the work are rooted in the viewpoints of SME entrepreneurs and CEOs in the manufacturing industry.

3.4.3 Four scenarios and successful business models

In this For Industry scenario work, we searched for identifiable key factors shaping the future (see Chapter 3.1 of this report for more details), where such factors, scenario coordinates, can be used to create alternative scenarios with a broad, but still realistic, scope. We fashioned these results into two word-pairs: global – local and growth – scarcity. The word-pairs conform our four scenarios in a four-fold picture: Global-growth, Local-Growth, Global-scarcity and Local-scarcity (Figure 1).

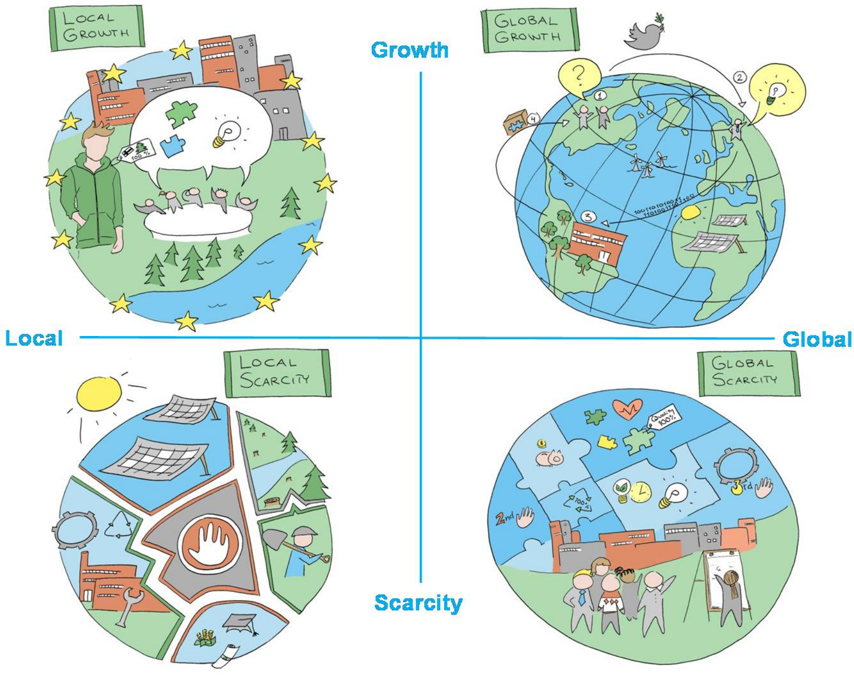

Figure 1. Four future worlds of For Industry scenarios and characteristics of the scenarios.

The global scenarios describe future worlds of free trade where value chains are global and competition is extremely strong. Manufacturing SMEs can be successful in highly specialised (niche) markets. Service or some kind of guarantee-based pricing model may form the dominant earning logic in the markets.

In *the local scenarios*, Northern Europe or the EU form the business area for Finnish SMEs. The difference between the local growth and scarcity worlds is that in local growth, local business is voluntarily driven by customer preferences while in local scarcity it is more or less forced due to borders between countries or unions. Replacement of imports is an important business driver for manufacturing companies in the local scenarios.

In *the growth scenarios*, business is driven by economic growth and the good buying power of consumers. The focus of business is on specialised customer needs. Innovations and high levels of technological competence are important factors of success.

In *the scarcity scenarios*, scarcity of some critical raw materials and components is the key driver of business. In global scarcity, raw materials would be available but they are very expensive. In local scarcity, manufacturing suffers from restrictions of raw material import. The use of local materials is important in the scarcity scenarios.

In the future world of *global growth*, competition is worldwide and hard. There are many customers around the world with good buying power and the markets are growing in a global sense. The world of the scenario is highly digitalised. Information is moving fast around the world through digital media, as well as the customers and the workforce – value chains of the production and the markets are truly global.

The future world of *local growth* represents a world where key drivers of change towards the future world include ethical and environmental production problems for many countries in Asia, Africa and South America, low-quality products manufactured outside the EU, and increasing protectionism in different parts of the world. These factors will cause people in Europe to tire of globalisation challenges. Another driving factor is the increasing trend of very local products, such as organic food from neighbouring farmers.

Business success factors for SMEs in the world of *global scarcity* include the efficient use of resources, including material and energy efficiency, and Finnish natural raw materials. The circular economy is a key word for success. Digitalisation should support the efficient use of resources. Finnish companies should also focus on exporting high value-added products, made from local raw materials, to global markets. The scarcity of a skilled workforce and the high mobility of employees create major challenges; In order to be successful, the companies must find ways to keep their critical employees satisfied so that they will stay with the company.

The scarcity of a skilled workforce creates a significant challenge for Finnish manufacturing companies also in the world of *local scarcity.* Substitution of imports creates opportunities, for example, for repair, remanufacturing, and re-engineering businesses. There is also a significant need to manufacture commodities that were manufactured in Finland a long time ago, but whose production was gradually moved to Asia in the 1980's–2000's. The world of local scarcity clearly addresses versatility instead of deep specialisation.

All of the described four scenario worlds and the business success factors in them would offer potential for Finnish manufacturing SMEs to conduct successful business, but the models of successful business may differ. In the process we created business models that may work in the various specified scenario worlds. The successful business models in the scenarios have some scenario-specific, characteristic, main features. Examples of these are given in Figure 2.

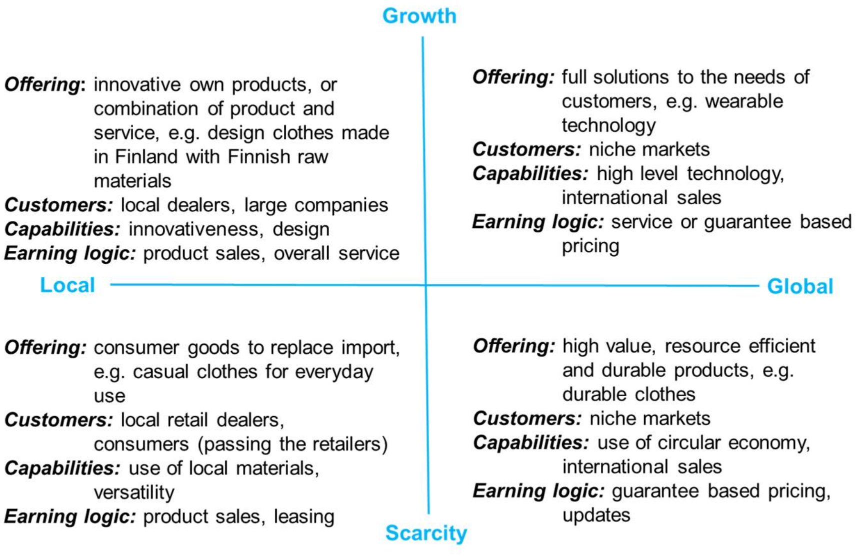

Figure 2. Characteristic features of SME business models in the scenarios.

For the global – growth scenario, we chose *Optimisation of use* as an example of a business model that can work well. The offering in this business model consists of a turnkey solution for a complex production system combined with system maintenance service. The competitive advantage in the offering comes from the knowledge of how to optimise production system use. Consequently, earnings come according to productive operation hours. In order to be competitive in global markets, the offering must be well focused on highly specialised production systems.

Wellbeing has been chosen as an example business model for the local – growth scenario world. Here, wellbeing means a symbiosis of wellbeing services and manufacturing industries where the actual offering may consist of automation-assisted wellbeing services, diagnostics services, health data management, etc. The business success is based on the notions that people are starting to spend their money on wellbeing services after their basic needs have been satisfied – so potential in the growth world.

We describe *modernisation* as an example of a business model in the world of the global – scarcity scenario. Modernisation means the continuation of the life of an investment product (or system). The actual offering may mean a variety of things: automation of manual machines, updating the functionality of the product, updating parts or materials of the product, etc. The earning logic of modernisation may challenge the service provider (SME) as customers may increasingly want some kind of guarantee-based pricing principle (i.e. pricing connected with the guarantee of performance).

In the example of a business model in the scenario world, local – scarcity, we focus on the replacement of imports and present the business model, *Consumer Products Made in Finland*. The offering in the business model covers goods for daily life, such as clothes, shoes, household appliances, hand tools, bikes, etc. These are goods that are more or less essentials for consumers and that used to be imported from abroad (mainly from Asia) during the global business period. In the scenario of local scarcity, these goods must be manufactured locally, for local markets and by using locally available materials.

3.4.4 Conclusions

The study represents four future scenarios characterised by combinations of the word pairs, global – local and growth – scarcity. It may well be that none of the scenarios will happen as they are described in this work. But, the future may well be some kind of a combination of these scenario worlds. In other words, all the scenarios include at some points the elements that will take place in the future.

We have made no predications as to the most likely scenario. Such speculation does not belong in a study where the aim is to expand the mind-set of readers when considering alternative scenarios of the future. However, all four scenarios purposely include a couple of features that may be quite unlikely to happen. There are also some features in all of the scenario worlds that are likely to occur in Finland.

The target year of the scenarios in this work was 2025, but it may well be that the transition from the current regime to a new one will be a short and abrupt process over a few years or, alternatively, it will be a much slower process than is reported here.

Finally, scenarios and potential business models clearly indicate that it will be possible for a manufacturing Finnish SME to conduct successful business in each of the potential future worlds. The business models for successful business may however differ. A company may incorporate the For Industry scenario work into its own strategy work and prepare company-tailored alternative future scenarios and business models suitable for these scenarios. It is important to take a closer look at the similarities and differences in the scenarios from a business perspective, and in that way be prepared for the changes in the future as well as be proactive towards future potential.

3.4.5 References

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4. Digital Engineering

4.1 Digital engineering and agile manufacturing as future enablers

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The ongoing hype in digitalisation has also increased interest in digital engineering and design from the whole product lifecycle point of view. Combined with new additive manufacturing methods and progress in material engineering, digital engineering provides new and interesting technological and business opportunities. Three topics, Computational material engineering, Computational product engineering and Agile manufacturing, were the essential core of the Digital Engineering module in the For Industry research programme.

4.1.1 Introduction

Digitalisation of product process has been going on for decades, especially in engineering and design. Computer-aided design (CAD), computer-aided manufacturing (CAM) and computer-aided engineering (CAE) have been applied in industry since the 1970s, and they are familiar tools for most companies in the mechanical engineering sector. Digital design and engineering are experiencing a renaissance in conjunction with the ongoing hype in digitalisation. The concept of digitalisation is much wider than the concept of digital engineering. On the one hand, digitalisation benefits from digital engineering by having the means to efficiently design and implement complex systems and products and, on the other hand, digitalisation provides new motivation and technologies for digital engineering, such as cloud-based computing and utilisation of digital sensor data. At the same time, rapid progress in manufacturing technology and the emergence of metallic additive manufacturing have altered the balance of the mechanical engineering domain and of business. The dynamics of the design and manufacturing domain have been redefined by globally distributed manufacturing, increased geometrical design freedom and a drastically altered ratio between series size and cost. All this has put pressure on traditional industry and its ways of doing business, and at the same time has provided new business opportunities.

The Digital Engineering module in VTT's For Industry programme selected three main focuses for its research (Figure 1):

- computational material engineering
- computational product engineering
- agile manufacturing

The selection was based on previous progress of research in the selected topics and on the potential added value of combining existing research topics in order to gain something that is greater than the sum of the components.

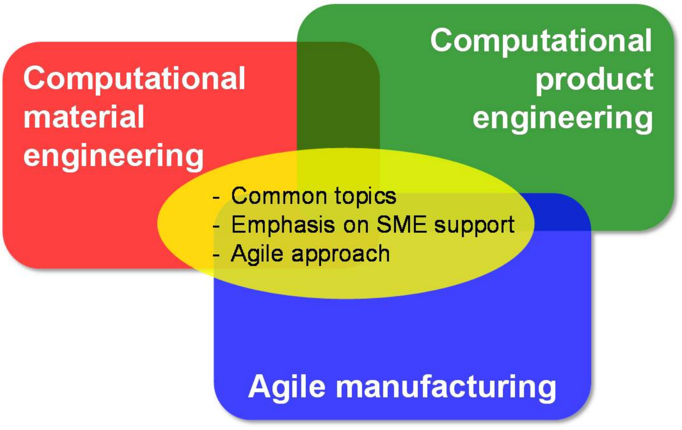

Figure 1. The selected three research focuses of the Digital Engineering module and how they are linked with each other.

The theme of *computational material engineering* emphasised research in integrated computational material engineering (ICME) and especially application of multiscale materials modelling. The work focused on studying, developing and applying methods and computational tools for tackling computational material research from the microstructure level up to continuum mechanics used in machine design.

In *computational product engineering*, the main focus was in utilising topology optimisation in design process, and in computational method development. The work was related to additive manufacturing and material design, thus providing a bridge between the other topics in the programme module. The term computational product engineering enables the scope to be wider than e.g. computational engineering, which is usually perceived as a part of product development. Computational product engineering refers to a holistic view to the whole product lifecycle, and can thus include e.g. aspects of product use and maintenance.

Additive manufacturing (AM) is defined as a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. It is grouped into seven process categories. The term 3D printing is nowadays considered as a synonym for AM, even though earlier it was associated with low end machines (ISO/DIS 17296-1). The *agile manufacturing* theme focused on additive manufacturing (AM) of metallic parts, including materials, 3D printing processes and design for AM. The research scope was extended to hybrid manufacturing processes, due to the fact that most of the parts manufactured with AM require machining and other finishing procedures.

The selected three focuses emphasised the beginning of the product lifecycle, but took the whole product lifecycle into account (Figure 2). This was in order to keep in mind the fact that a remarkable share of the mechanical engineering business comes from the later phases of the product lifecycle and must be taken into account in engineering and design of new products and systems.

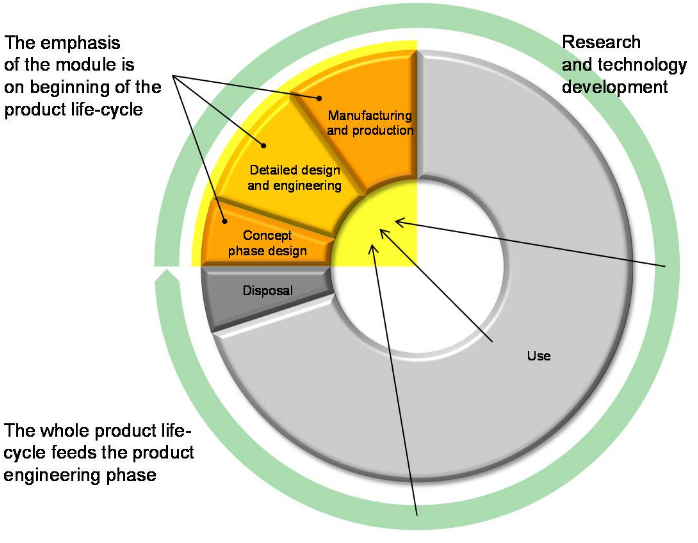

Figure 2. The emphasis and scope of the selected three focuses in the Digital Engineering module is on early stages of a product's lifecycle

In the beginning of the For Industry programme, the Digital Engineering module defined its targets as follows:

1. Collect existing knowledge and know-how about the selected focuses and share it, both inside VTT and outside.
2. Define and disseminate the added value of the combined module main focuses.
3. Define VTT's strategy for the module's focuses and activate research on the selected topics.

4. Increase R&D activities for business in the selected topics in Finland.

As the programme was active for only two years, some of the defined targets could not be implemented.

4.1.2 Current status

The selected three research focuses for the Digital Engineering programme module have quite different technology maturity statuses. In computational material engineering and additive manufacturing, progress in method and technology development is rapid and the domains are evolving quickly. On the other hand, computational product engineering and especially simulation-based engineering and design are relatively mature and have a rich palette of methods and computational tools. The ongoing digitalisation hype has activated all these domains and accelerated research and development at all levels.

The research in the Digital Engineering module had a wide background from the beginning of the programme (Figure 3). The selected three focuses, i.e. computational material engineering, computational product engineering and agile manufacturing had a relatively long research history of their own, and the main objective of the module was to create new research knowledge by combining the topics.

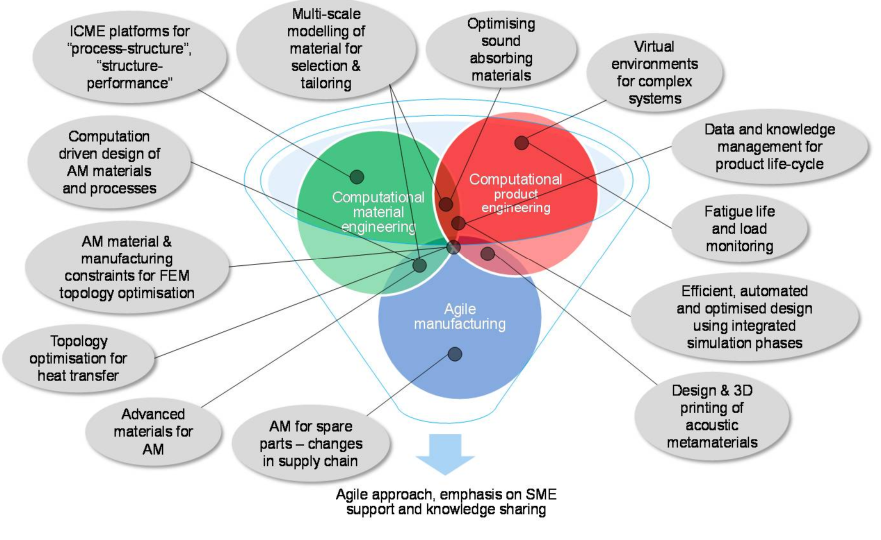

Figure 3. Research subtopics for the selected focuses in the Digital Engineering module.

4.1.2.1 Computational material engineering

ICME frameworks are typically extensive computational platforms, e.g. a large jointly funded research project can focus solely on introducing an ICME solution to a particular subject and problem area. A top-level example is presented in Figure 4, as provided by the Minerals, Metals and Materials Society (TMS) in a recent overview of ICME implementation case studies. It is noteworthy that the framework contains multiple elements linked primarily to the overall design process, and e.g. the material elements themselves are not readily visible. Implementations of ICME on a grander scale can be viewed as design-oriented ecosystems, also encompassing features from product design, in which solving the materials-affiliated problems assumes a central role. The material centric dashed region is further elaborated in Figure 5. These aspects typically contain in one form or another a solution to the Process-Structure-Properties-Performance (PSPP) problem or a subset of it. The overall complexity of PSPP problems is of such a high degree that applications of ICME commonly focus on deploying such a solution for a particular problem area and industrial need.

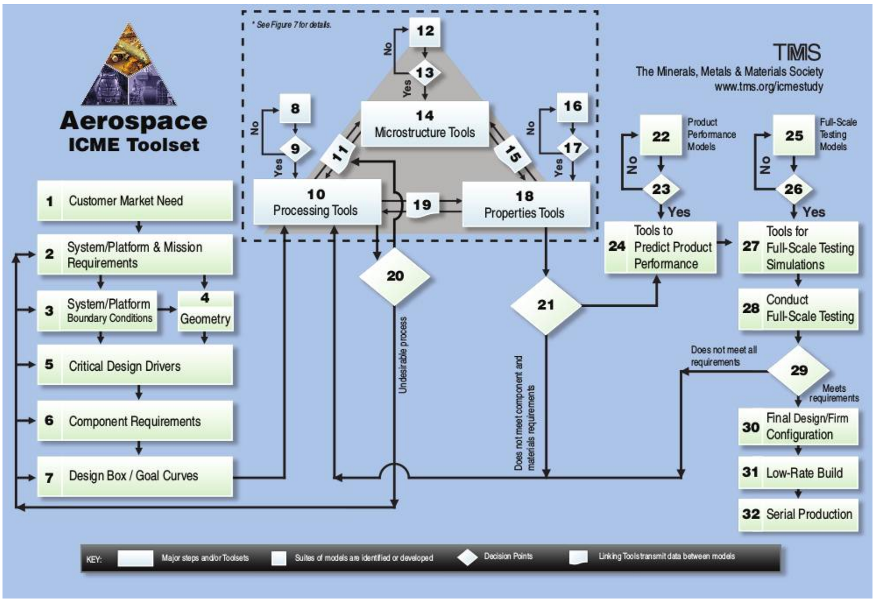

Figure 4. Example an ICME toolset for aerospace applications (TMS, 2014).

Multiscale material modelling is one of the pearls of VTT. After about fifteen years of strong focus on this topic, VTT is already near the top of the field globally, considering our research spearheads. The concrete embodiment of the ICME research and development at VTT is the ProperTune™ platform. This is internationally recognised and contains better tools than most of its competitors, some of them being the best in the world. VTT ProperTune™ and its service offering acts as the dissemination and exploitation channel for the ICME research and development work. VTT is constantly developing the package by adding new capabilities and incorporating modelling solutions for new materials and phenomena. The ICME project portfolio contains and has contained numerous customer and jointly funded projects as well as some internal projects in the field, which have all played a significant role in the development of VTT's ICME capabilities.

4.1.2.2 Computational product engineering

The domain of computational product engineering is relatively mature when it comes to the supply of computational methods and software applications for different purposes. Within computational engineering, there exist various methods such as the finite element method (FEM), discrete element method (DEM), computational fluid dynamics (CFD), multibody system (MBS) simulation and statistical energy analysis (SEA). For these, there are several software tools available for each method, utilising both commercial and open source software. In addition to modelling and simulation tools, there are several computer-aided engineering (CAE) environments that integrate different design, modelling and simulation methods and tools into a single framework. The trend appears to be towards larger integrated environments and, on the other hand, towards having progressively more simulation features included in CAD environments.

The role of optimisation in computational engineering is growing. This is due to the progress in optimisation methods, computational tools as well as in computing technology. Cloud computing provides an attractive alternative for making extensive computational resources available when required. The challenges with cloud computing are still e.g. lack of experience in using it and, to some extent, trust in data security when strategic product data is sent outside the corporate intranet.

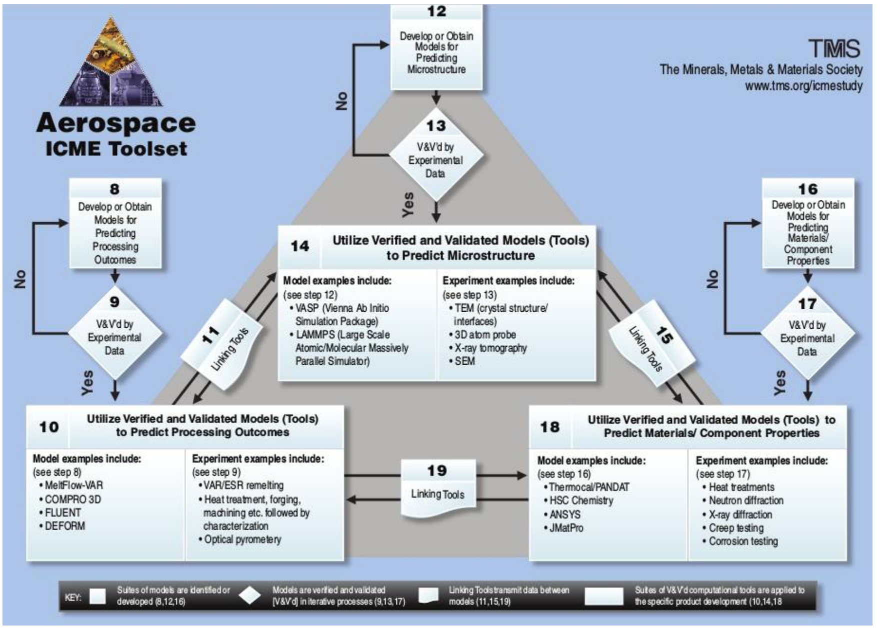

Figure 5. Example of ICME material design models, experiments and data for aerospace applications (TMS, 2014).

The importance of the engineering and design process itself and how computational tools are used within it is increasing. As the efficiency of computational tools increases, the bottleneck of utilising them in the process and especially of utilising the produced results is emphasised.

A research project funded by Tekes – the Finnish Funding Agency for Innovation, *Computational methods in mechanical engineering product development – SIMPRO* (Kortelainen, 2015), focused on developing the utilisation of computational methods and tools in different phases of a product's lifecycle.

4.1.2.3 Agile manufacturing

The global market size of primary additive manufacturing was 5.1 billion dollars in 2015, and the annual growth rate has been approximately 30%. The biggest growth rate was in direct manufacturing, where it was 66% in 2013–1014. Both public and private stakeholders are making large investments globally in AM research, and the technologies are developing rapidly. (Wohlers, 2015/2016)

The main focus in utilisation of AM has been in polymer-based processes, but currently metallic AM is growing more quickly. Market consolidation, which has been visible in polymer-based systems during the last couple of years, has also recently started in the metal AM sector. Because the costs of manufacturing are still relatively high in the case of metal AM, the focus in material development has been in materials which on the one hand are used for very high value components (e.g. titanium), or on the other hand have high market volume (such as steel alloys).

On the national scene, industrial interest in AM is growing, both among end-users and potential subcontractors. It can be expected that within one or two years, commercial service providers will enter the metallic AM market. We have already seen the first developments in this field.

VTT´s AM offering focuses especially on metals, particularly on the powder bed laser melting process. In this sector, VTT's expertise and facilities cover the whole chain of AM, starting from material development, through component design and the AM process, and ending with post processing and component performance validation. VTT is able to cover the whole chain both experimentally and digitally (i.e. modelling and simulation), thus summarising quite nicely the topics within the For Industry programme Digital Engineering module.

4.1.3 Review of main results

The research related to the Digital Engineering module focuses was implemented in several research projects, funded either jointly by several parties or by VTT. One of the major highlights of the module work was the increased research activity and co-operation in combined research themes, such as:

- Computational material engineering and computational product engineering: development of a method to model and compute the material microstructure parameters for acoustic simulation
- Computational material engineering and additive manufacturing: initiation of the research and development of new powder materials for metallic 3D printing (Komi, 2016)
- Computational product engineering and additive manufacturing: application of topology optimisation in the design process for additive manufacturing (Komi, 2016)
- Computational product engineering and additive manufacturing: Collection of concrete design guidelines for the design for additive manufacturing (Kokkonen et al., 2016)

The research activity related to the module research focuses significantly increased VTT's concrete know-how in additive manufacturing, design for AM and related material engineering. It also networked the researchers, both within VTT and also nationally and internationally. One of the major highlights in networking and research dissemination was the organisation of the NAFEMS Nordic seminar *Exploring the Design Freedom of Additive Manufacturing through Simulation*, held in Helsinki on November 22–23, 2016.

Some of the research activities in the Digital Engineering module are presented in more detail in the following sections of this chapter.

4.1.4 Future visions

4.1.4.1 Computational material engineering

The rapid increase in computing power has enabled modelling of complex materials and phenomena on the nano-microstructural scale. Concurrent multiscale modelling from the atomic scale all the way to component scale is already on the horizon. VTT is strongly involved in this trend. This will enable the ICME approach of computation-assisted materials development, including material and treatment screening and virtual testing and prototyping.

Over the years, ICME has experienced a number of trends; the term itself was coined around 2007–2008. Initially, starting from around 2000, the focus was on developing solely multiscale modelling technologies. However, after about a decade of work it was noted that successful materials modelling activities are required to include a wider subject area. ICME offers a solution by providing integrated approaches in which computation is coupled with experimental work and management of digital data, which promotes an open and networked approach to working with problem solving. Exploitation of ICME and development of affiliated solutions is a present trend, applying ICME ideas to novel problems and exploiting the toolsets. Another trend describing the developments driven within ICME is described with the concept “modelling across scales” described by a TMS working group on the topic, which highlights the maturing of certain specific modelling approaches and methods in order to obtain multiscale functionality and results in new models. However, large ecosystems still do not exist, and it can be stated that globally only two projects at present are targeting the release of an encompassing ICME solution within the current decade: The Materials Genome Initiative (MGI) programme coordinated by the National Institute of Standards and Technology (NIST) and the Structural Innovation for Materials programme coordinated by Japan Science and Technology Agency (JST). The efforts are internally significant, since the MGI programme has been running on a 100 million dollars per year budget, while the SIP-SI4M annual budget is of the order of 30–50 million dollars during its 5 year run, starting from 2014.

Although the basic structure of the ICME field has now been rather well established, it is still expected that particularly the specific toolsets and modelling solutions will take form towards the end of the current decade. Multiple areas of application still struggle with non-existent or imprecise modelling solutions, and the complexity of the related materials phenomena also drives and necessitates prolonged steps to be undertaken in the development of appropriate and capable modelling solutions. However, certain specific industries and high impact areas of application such as aerospace, defence and automotive, often in unison with novel manufacturing technologies, such as AM, are seen as the forerunners adapting the novel technological solutions and benefiting from the resulting impacts on their materials and products.

4.1.4.2 Computational product engineering

The complexity in concrete products and systems as well as in processes and business is increasing. For example, the ongoing progress in digitalisation is changing technologies rapidly and providing new opportunities, but also causing some challenges. At the same time, the major objectives in product business still apply, i.e. providing better products, getting them more quickly to the markets, and minimising the design and manufacturing costs.

Managing the complexity and utilising the opportunities is an opportunity for success in the markets, and the computational approach has been identified as one of the most important key factors for success. The domain of computational engineering has matured and there exist several tools for all the major engineering needs. In computational engineering itself, the focus is moving towards larger computational studies, efficiently mastering the overall engineering and design process, and taking the whole product lifecycle into account in detailed product development (Figure 6). A concrete example of this development is the increase in the utilisation of mathematical optimisation in design and engineering. When utilised efficiently, optimisation can provide remarkable improvements both in design results and in design time. The overall increase in utilising a computational approach in product design and development will increase the importance of validating the computational methods and tools as well as the processes to which they are applied.

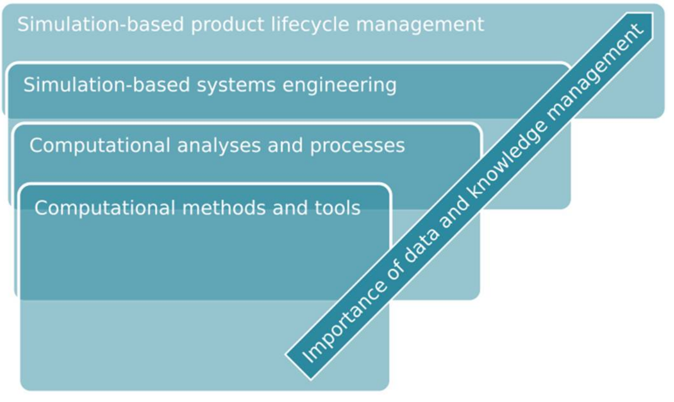

Figure 6. Four different levels of the simulation-based product process (Kortelainen, 2015).

The rapid and steady progress in computer and software technology has made it possible to produce numerical simulation data faster than ever, and the foreseen progress indicates that this trend will continue. This has created a new bottleneck in computational engineering, i.e. how to utilise the produced data. At the same time, the research and development of the Big Data concept has produced new solutions to manage and utilise very large amounts of data. The vision is that the emphasis in computational research and development will move towards automating the analysis of produced computational data. The rapid development in all the necessary areas, such as computer technology, data analysis and machine learning, data and knowledge management, and computational engineering technologies, are supporting this trend.

Gaining the maximum advantage from digital engineering and design requires concurrent progress in computer technologies and infrastructure, computational methods and technologies, and how these are applied in engineering and design, and close co-operation between all the stakeholders of the ecosystem (Figure 7). In a vital ecosystem, all the stakeholders provide added value to each other and have a role in the big picture. As comprehension of the importance of the computational approach increases, as well as the positive influence of a healthy ecosystem around it, these factors will be initiated both in Finland and worldwide. To make this happen requires expertise and knowledge, trust and continuous communication between the stakeholders.

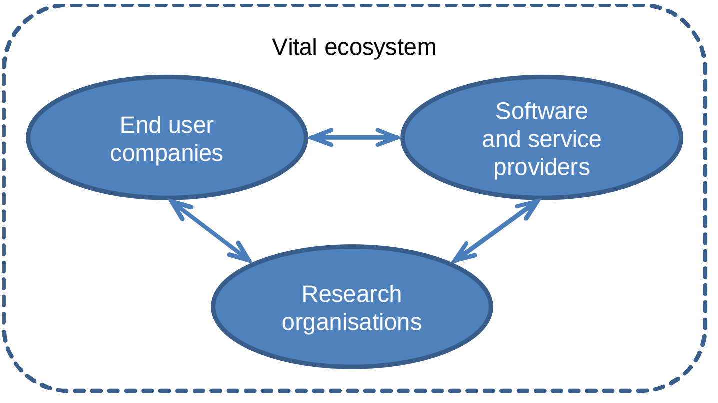

Figure 7. Model of an ecosystem in digital engineering and design.

4.1.4.3 Agile manufacturing

VTT has a strong track record in metal powder technology, developed in the field of e.g. thermal spraying. Based on this competence, development of new metallic AM materials can be accelerated. Currently, the number of metallic powders for AM available in the market is limited. In the field of polymers, development is carried out by several players and the variety of available materials is wider. In both areas, there appears to be room for development of new materials (alloys and composites) with improved properties.

In manufacturing, VTT will focus its investments on metallic AM, and especially on selective laser melting (SLM) based on powder bed fusion technology; most of the available metal AM systems are powder bed fusion processes.

Hybrid machines, in which computer numerical control (CNC) machining and AM are combined, offer new perspectives in manufacturing and the level of interest in industry is high. Nowadays AM technology can also be added to existing CNC machines. This research should be carried out in co-operation with partners.

Another interesting area in hybrid-type manufacturing is combining powder bed fusion and VTT´s direct write technologies (DWTS and DWP) in order to create new, embedded intelligent solutions for parts and components.

4.1.5 Conclusions

The computational approach already provides valuable tools for efficient research, engineering and design. The availability of commercial tools with support services is wide, and end users can select from among several options for a wide variety of engineering and design needs. However, there is a need for further research and development in modelling and simulation methods, computational tools and systems, and overall engineering, design and manufacturing processes. Especially in rapidly evolving areas, such as computational material engineering and design and optimisation for additive manufacturing, the methods and tools are evolving quickly. This makes following the state of the art of this discipline challenging, but for those who are agile to adopt the best practices it provides excellent opportunities for utilising new technologies, not only in products and systems but also in engineering and design.

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4.2 Integrated computational materials engineering for emerging manufacturing technologies

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Emerging manufacturing technologies such as additive manufacturing (AM) provide new freedoms and an enlarged design space with respect to materials, the manufacturing process and geometric part design. The technologies support digital paradigms of design, and synergies between e.g. optimal process and material designs for specific parts are expected to facilitate the development of innovative and competitive products. However, due to the inherent complexities of these emerging manufacturing technologies, even achieving good surface quality and soundness of material can be troublesome for selective laser melting (SLM) of complex parts. In such a case, knowledge of the effect of process parameters on the product properties is needed, information which is best obtained by introducing AM tailored modelling and simulation capabilities and merging their utilization with practical experimental work. Current work presents a case study of a thermomechanical process model and a multiscale modelling concept for simulation of the effect of different process parameters on the SLM build process. SLM machine build files are interfaced to the model for realistic geometries and 1-1 simulation of the manufacturing process. The toolset can be used e.g. in predicting distortions, residual stresses and porosity, subsequently enabling faster ramp-up of production of better quality and competitive AM products.

4.2.1 Introduction

Every now and then when producing a component by means of additive manufacturing (AM), especially when using the selective laser melting (SLM) technique, parts fail as soon as the support structures used in the manufacturing process are cut off (or even as soon as the part has cooled down). This is due to the residual stresses caused by volume change in the material as the laser rapidly heats up and melts and compacts the metal powder, followed by cooling down and solidification of the metal. These rapid temperature changes also introduce porosity and other defects that deteriorate the material and lower its overall resistance to deformation. Although manufacturing defects and residual stresses seldom shatter the produced component during the manufacturing process, they significantly deteriorate the overall material behaviour during the component's lifetime, and can be detrimental to certification efforts. Thus, it is important to seek strategies to adjust the process parameters so that the material is as pristine as required and the residual stress state is acceptable for the component. A concept that can be used to simulate the design and AM process is developed, interfacing directly with an SLM machine and part build configuration. With current computing power, the used algorithms are not yet efficient enough to simulate manufacturing processes in situ, but the approach enables modelling of realistic part features with ease.

Currently, process parameters (e.g. scanning vectors and laser power) are usually set by the equipment manufacturer so that the producing of parts is feasible, but adjusting all of them, especially the scanning strategy involved, is less straightforward or usually even impossible. It is possible to affect the material several layers after the layer in which the unwanted phenomenon occurs, and control strategies could be introduced to react to process anomalies as well as to improve process consistency and stability. In some cases it would also be beneficial to have different process parameters for parts which have residual stresses (of particular sign) in specific parts of the component (e.g. to counteract bending stresses, or mitigate initiation of detrimental fatigue cracks), or even porosity in some parts of the component (e.g. to serve as a lubricant reservoir or lighten the component). Constant parameter sets are also restrictive in terms of increasing part build rates. A benefit is seen in altering materials microstructure throughout the part by affecting heat input to the material in order to produce harder or softer and hence more ductile regions in the part similarly to the effect of quenching, and for certain hard-to-manufacture materials, lessen the propensity of producing unfavourable microstructures.

In addition to the manufacturing process model, some insight is provided into part optimisation, calibrating the thermomechanical material behaviour and predicting the material properties of manufactured or simulated parts. As the AM process is flexible compared to traditional manufacturing methods, the shape of the part can be better designed to be more suitable for the designed application case and to optimise material usage.

When using Integrated Computational Material Engineering (ICME) to optimise the microstructure in a volumetric manner, traditional continuous cooling transformation (CCT) and time temperature transformation (TTT) do not provide sufficient information. As in real life applications, the temperature varies and cooling is not continuous throughout the volume. Thus more complex and physics-based approaches are needed. This raises the need for discrete or even lower scale models for calibrating the thermomechanical behaviour of the AM process model, as well as including powder bed scale so-called mesoscale behaviour, making the problem multiscale in nature. As the component is in many cases less robust (material usage and shape are optimised), it is even more essential to know how material behaves in the component. In addition, optimising the AM solution by exploiting interactions between part geometry, material and process parameters all contributing to the design space cannot currently be carried out, which can be considered a serious limitation. In order to satisfy this need, we need to utilize multiscale modelling, e.g. microstructure-based modelling that can provide reliable predictions for the materials mechanical behaviour and evaluate engineering material properties of parts after the build.

4.2.2 Multiscale modelling concept for metal AM

Current work is part of the development of an AM modelling concept, presented in Figure 1. In current work the focus is in integration of a thermomechanical model to an SLM machine configuration, but the other characteristics of the multiscale problem are briefly addressed in the following:

- The powder and alloy design module of the modelling procedure is used to calibrate the thermodynamics for the process model and to design suitable material and powder solutions. Discrete models are used to simulate the laser metal powder bed interaction and to calibrate the thermomechanical behaviour of the used metal powder. Using the calibrated thermomechanical behaviour, phase field (PF) modelling can be used to predict the phase distribution and microstructure of the produced component. PF can also be used to study wetting and affiliated interface phenomena when the metal powder is melted in order to adjust and fine tune the composition of the metal powder and to study the effects of its morphology, microstructure and porosity.
- In the centre of the figure is the SLM process and design module that is used to predict the heat transfer and conduction inside and out of the component, typically modelling either the complete powder bed or certain specific parts of interest. The model uses SLM machine laser scanning vectors, laser power and affiliated parameters as inputs in order to produce a finite element (FE) model of the component and manufacturing process and solve the heat transfer problem. The model is able to predict the porosity of the manufactured component as a function of the laser power and scanning speed by tracking local phases during the transient thermal history. (Laakso, 2016.)
- In part geometry design, component topology is optimized specifically for different applications without the restrictions of traditional manufacturing methodologies (Figure 2). Material is left only in the points where it is needed according to a continuum FE model. The continuum model is also used to locate weak points of the structure. The AM process model can be used to simulate those weak points in more detail, as well as try to find optimized process parameter setups. Using the thermal history, the microstructures of these points can be predicted with the PF model and its results can be analysed more precisely in the material property & performance design module.

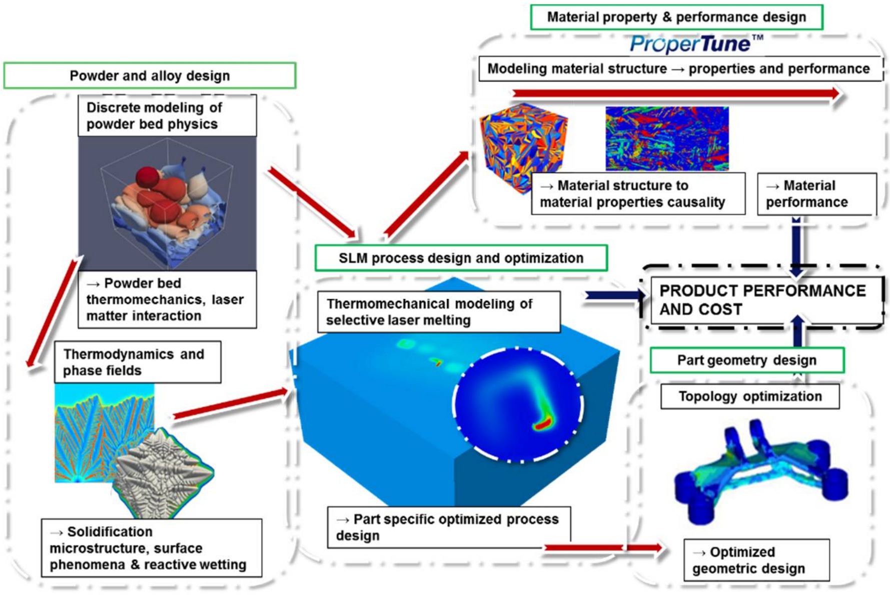

Figure 1. Multiscale modelling concept for metal additive manufacturing.

A material's mechanical performance is analysed in the Material property & performance design module. This analysis step uses microstructures either generated with a PF model, measured from an actual component with e.g. scanning-electron microscopy, or synthetically generated 3D structure with statistical microstructural information obtained from quantitative microscopy. The module is used to investigate how different microstructural features of the material (phases, material orientations, defects, etc.) affect material performance, or to predict engineering material property maps in the AM manufactured part. Porosity and possible inclusions and precipitates are included in the mechanical model as actual geometrical features or variations in mechanical properties. (Andersson et al., 2015.)

4.2.3 Results

Predicted material soundness in relation to process parameters is depicted and compared to experimental findings in Figures 2 and 3.

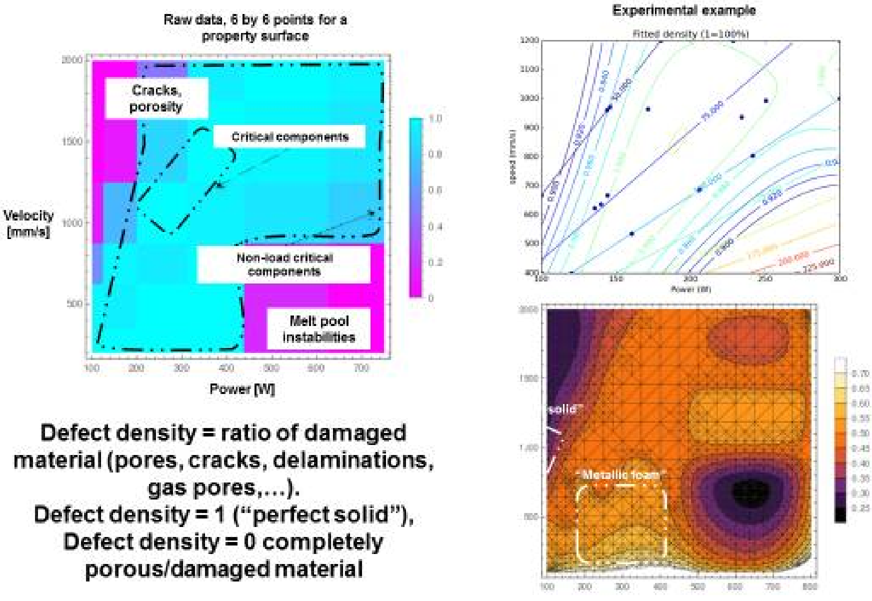

Figure 2.Comparison between model prediction of the material soundness (left) and experimental findings (right), see (Laakso et al., 2016) for further details.

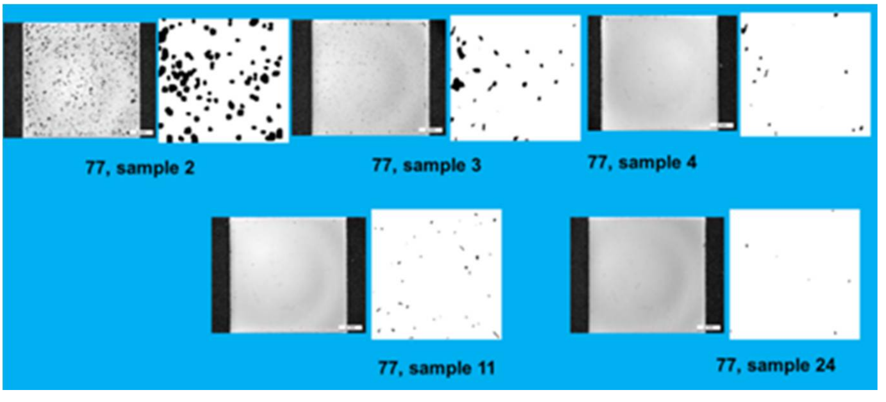

Figure 3. Comparison between model prediction of the porosity (left) and experimental findings (right), see (Laakso et al., 2016) for further details.

4.2.4 Summary and conclusions

The presented modelling concept for metal AM has the potential to combine a realistic thermomechanical and -dynamical behaviour with component geometry designed for AM, and consequently is able to produce a quality prediction for the component integrity and thermal history. Results can be further used as a design tool for improving the process itself (an iterative process between the SLM process model and powder and alloy models) or in a microstructural analysis in which a material's mechanical behaviour is analysed with respect to its ultimate functionality profile with respect to e.g. fatigue resistance.

A very practical application of the presented modelling toolset is support design. It is expected that there is a residual stress state inside the component due to the scanning strategy, as shown for example in Figure 1. Outer layers are melted first, and only after that the powder inside is consolidated. This is supported by the fact that components occasionally fail after removal of the supporting structures used to conduct the heat out of the component and to support it mechanically during the manufacturing process. Methodologies such as the one presented here can be utilized for designing better support structures and decreasing the added costs induced by post-build part machining. The numerous possibilities of metal AM can then be better exploited by the manufacturing industry.

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4.3 Simulation, optimisation and design of a 3D printed sand mould for a cast metal component

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An industrial case was utilised to investigate the redesign and manufacture of a cast component using an additive manufactured sand mould. A simulation, optimisation and design workflow was established for use with this manufacturing approach, as well as a manufacturing network within Finland. It was found that much of the geometric freedom of design offered by metal additive manufacturing was maintained when utilising this approach, while some of the current limitations of metal AM, such as maximum part size, available materials, high costs and questions of quality assurance, were circumvented.

4.3.1 Introduction

Additive manufacturing (AM) of metal components has brought about new approaches for optimisation and design, as the process inherently allows far more geometric freedom than traditional manufacturing techniques. Using careful design, this geometric freedom can readily be translated into improved functionality, performance and/or weight reduction (Gao et al., 2015; Yang et al., 2015; Salonitis & Zarban, 2015; Komi, 2016). However, there are currently prohibitive limitations on maximum part size, available materials, high costs, and in some cases quality assurance questions that constrain the adoption of these processes in industry. For these reasons, an alternative approach has been investigated for design of advanced cast metal parts that are created in additive manufactured sand moulds.

4.3.2 Case study

In order to examine this process further, an industrial case was studied. The component comes from Raute Oyj, a technology company with customers in the wood products industry. The component chosen for redesign was the body structure of a device used for trimming peeled veneer to a desired length. Some images of the component and a connected adapter are presented in Figure 1.

The primary goals of this project were to establish a simulation, optimisation and design work flow for use with this manufacturing approach, and to establish a manufacturing network within Finland which can be called upon when needed for similar projects in the future. The main goals in the product redesign were to consolidate parts (e.g. body part and adapter), improve functionality by adding integrated air channels for removal of wood debris during operation, and reduce material usage.

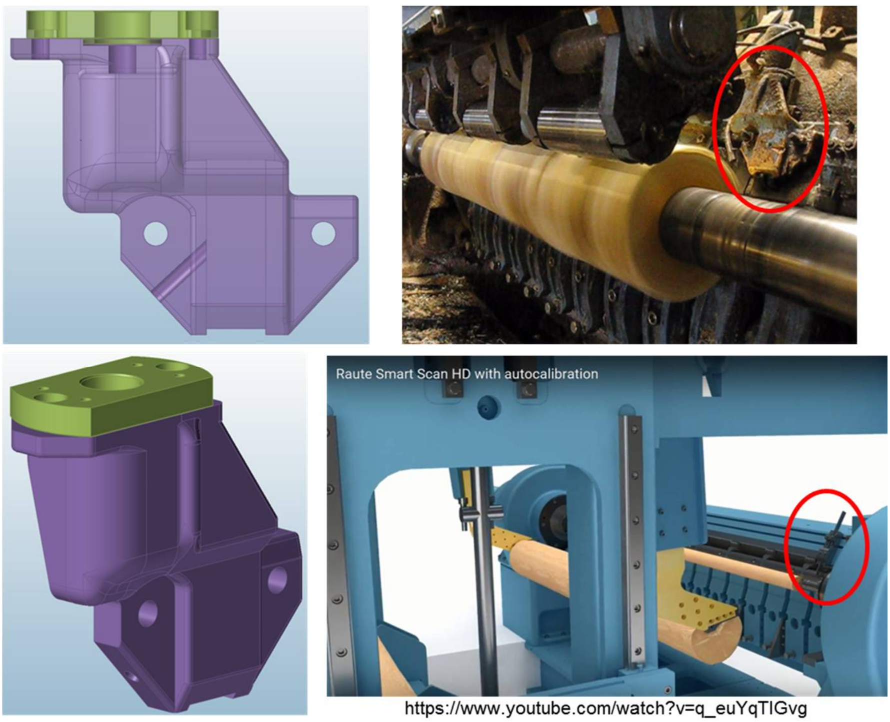

Figure 1. Raute body component (purple) and adapter (green) for a device used to trim peeled veneer are shown on the left, while one version of the device is circled and shown in its actual operating environment on the right

4.3.3 Simulation and component redesign

Finite element-based topology optimisation was utilised as a design tool to help guarantee the most efficient use of material within the body component and adapter. Constraints related to the casting process were taken into consideration when interpreting the optimisation results and generating the final design. One of the design iterations from this process can be viewed in Figure 2.

Two internal air channels were integrated into the design in order to improve the performance of the final product. The idea was that a connecting piece for pressurized air could be inserted on one end, and a nozzle would be positioned at the other end of each tube such that a blast of air could be used to remove wood debris from the knife region during operation. It was decided that stainless steel tubes would be formed and inserted into the moulds for creation of the channels, because the channel diameter was so small that such long, thin sand mould cores would be extremely fragile and prone to breaking during the casting process. The position of the channels within the final component design can be seen in Figure 3.

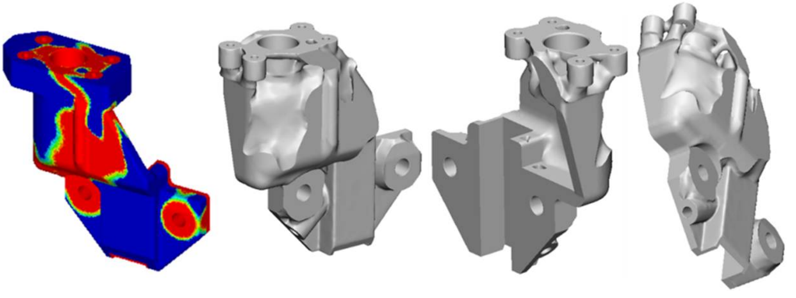

Figure 2. One topology optimisation result and images of the interpreted design.

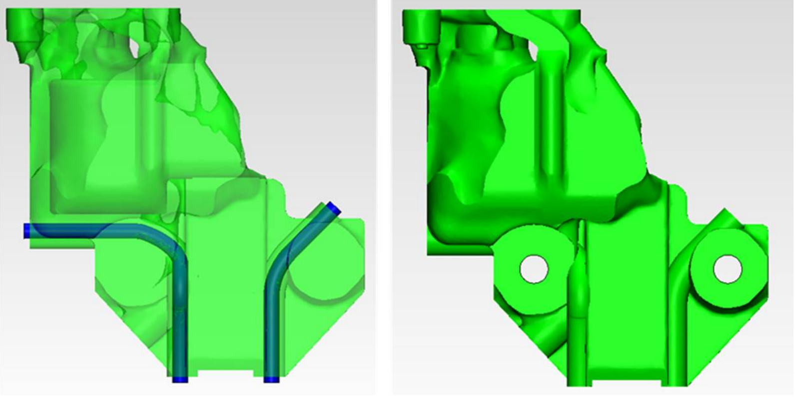

Figure 3. Integrated air channels (blue) added to the topology-optimised design.

Due to the geometric complexity of the final component design, VTT collaborated with Hänninen Engineering Oy for casting simulation and mould design in order to ensure that the part could be manufactured successfully. It was decided that all necessary bolt holes, etc. would be machined after casting and thus they were removed/filled within the component geometry used for mould design. Images depicting the gating (i.e. channels in the mould through which molten metal is poured into the cavity) and risers (i.e. reservoirs of molten metal necessary to compensate for losses due to shrinkage when metal solidifies) for this component can be found in Figure 4. This complete gating system was verified with casting simulations performed using Flow-3D Cast software. Sample results can be found in Figure 5, in which images describing the solidification process and component temperature at several instances in time are depicted.

Based on these simulations and discussions with experts from Hetitec Oy (responsible for 3D printing the sand mould) and Tuiskulan Metallivalimo Oy (the used foundry), small changes to the design were applied for improved manufacturability. The final version was subjected to a final structural FEM simulation to guarantee that all original design criteria were met.

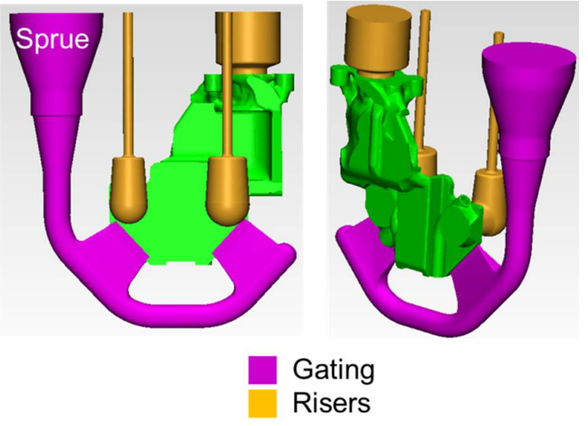

Figure 4. Gating system and riser design for sand mould

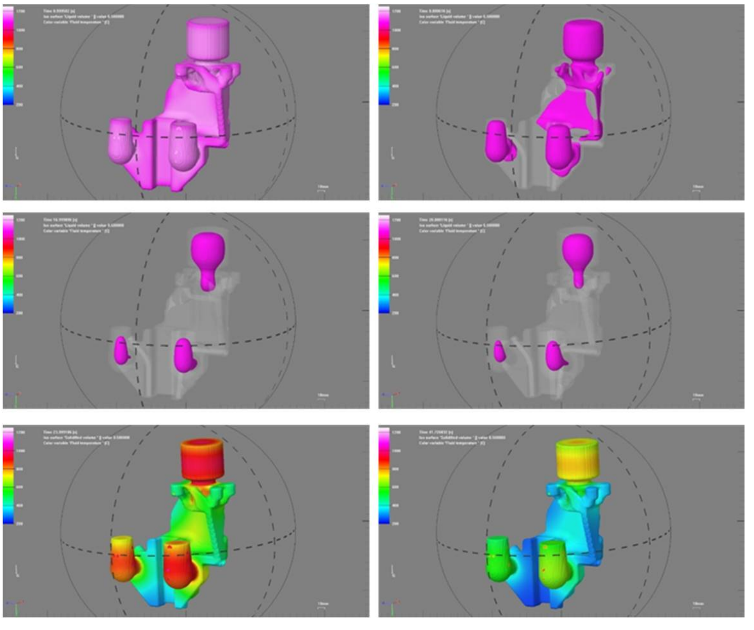

Figure 5. Casting simulation solidification results at four instances in time (top images), and temperature after casting at two instances in time

Once the component and casting designs were finalized, the mould was designed. Two key guiding principles were followed when determining the parting line of the mould: (1) it must be possible to remove all excess sand after 3D printing of the mould, and (2) it must be possible to insert the stainless steel tubes that will be used for creation of the internal air channels. Images of the final mould geometry can be found in Figure 6.

Due to the complex, three dimensional shapes of the formed stainless steel tubes and the tight tolerances needed to fit them into the sand moulds, guides were designed and additive manufactured to aid in the forming process. Images of the guides can be found in Figure 7.

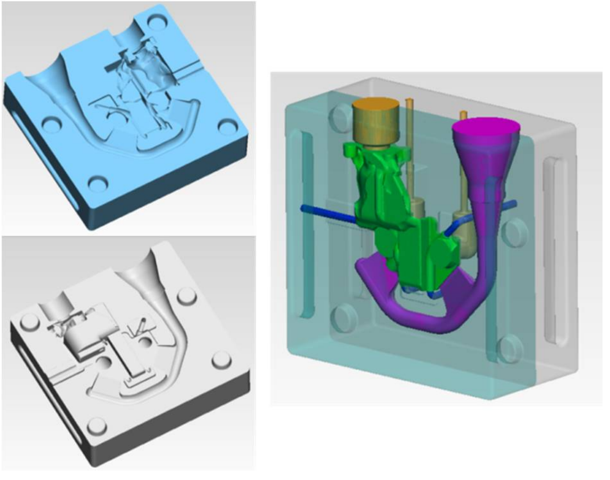

Figure 6. Geometry of the two halves of the sand mould.

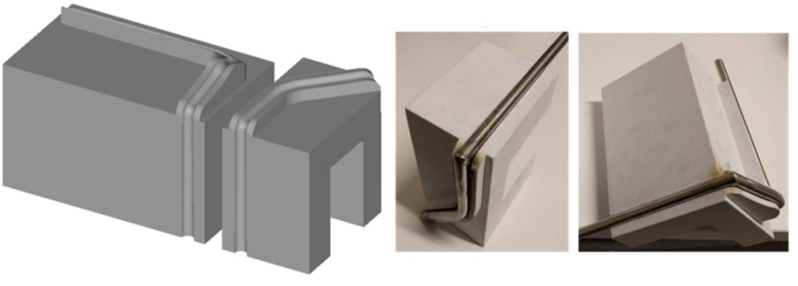

Figure 7. 3D printed guides for use in the creation of formed stainless steel tubes.

The designed sand mould was printed by Hetitec Oy with their Voxeljet VX100. This printer utilises binder jetting technology with a phenolic binder, and has a build area of 1060mm x 600mm x 500mm. It was possible to print four copies of the mould simultaneously. After printing, an alcohol-based zircon coating was applied to the inner surfaces of the mould to improve the surface quality of the cast component. Images of the printed mould can be found in Figure 8.

Figure 8. Photographs of the 3D printed sand mould.

After printing, the formed stainless steel tubes were inserted into the moulds, the mould halves were clamped into position, and the component was cast at Tuiskulan Metallivalimo Oy foundry in Lahti. Images from the mould preparation and the casting can be found in Figure 9.

Figure 9. Images of mould preparation and casting at Tuiskulan Metallivalimo.

4.3.4 Results

The main focus of this project was to establish a workflow and a Finnish manufacturing network for creation of cast metal components using additive manufactured sand moulds. The key steps in the workflow developed proceeded as follows: (1) component redesign to take advantage of geometric freedoms offered by AM, bearing in mind manufacturing limitations, (2) gating and riser design and casting simulation, (3) mould design, (4) additive manufacture of sand mould, (5) mould preparation and casting. These steps are visualized in Figure 10.

Through the redesign process, two parts were combined into one, functionality was improved by integrating internal air channels for removal of wood debris from the knife region during operation, and the mass of the components was decreased by 38%. The manufacturing network that was established included Hänninen Engineering Oy with experts in mould design and casting simulation, Hetitec Oy for the 3D printing of the sand mould, and Tuiskulan Metallivalimo Oy as the foundry responsible for casting the component. Good communication between all members of this network and VTT was vital for the success of this project.

The geometric freedom of design that AM offers was indeed available for exploitation using the manufacturing process studied, although as with all manufacturing approaches, there were some limitations. For the creation of the 3D printed sand mould, two key requirements need to be adhered to: (1) a wall thickness of 3 mm must be maintained within the mould, and (2) it must be possible to remove the excess sand after printing. The restrictions arising from the casting process included a minimum wall thickness (which is material-dependent) and the realization that long, thin channels require long, thin (and very fragile) cores. Furthermore, the surface roughness of a component cast in a sand mould makes this process unsuitable in some cases.

4.3.5 Conclusions

An industrial case was studied to investigate the redesign and manufacture of a cast component utilising an additive manufactured sand mould. As with all manufacturing techniques, there were some limitations as discussed in this paper. However, as this approach overcomes some of the current limitations of metal AM, it is certainly worth considering when larger part size, lower costs, certain materials or a long-established manufacturing technology are required.

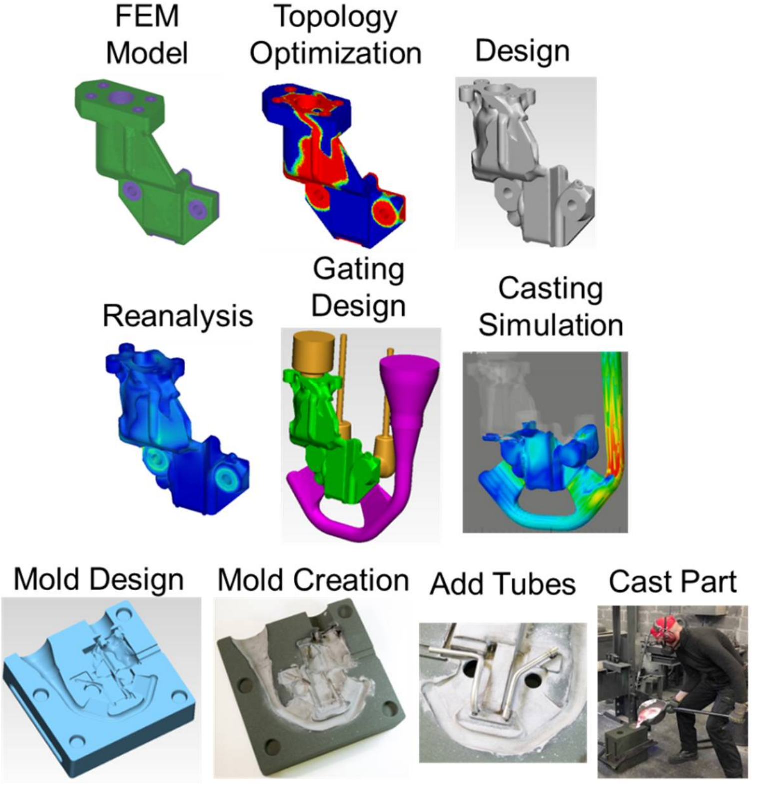

Figure 10. Workflow utilised for simulation, design and manufacture of a cast metal component using an additive manufactured sand mould.

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4.4 Improving the mechanical properties of SLM-processed tool steel by process optimization

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This paper is a response to lack of knowledge of the mechanical properties of printed H13 tool steel. The process parameters are optimized by printing test samples for porosity measurements followed by fitting a numerical model to the measured porosity values. The optimal parameters are determined and used for printing tensile test samples for mechanical testing. The optimal parameters result in lower porosity and improved yield- and ultimate tensile strengths for the heat-treated samples compared to the non-optimized parameters. The strength values are comparable to those of conventionally manufactured samples.

4.4.1 Introduction

In the SLM process, each layer can have separate pre-defined input process parameters. The most significant parameters in relation to quality of the finished part are laser power, scanning speed, hatch width and layer thickness (Hanzl et al., 2015). Suitable parameters are typically provided by the machine manufacturers, but only for a limited number of materials. In order to build dense, crack-free parts with acceptable mechanical properties from less common powders, a well-defined set of process parameters is required. The objective of this work was to optimize the initial SLM process parameters (power, scanning speed, hatch width) to decrease the porosity of the H13 samples and consequently improve the mechanical properties of printed parts. The mechanical properties are determined by performing tensile tests.

4.4.2 Experimental methods

Commercial gas atomized H13 powder supplied by SLM Solutions GmbH was used for the printing using the SLM 125 HL selective laser melting system (400 W laser) manufactured by the same company. The powder had a spherical shape and a narrow particle size distribution. The powder supplier provided process parameters for the powder that are referred to as “initial” parameters in this paper. Two sets of 25 test samples were printed for parameter optimization and prepared (ground & polished) for optical imaging. Porosities were measured from the cross-section images using Fiji image analysis. The method of D-optimal design of experiments was implemented in order to calculate the parameters for the sample sets. For the first sample set the power was kept constant at 175 W and for the second set the hatch width was kept constant at 100 µm. In the experimental designs the ranges for hatch width, scanning speed and laser power were 90–150 µm, 400–1200 mm/s and 100–300 W, respectively. A constraint was set to limit the parameter design space by limiting the volumetric energy density to the range of 50–100 J/mm³, as this was found to be suitable on the basis of literature information (Spierings et al., 2011). A powder layer thickness of 30 µm was used in the experiments. The tensile test samples were printed in horizontal, 45° angle and vertical orientations relative to the substrate plate using the initial parameters. Nine samples were built in each orientation and three samples in each build orientation were tested in the following condition: as built, stress relief annealed, hardened and tempered. Another set of nine tensile test samples was printed using the optimal parameters calculated on the basis of the results of the DoE sample sets. The tensile tests were performed at room temperature.

4.4.3 Results

The printed DoE test cubes and the tensile test samples are presented in Figure 1. A cubic polynomial function was fitted to the measured porosity data points and surface contour plots were drawn to help visualize the parameter design space (Figure 2).

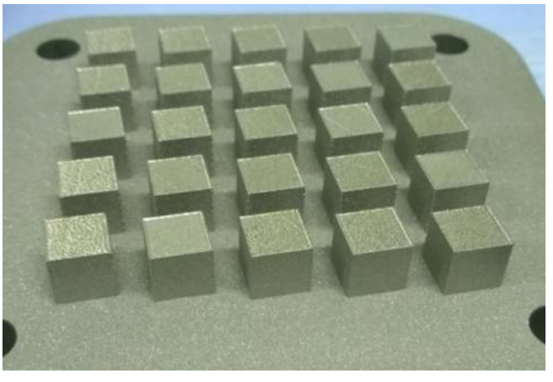


Figure 1. Left: 25 cubic samples used for parameter optimization.
Right: tensile test samples printed in three orientations.

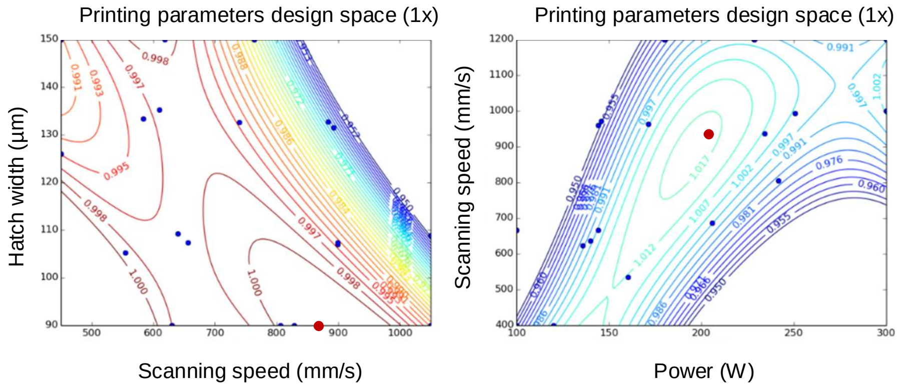


Figure 2. Left: Density contour plot with hatch width and scanning speed as process variables (Power = 175 W), and right: density contour plot with scanning speed and power as process variables (Hatch width = 0.1 mm). The red dots represent the optimal parameters in each parameter design space.

The tensile test results are presented in Table 1. According to the results the build orientation appears to have an effect on the mechanical properties, which can best be seen with samples tested in as-built condition. The vertical build orientation resulted in the highest yield and ultimate tensile strength values, whereas the horizontal orientation resulted in the lowest. The yield and ultimate tensile strengths for samples printed using initial and optimal process parameters are presented in Figure 3, showing the improvement of mechanical performance with optimal parameters.

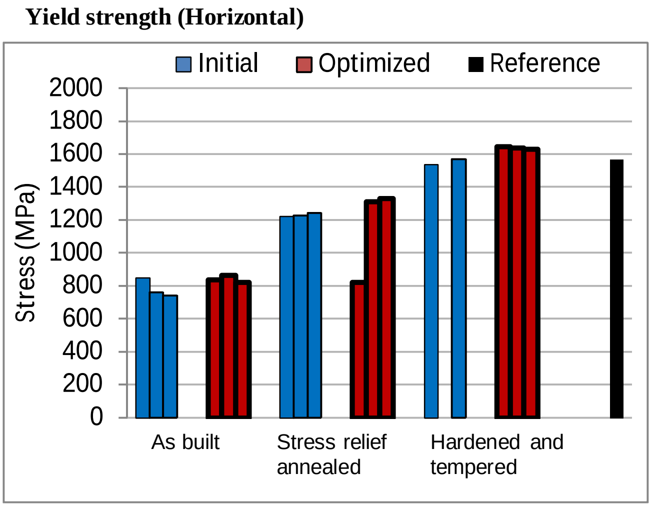
Table 1. Mechanical properties of SLM-built H13 tool steel. The results are reported as average values of three samples unless otherwise indicated.

	Yield strength (MPa)			Ultimate tensile strength (MPa)			Elongation (%)		
	As built	Stress re-lieved	Hard-ened and tempered	As built	Stress relieved	Hardened and tempered	As built	Stress re-lieved	Hardened and tempered
Horizontal (optimal)	841	1155	1639	1298	1541	1723	1.9	5,7	0.9
Horizontal	784	1232	1553[1]	1333	1438	1612[1]	1.8	4,4	1.2[1]
45°	957	1214	1570[2]	1474	1432	1589[2]	1.4	4,7	1.2[2]
Vertical	963[1]	1166	1633[1]	1553[1]	1380	1714[1]	1.9[1]	7,7	1.1[1]
Reference			1520[3]			1820[3]			12[3]

[1]One sample broke before 0.2% stain and was omitted from the results

[2] Two samples broke before 0.2% strain and were omitted from the results

[3] Reference values at room temperature (Uddeholm (2013))



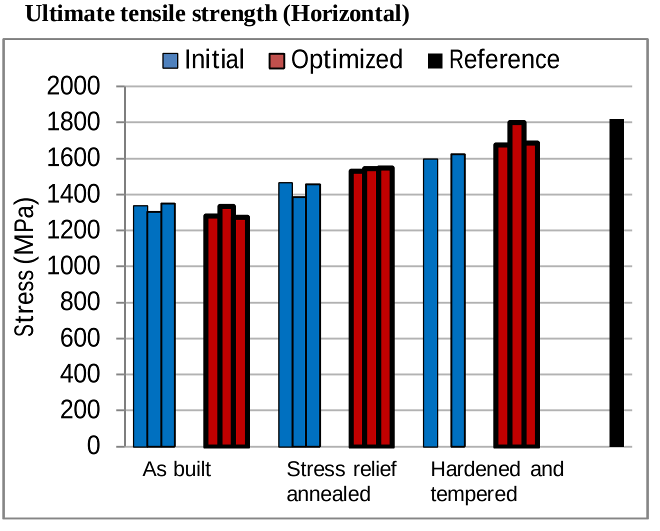


Figure 3. Yield and ultimate tensile strengths of horizontally printed H13 tensile test samples with different build parameters. The stress relief procedure was as follows; heating up to 650 °C in two hours, holding at 650 °C for two hours and cooling in the furnace to room temperature. The hardening and tempering procedure was as follows; heating to 1030 °C, holding for 30 minutes and then quenching in oil (50 °C). After quenching, the samples were tempered twice at 400 °C for 2 hours and cooled in air. The reference sample was conventionally manufactured Uddeholm Orvar supreme tool steel. The reference sample was hardened for 30 minutes at 1025 °C, cooled in air and tempered (2 h + 2 h) at 610 °C (Uddeholm, 2013). Reference for the elongation value: Uddeholm (2010).

4.4.4 Conclusions

Porosity reduces the mechanical performance of materials and should therefore be minimized. In the SLM process the selected parameters affect the behaviour of the molten material and consequently the defect density in the finished part. This paper presented a method for optimization of the selected process parameters that ultimately led to improved mechanical properties in SLM-processed H13 tool steel. Using the DoE method, it is possible to define the parameter window leading to low porosity with a relatively small number of samples, making it a cost-effective approach. This approach could be implemented to optimize the SLM process for any material. Currently, the mechanical properties have been studied only for a relatively small number of materials, as material development advances more rapidly for materials with the most industrial significance (Lewandowski & Seifi, 2016). There is a demand for future research into gaining better understanding of material properties such as corrosion resistance and fatigue strength, which are important topics in the AM field.

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5. Automation and Robotics

5.1 Challenges and opportunities for automation and robotics

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Modern manufacturing, especially in Europe and the US, is facing ever increasing challenges of flexibility and agility. Advanced robot technologies with Industrial Internet-of-Things (IIoT) technologies create new opportunities for successful manufacturing and production. Collaborative robotics offers a way to utilize human skills and intelligence in challenging production scenarios, but implies the use of advanced sensor and device technologies ranging from field equipment to cloud based services. Some challenges and insights into key technologies are outlined.

5.1.1 Introduction

Modern manufacturing and production systems are facing many challenges, common in sectors requiring high levels of flexibility and in regions where personnel costs are comparatively high, especially in Europe and the USA (PRWEB, 2015):

- Number of product variants & parts is very high
- Lot sizes are very short, even including lot-size-one deliveries
- Time to delivery is very short
- Increasing labour costs
- Flexibility comes (too) often when using manual work

The competitiveness of the Finnish manufacturing industry, especially of small and medium sized enterprises (SME) is also highly dependent on the flexibility and cost efficiency of the production. The products of Finnish SMEs are typically manufactured in small series and tailored to customer needs. An important competitive edge is the time from order to delivery, which should be as short as possible without compromising the quality.

The automated handling and manipulation of parts and material is becoming more important in all manufacturing sectors, and will be one of the key factors for increased robotic investments. The expected positive market development in industrial robotics will not be possible without substantial change in the characteristics of industrial robot applications. Especially new applications and areas requiring ultimate flexibility or capabilities comparable to human skills are receiving more and more attention. This has also been identified by the European Technology Platform (ETP) initiatives EUROP and MANUFUTURE. The strategies proposed by the ETPs are to create more value, such as customizing, individualization and life-cycle orientation, but these are not supported by current robotics practices, which historically are optimized to the “economy of scale” (Hagel III et al., 2015). Extreme customizing, life cycle orientation and service perspectives change the ways of understanding products and production.

In a wider scale and globally, manufacturing and automation are undergoing a drastic change with the introduction of new innovations and progression in supporting technologies, especially in Europe and the USA. Reshoring manufacturing e.g. from the Far East takes place with growing rapidity due to the increasing cost of human labour in the Far East. Nearshoring or newshoring takes the reshoring trend a step further. Manufacturers are finding that having production centres close to the market base reduces lead times and improves agility. Concerns of working condition and work safety have also led to a search for improved ergonomics and integrated safety technologies (Erickson, 2014).

There are four major trends behind the changes, hopefully driving the supporting technologies towards integrated and easy to use manufacturing platforms. These are Internet of Things (IoT), Big Data, Cloud Computing and Industry 4.0. These all face some challenges but are interrelated and also provide substantial opportunities.

The IoT challenge is in learning the new technology and understanding how to design carefully for systems that dwarf even the largest fieldbuses. As the IoT concept continues to develop, the technology will evolve to accommodate the growth — more wireless operations will be added, everything will be made more secure, higher levels of network traffic will be managed, and more IP addresses will be created. Ultimately, however, it will be up to the company to decide how to operate differently when virtually anything can be on the network.

Within Big Data, the trend of “collecting everything” continues today, but with software that knows how to analyse and help to utilize the data. The opportunity lies in the ways of connecting the information to a company’s business challenges in order to recognize new opportunities to gain efficiency, insight, speed and competitive advantage.

Like the IoT and Big Data, vendors of Cloud Computing will handle the technology but it is up to companies to assess the benefits and risks of having the critical data available and secure when it is located and managed by someone else and somewhere else. Once these criteria are satisfied, however, it is possible to determine how the company might benefit by having virtually unlimited computing power, storage and, eventually, new avenues of collaboration. The key to using more sensors in remote locations is the standard IEEE 802.15, which uses less power. The technology incorporates a tolerance level into the sensors so that they only send data when something goes wrong (Hand, 2014).

The new opportunity with Industry 4.0 is using the wealth of information available from smart, networked devices to revolutionize industrial processes linked to IoT, cloud and Big Data technologies. The challenge is to think big and drive the change necessary within an organization in order to capitalize on information available today for success tomorrow. Industry 4.0 has a comparable approach introduced in the U.S., known as "Smart Manufacturing". Just like Industry 4.0, Smart Manufacturing involves the integration of cyber and physical systems, which can enable innovative production processes and new product systems (Gallaher et al., 2016).

5.1.2 Robotic markets & trends

Much is expected from new automation technologies, especially from robotics, which is also reflected in expectations for the growing industrial robotics markets. Globally, these are currently at the level of 30 BUSD (in 2015) and are expected to increase substantially, up to the level of 40 BUSD (by 2020) during the next five years (Chausovsky & Sharma, 2015). In the field of industrial robotics, which is currently growing at 8 % p.a., Europe's share of the world market is about 32%. Here it will be important to find new applications outside the automotive sector. A recent study by McKinsey estimated that the value of the application of advanced robotics in healthcare, manufacturing and services could have an annual economic impact of between $1.7 trillion and $4.5 trillion worldwide by 2025 (SPARC, 2017). The so-called "Collaborative robotics" sector is expected to increase approximately tenfold between 2015 and 2020, reaching more than $1 billion from ca. $95 million in 2015 (Supplychain247, 2015).

The challenge is that automation and robotic technologies can enable cost efficiency for production flexibility & agility, but only if/when they are applied appropriately. This requires addressing the manufacturing needs of especially SMEs, which is considered as an important step change in capability for robot technology suppliers. These needs centre around the following factors (SPARC, 2016):

- The need to design systems that are cost effective at lower lot sizes.
- The need to design systems that are intuitive to use and are easily adapted to changes in task without the need to use skilled systems configuration personnel.
- The ability to work safely in close physical collaboration with human operators.

These challenges can and will be approached by extending the capabilities of industrial robots, utilizing the technologies of the new internet-of-things era. Chamber listed six key trends in robotics that will probably have a great effect on a wide variety of industrial sectors and provide benefits well beyond what was once considered possible (Chambers, 2014):

- *Increasing ease of use, deployment and maintenance*: by simplified programming and designing robotic systems, to achieve robots that can "program themselves" using sensors. Key technologies and methods to be utilized are

Human/Machine Interfaces (HMI), Augmented Reality (AR) and sensor-based control.

- *Human-Robot Collaboration*: humans and robots, working as colleagues on assembly lines and in other applications sharing the same work space. Key technologies and methods to be utilized are safety engineering, HMI, AR, and sensor-based robot control.
- *Improved robot "senses"*: robots to interact with the world around them: to find, identify and manipulate objects. Key technologies and methods to be utilized are sensor systems and sensor-based robot control.
- *New ways of working with robots*: anywhere with an Internet connection (design, sales, installation, commissioning, operation, oversight, and service). Key technologies and methods to be utilized are Industrial Internet of Things (IIoT) connectivity, integrations to digital models & digital (computation) services.
- *Training the robot employees of the future*: a whole new ecosystem of high-paying and rewarding jobs (Designing, building, marketing, selling, installing, operating and maintaining robots). Key technologies and methods to be utilized are IIoT connectivity, integration to digital models & digital (computation) services, HMI, and sensor systems.
- *Improved ROI*: increase productivity, reduce overheads, provide flexibility, reduce waste, and increase quality. Key technologies and methods to be utilized include all those given above, as the outcome emanates indirectly from the other five robotic trends.

5.1.3 Collaborative robotics

Collaborative robotics is expected to have a huge impact on robot automation by enabling introduction of human intelligence and skilled flexibility to the production loop. Currently, automation in small series production is mostly hard automation, often based on NC machinery. For those cases in which robots are used for handling or processing parts and material, robots are behind safety fences. New standards for industrial robots and systems (IEC 10218-1/2, ISO/TS 15066, ANSI/RIA R15.06-2012) allow operation of robotic systems where robots are no longer isolated from operators. Human operators and robots are allowed to "collaborate". ANSI/RIA has given definitions for "collaborative robotics" as follows (ANSI/RIA, 2012):

- collaborative operation: a state in which purposely designed robots work in direct cooperation with a human within a defined workspace
- collaborative workspace: workspace within the safeguarded space where the robot and a human can perform tasks simultaneously during production operation.

In collaborative robotics, human operators can share the workspace with robots during running production, and the new safety standards are providing the system designers and users with appropriate constraints and some guidelines to maintain operator safety. There are four principal modes for human/robot collaborations (ISO, 2011; ISO, 2016):

- Safety-rated monitored stop: No robot motion when an operator is in the collaborative work space
- Hand guiding: Robot motion only through direct input of an operator with safety-rated monitored speed
- Speed and separation monitoring: Robot motion only when the separation distance exceeds a certain minimum, with safety-rated monitored speed
- Power and force limiting by design or control: In contact events, the robot can only impart limited static and dynamics forces

Many industrial robot controllers are already equipped with certified safety controllers with interfaces to safety sensors as well as a “soft axis” for flexible speed control based on the use of safety sensors. However, there are not very many existing applications in industrial practice, and these are often developed in a customised manner. Most of the collaborative applications are for more or less simple part handling applications, following the power and force limiting mode and relying on new light-weight robots.

5.1.4 New features & enablers

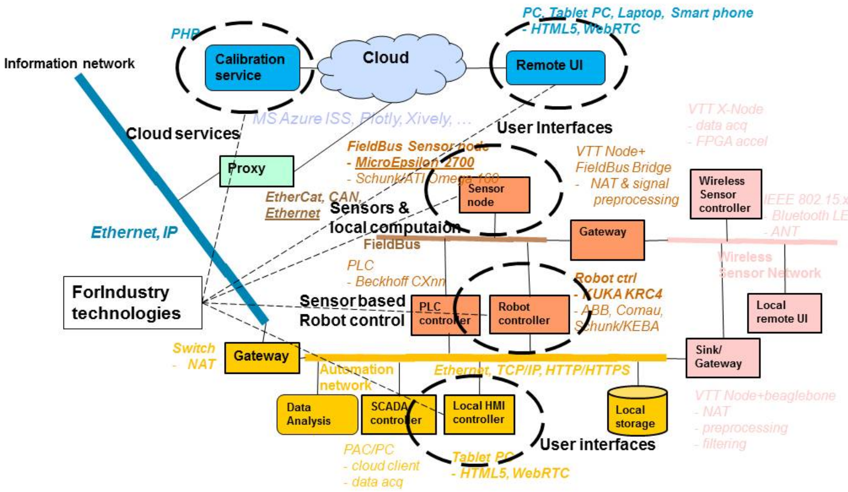

Figure 1. Key technologies for robotic manufacturing, tackled in VTT’s For Industry program: 1) Sensor systems and local computation, 2) Sensor-based robot control, 3) Cloud-based services and 4) User interfaces.

Enabling technologies and methods to implement robotic manufacturing systems of Smart Manufacturing - and towards the six trends/features above – include a set of key technologies, which have also been focus areas in the Robotics and Automation part of VTT's For Industry program. Collaborative robotics has been strongly present and representative developments are introduced in the following sections as contributions in three key technology areas, supporting especially collaborative robotics:

- 1) Sensor systems and local computation
  - HULDA – Human Detection Around Heavy-Duty Vehicles: introduces a modular sensor system for human detection based on optical and UWB radar sensors
  - Edge Computing for Industrial Internet of Things - a HW programming concept: introduces an application of flexible high level programming of algorithms for low power wireless sensor systems
- 2) Sensor-based robot control
  - Interactive robot programming by hand guiding: introduces a new wireless force/torque sensor system and related impedance control algorithms for interactive robot guidance and programming
  - VTT Dynamic Safety System and configurator: introduces a dynamic safety sensor system with a software to configure the safety system easily
- 3) Cloud-based services and User interfaces
  - Remote User Interface for CyberPhysical Robotics: introduces a remote robot-sensor calibration service operation for sensor-based robot cells, relying on cloud-based computation services.

These development examples pave the way to more common utilization in demanding agile and flexible manufacturing applications.

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5.2 HULDA – Human detection around vehicles

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The goal of the Hulda project was to combine VTT expertise in UWB-radars and imaging technologies in order to create a new type of human detection systems for safety and heavy machinery applications. The tangible target was to realize a proof-of-concept demo of an all-weather human detection system consisting of impulse radars and 360-degree optics, both of which are in the core of the VTT Sensing and Integration and Data Driven solutions research areas.

5.2.1 Introduction

Reliable detection of humans in harsh conditions is a generic problem which still needs to be solved. Especially dark, dusty and rainy conditions keep challenging the existing sensor systems and human operators, as they cause degradation of existing sensors or, in the worst case, sensor malfunctioning and missed alarms. In order to create and build greener, safer and more efficient machines, new technological solutions which combine the existing solutions in a novel and innovative way are needed.

Currently, in typical heavy machinery or military applications, 4-8 LWIR cameras have to be used to cover the 360-degree field-of-views around the vehicle. Human detection should work in all weather conditions and in darkness, and the system should be capable of differentiating people from animals and inanimate objects. In addition, the system should predict the path of movement and create early warnings when necessary. The cost of the detection system should decrease, together with weight, volume and power consumption. Furthermore, the assembly, maintenance and the use of the sensing system should become easier and more intuitive.

The Hulda-project solution for all-weather human detection is a fusion of impulse radar 3D position measurement and 360-degree omnidirectional optics. The radar can provide down to 4 mm accuracy and it can measure the object location and direction of movement. On the basis of the measured parameters the radar module can predict the path of movement.

Omni-directional 360-degree optics can be implemented in thermal LWIR or normal VIS-range versions. The thermal version works in the region of human thermal signatures and it can discriminate living and cold objects. In the visual range, shape-based human recognition and tracking can be used. When single camera-based 360-degree measurement geometry is used, only one camera module per vehicle is needed. This will keep the price, weight, volume and power consumption low, while the assembly and maintenance efforts are limited to a single module.

Figure 1. Hulda demonstrator consists of radar and omnidirectional camera modules. The modules can be used together or as separate sensor units.

5.2.2 Method

In order to implement the proposed sensor fusion-based solution the project was split into several sub-tasks, which were partly overlapping. In order to define and find the best market segment, two separate market surveys were made. The first survey focused on the omnidirectional lens markets and competitive solutions which combine radar and camera-based technologies. The second survey was more focused on the radar-based safety sensors and solutions which already fulfil the current safety sensor regulations and standards.

On the basis of the market potential studies and feedback collected from VTT's customers and key account managers, the user requirements and specifications were listed. The hardware and software implementation of the project were carried out on the basis of the specified requirements. The following sections will sum up the progress in each task. At the end of the document a brief summary of the results will be presented.

5.2.3 Specifications

As the field of human detection applications is quite broad, there were several contradicting or overlapping requirements set for the proof-of-concept demonstrator. Eventually, after some iteration, the project group divided user requirements into general, hardware and software requirements. A simplified list of requirements is shown in Table 1. The most challenging requirement was that both mechanics and software needed to be fully functional and still modular. This was required for the technologies to be easily adopted and modified into current applications and needs. In addition to robust casing, high priority was placed on requirements related to human detection and motion prediction in rough conditions.

Table 1. Specified demonstrator properties were divided into must and wish categories. In the project, priority was given to the properties which must be implemented.

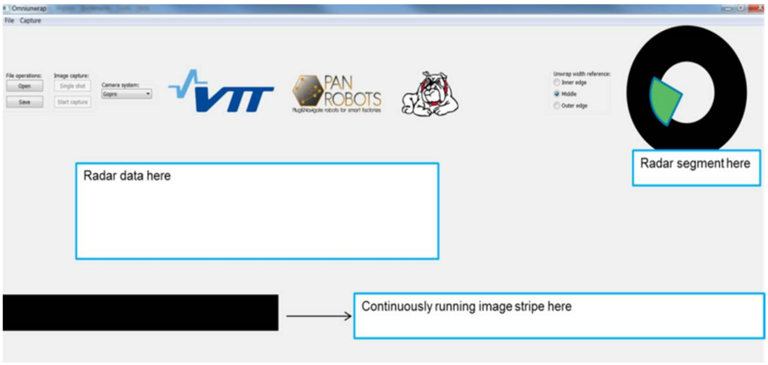
Must	**Wish**
Interchangeable 360 camera module	Motion prediction
One or several UWB radars	Remote interface
Data visualization	GUI with camera access
Robust design	Illumination
Human detection	Low cost
Motion detection	Low power consumption
	Small size
	Easy maintenance

5.2.4 Hardware implementation

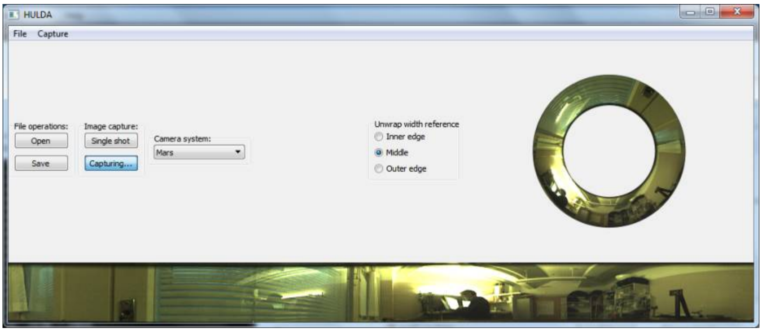
The main goal of the hardware task of the Hulda project was to design, build and assemble a casing concept which could serve in field applications as well as in demonstration events and trade fairs. In the final design, separate cases for the omnidirectional element and for the radar were manufactured. This will allow modular and similar or separate use of all modules. It is possible to use several radar modules, each with a 90-degree field of view, around the camera to provide full 360-degree radar coverage around the sensor. Cases were manufactured from 3D-printed plastic. If more robust casings are needed, these printed parts can be used as masters for the more robust urethane casted parts.

5.2.5 Software modules

Modular Hulda software takes care of several tasks. First, the software is used in the sensor set-up and data acquisition from the radar and camera sensors. Secondly, the software modules process and combine the radar and image data into a format which can be displayed to the user. The software is designed to be modular and it can be used with different radar and camera combinations.



(a)



(b)

Figure 2. The Hulda user interface is used to visualize the omnidirectional camera data and the radar data, UI draft (a) and realized interface (b).

VTT Omnilens software was programmed to use the camera API, and image processing was configured to match this particular lens-camera combination. The Omnilens user interface was based on Qt 5.3.0 and for image resizing, colour and filtering operations OpenCV 2.4.9 was used. The omnidirectional image was transformed to a stripe/flat image using polar to rectangular coordinate conversion.

Radar output remains to be integrated with the software. When a change in radar signal is detected, distance and intensity up to four meters are recorded and combined with image motion detection data. From this combination, shapes with human features can be labelled. The omnidirectional camera is able to measure direction accurately, whereas the radar can measure the distance more reliably than a single camera. If a human presence is detected, visual and audible alarms can be triggered.

In conditions which are too poor for automated visual motion detection by the omnidirectional camera, a radar signal can indicate the approximate direction in which an approaching object is detected. This area would then be shown for a visual check.

5.2.6 Results and future actions

Through the Hulda project, VTT has gained more information on how to design and manufacture unique and special all-weather human detection based on sensor fusion. This has created a novel opportunity for sensor system manufacturers globally. It has also generated know-how and expertise in cooperation with work machine manufacturers and end users.

As a future action, the group aims to present the design and validation results of the Hulda project in a suitable conference. One candidate is the SPIE Security and Defence conference in September 2017. In addition, a proof-of-concept demonstrator is expected to be shown in the VTT customer seminar Sense'17, which will be organized in April 2017 in Espoo, Finland.

5.2.7 Conclusions

With the Hulda demonstrator, VTT can demonstrate our expertise in the field of customized fusion sensor systems and meet customer requirements in the field of reliable human detection. All-weather human detection systems have considerable commercial potential and they can be used in several applications. The possibility to use VIS-, NIR- and LWIR-range imaging sensors in combination with impulse radar will further improve VTT's potential in the world of modern knowledge-intensive products and services.

5.2.8 Further reading

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5.3 Edge Computing for Industrial Internet of Things – the HW programming concept

Tero Peippola, Jari Rehu & Tapio Heikkilä
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Internet of Things is generating increasing amounts of sensor node data which must be processed, stored and/or transmitted for further use. At the same time radio bands are becoming crowded. In reactive systems, not all data can be stored for further analysis. As computational power in integrated circuits is growing faster than available radio bandwidth for single IoT devices, Edge Computing is an emerging opportunity for these problems. As the market is full of general purpose processors, we have studied methods of creating optimal application specific solutions for FPGA and ASIC while maintaining reconfigurability.

5.3.1 Introduction

Internet of Things is generating increasing amounts of sensor node data, which must be processed, stored and/or transmitted for further use. At the same time radio bands are becoming crowded. In reactive systems, not all data can be stored for further analysis. As computational power in integrated circuits is growing faster than available radio bandwidth for, Edge Computing is an emerging opportunity for these problems.

VTT has been developing a sensor node platform (Figure 1) capable of rapid wakeup-cycles and local data processing with Field Programmable Gate Array (FPGA). FPGAs can be used to implement custom processing units. They can be re-programmed with optimal logic for each application.

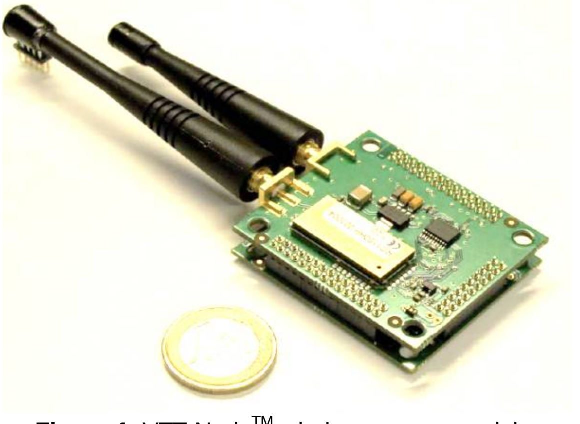

Figure 1. VTT Node™ wireless sensor module.

A few problems still exist. Costs and power consumption are much higher than those of mass produced application-specific integrated circuits (ASIC). An FPGA can still be more optimal than a digital signal processor (DSP) or a microcontroller.

FPGA- and ASIC-design have traditionally been implemented with a high-level description language (VHDL/Verilog). This can be an optimal solution, but it is very time consuming and not very configurable.

Recently high level synthesis (HLS) tools have been performing translation from higher level language (C) algorithm to hardware description language (HDL). While these are a more automated way to create logic, the results are usually not configurable. Furthermore, scaling of computational power in low-end FPGAs can be challenging.

5.3.2 Experimental design

We have been experimenting with TTA-based Co-Design Environment (TCE). This was earlier evaluated as a feasible candidate for FPGA in VTTNode™. TCE is a toolset for designing and programming customized processors based on the Transport Triggered Architecture (TTA). Development is directed by the Customized Parallel Computing (CPC) group at the Department of Pervasive Computing of Tampere University of Technology (TUT). Our work concentrated on integrating TTA in VTTNode, and was inspired by the work of Nyländen et al. (2015).

A transport-triggered processor has multiple transport buses connecting functional units (FU). These can be added or removed in order to scale system performance. A control unit (a special FU) reads instruction memory and controls bus connections, implementing move operations.

Our target application was an IIR filter capable of processing multiple channels simultaneously. For a reference, we used a fixed-point design implemented in VHDL language. This had custom pipeline architecture with configurable coefficients. Scalability of this type of implementation requires changes to architecture. For benchmarking, 3 identical filter engines were implemented in parallel.

TCE had an option to generate CPU with a half precision floating point (fp16) unit. As fixed point algorithm design and implementation is highly challenging, a half precision floating point was used. This should speed up development and widen the audience of VTTNode™ while still keeping performance similar to that of a fixed-point design.

We designed an extended minimal TTA-processor with STREAM input and output units for interfacing existing FPGA control logic and ADC. Thus, design was a drop-in replacement. A single fp16 MAC-unit was added to perform operations across multiple channels (Figure 2).

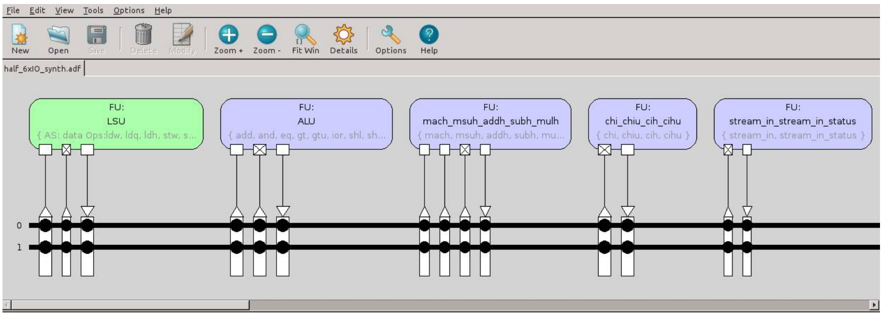

Figure 2. A TTA-processor with half precision FU and stream input and output units.

TCE creates a toolchain for the newly created target processor. The toolchain can compile OpenCL- or ANSI-C code for this custom processor. This evaluation was made in C-language algorithms, as TCE currently has only experimental support for OpenCL language.

Standard ANSI-C language can be used to implement major parts of the algorithm. First tests were performed with unmodified ANSI-C and full precision floating point units. Since ANSI-C does not currently support half precision floating point datatype (fp16), C-macros were used to implement operations (STREAM unit input/output).

For hand-crafting parallel operations, programming in TTA-assembly is still possible. This is laborious, but still a configurable way to develop applications compared to plain HDL-design.

5.3.3 Findings

The development workflow was split into two paths, one developing a C-language algorithm with a TTA-processor and the other integrating the TTA-processor in FPGA. This provides a natural interface between SW- and HW-designers.

The system model of the fp16 IIR filter was designed in Python-language. The model was used to create test vectors to verify functionality and performance of the TTA-processor in ttasim.

Meanwhile, a VHDL-code for the processor was generated with TCE-tools. Functional Units (FU) in the TTA-processor were configured with suitable pipelining and the design was simulated with ghdl and Modelsim. Then VHDL-code was synthesized using Synplify-Pro and routed for FPGA using Actel (Microsemi) design tools.

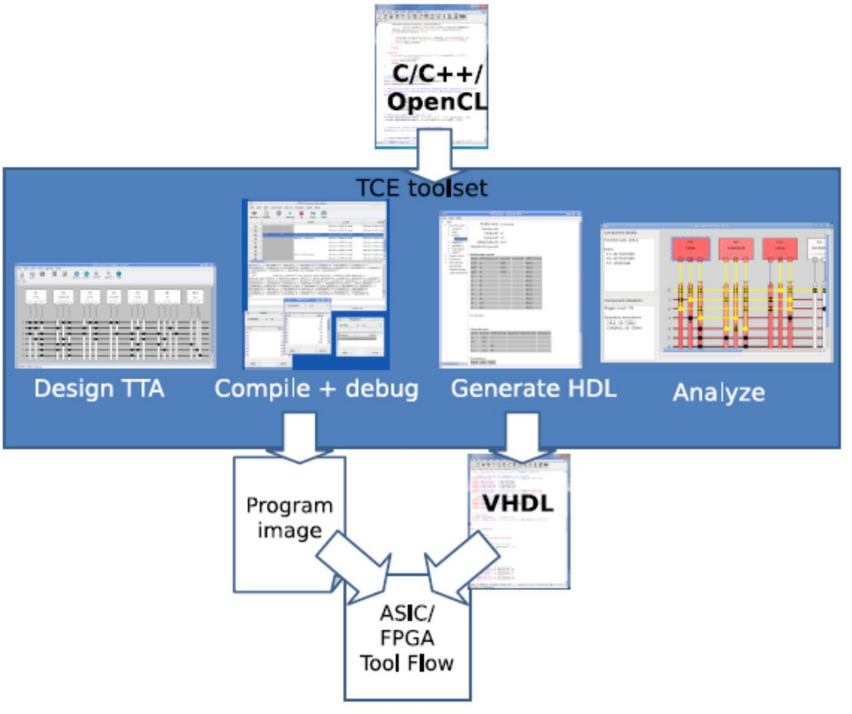

Figure 3. Design flow. The TCE toolset (ProDe) is used to create a processor and generate matching HDL. Application is compiled with tcecc and simulated with Proxim/ttasim. The HDL-tool flow generates a programming file for FPGA if the processor is changed. If the application code changes, only the TTA program image needs to be recompiled. (Picture: CPC/TUT, TCE User manual.)

Synplify could not translate VHDL memory instantiations for Actel IGLOO dedicated memory blocks. The memory was implemented in generic logic, making the design too large to fit in the selected FPGA.

In order to estimate performance in FPGA (Area, logic delay), memory interfaces were implemented in VHDL using dedicated IGLOO memory blocks. This was not fully verified in simulation. FPGA-implementation tools verified that this approach was feasible: FPGA area- and timing constraints were met.

Synthesis and routing tools were targeting 20 MHz clock frequency (Table 1). The design includes an interface between MCU and the TTA processor. As the main focus of the work was on integration of the TTA processor in the existing platform, some effort was put into processor and implementation optimization. The performance of this sub-optimal filter design was 103 kHz. Just adding one mode bus and data registers increased the filter throughput to 126 kHz without changing any C-code. TCE also provides a tool for design space exploration, which would help in architecture optimization.

Brief experimentation was also performed to verify the possibility of implementing a 24-bit floating point FU. Only logic area and delay performance were measured with synthesis tools, as full support would also require modifications to the whole TCE. As the results were promising, future work could also include such improvements.

Table 1. Logic performance with Actel (Microsemi) AGL1000 FPGA.

RAM implementation	Logic usage	Memory usage	Estimated frequency
Logic	140%	0%	18.7 MHz
BlockRAM	63%	25%	20.5 MHz

5.3.4 Conclusions

Currently, TCE (1.13) provides a way of developing algorithms in higher level language and then generating VHDL code suitable for FPGA or ASIC. This also creates a feasible path for mass-produced ICs targeted for computing in edge nodes.

OpenCL support will be widening suitable platforms from FPGA/ASIC to GPU computing. At the same time, parallel programming and performance scaling will be easier.

5.3.5 References

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5.4 Interactive robot programming by hand guiding

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VTT has developed a control system to support user ability to show robot work paths by hand-guiding, which can substantially cut the setting and programming time for the robot. The novelty of the control system is in the use of two force/torque sensors for recognising the pressure on the tool and the interaction force between the robot and the human operator. The new solutions significantly enhance the efficiency of productive operations and open up new opportunities for utilising robots.

5.4.1 Introduction

VTT has developed a control system for the industrial robots used for manufacturing of single-item products, which substantially cuts the setting and programming time for the robot. The time required for programming a robot can now be in minutes instead of hours using earlier traditional programming methods. The new solution significantly enhances the efficiency of productive operations and opens up new opportunities for utilising robots. The unique features of the new control system include the use of two force/torque (F/T) sensors, whereas traditionally robotic systems have one or none at all. The purpose of the F/T sensors is to recognise the pressure on the tool and the interaction force between the robot and the human operator. In this VTT solution, one F/T sensor is attached to a wireless control stick by which the robot can be steered through the operation step by step (Figure 1).

Figure 1. Interactive programming of grinding paths.

VTT has also developed a new method for easily and quickly calibrating the location and orientation of the wireless control stick with the F/T sensor, enabling free location of the control stick unit into the robot’s last link or load. The calibration procedure and experimental results were published and described in detail by Ahola et al. (2017).

The control stick and the control system operating in real time make it possible for a human controller to work in the same working space with the robot and hand-guide the robot's movements directly. Thanks to the interactive system, both the teaching of new tasks and continuous paths to the robot and direct control of the robot become much faster than before. This is particularly useful in the manufacturing of test pieces and single-item products, because heavy objects and even the entire assemblies can be moved in a flexible manner.

Interactive programming of robot paths by hand guiding is one of the collaborative robot operating modes described in ISO 15066, which sets safety requirements for collaborative robot systems. Thus by complying with ISO 15066 and by following the risk assessment process described in ISO 10218-2 for safeguarding of personnel, the robot integrators are authorized to implement collaborative robot applications on the factory floor. An overview of the risk assessment process for a hand-guided interactive robot system is given in Malm et al. (2015).

The new solution also enables service models to become more common in the industrial internet era. The data measured from the sensors of the robot can be stored in a cloud service, which makes it possible to run different analyses as a remote service. The robot's performance can also be monitored in real time through the internet. The new solution can be applied to any robots with an open control interface. In practice, this means several major robot manufacturers. The solution was developed in the HEPHESTOS project within the 7th EU Framework Programme, and in addition to robot manufacturers, VTT expects it also to interest the industry using robots and system suppliers.

5.4.2 Experimental

Figure 2 illustrates the hand guiding – or walk-through teaching approach. A robot is equipped with an F/T sensor in the wrist, a force controller PLC (Programmable Logic Controller), and a control stick, i.e. a teaching module with a joystick handle and an F/T sensor and a wireless sensor module. An operator guides the robot’s arm by grasping the handle, and moves the arm along the desired path. When the operator moves the robot’s arm, the path points are recorded and processed into a path for the robot for further use.

A prototype programming system was developed for intuitive programming. The teaching module has a joystick handle and a sensor unit consisting of a wireless sensor node, an F/T sensor, and batteries. The wireless sensor node has an ARM Cortex M0 processor, a 2.4 GHz radio, and an ADS1278 24-bit analog to digital (A/D) converter. The six-axis F/T sensor is a K6D40 (ME-Meßsysteme GmbH, Germany). The F/T sensor measuring range is ± 200 N and ± 5 Nm with regard to the x- and y-axes, and ± 500 N and ± 10 Nm with regard to the z-axis.

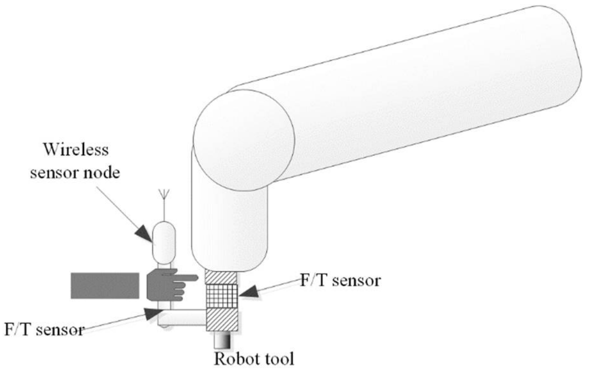

Figure 2. Operation principle of the walk-through approach.

Figure 3 shows the architecture of the intuitive programming system. Six channel strain gauge signals from the F/T sensor are amplified with signal amplifiers and are sampled at 250 Hz. After AD-conversion they are sent wirelessly to a gateway node. The gateway node is basically similar to the wireless sensor node but without sensor interfaces. The gateway with a RS232 bus outputs the strain gauge signals to a force controller, a Beckhoff's CX5020-series embedded PC/PLC (Beckhoff Automation GmbH, Verl, Germany). The RS232 bus is connected to an EtherCAT terminal (EL6001 Serial Interface RS232). The Beckhoff CX5020 reads the strain gauge signals from the EtherCAT terminal and transforms the signals to forces and torques by multiplying them with a calibration matrix, which is provided by the F/T-sensor manufacturer.

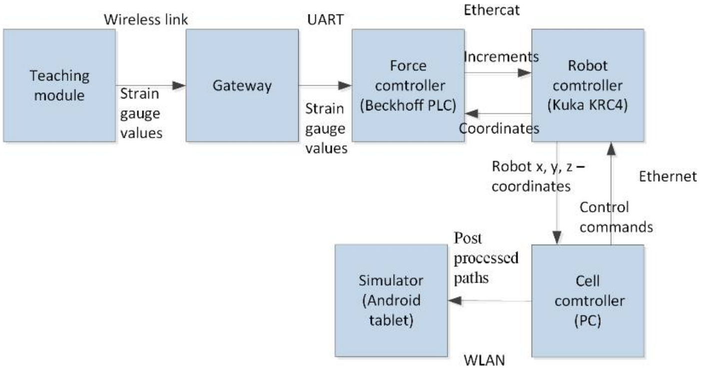

Figure 3. An intuitive robot programming system.

Two impedance controllers run in PLC applications in the CX5020, and the impedance controllers were implemented as structured text PLC programs with TwinCAT 2. The PLC application communicates with the KUKA KRC4 robot controller via EtherCAT. The position increments (Δx, Δy, Δz, Δx-rotation, Δy-rotation, Δz-rotation) produced by the impedance controller are transmitted to the robot controller via EtherCAT, and the KUKA Robot Sensor Interface (RSI 3.0) was used to execute the position increments in the robot controller at a cycle time of 4 *ms*. In the experiments, an industrial robot, KUKA KR120 R2500 (KUKA Roboter GmbH Ltd, Augsburg, Germany), was used.

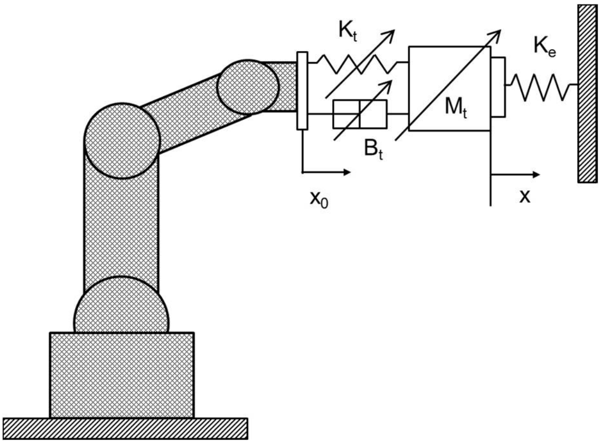

Figure 4. Schematics of the impedance controlled robot in contact with the environment.

In the impedance control principle, the position of the robot's end effector is adjusted based on the mechanical impedance model and the measured interaction force (Figure 4). The target impedance parameters, i.e. stiffness Kt, damping Bt and mass M_t, can be configured within the limits of the robot position controller bandwidth, control delay and stiffness of the environment, which together set the fundamental limits for the stability of the system.

5.4.3 Results/Findings

In order to demonstrate the manual guidance teaching method, we carried out tests using the teaching module and the KUKA robot. In Figure 5, a test arrangement is shown; the nominal machining paths were programmed by guiding the robot arm by keeping the teaching tool in contact with the surface of the work object. The robot's path points were automatically recorded by the PLC application at 0.1 second intervals. Then the raw paths were automatically sent from the PLC to the cell controller for post-processing, and the post-processed paths were sent from the cell controller to the simulation software. Figure 6 shows the paths in a Hammer Android application (Brunete et. al. 2016), running in a tabloid computer.

Figure 5. Testing of the walk-through teaching module.

The contact stabilities of the impedance compensators were designed to fulfil the robust stability criterion, as proposed by Vukobratovic et al. (2009) In our case, this led to a system in which the gain of the soft contact impedance compensator is at least an order of 100 times higher than the gain of a compensator tuned for stiff contact. With such a system, the operator may accidentally overload the robot, especially if the robot is in contact with a stiff environment. To prevent overloading, we down-scaled the handle force vector component of the opposite direction with regard to the measured robot-environment contact force vector.

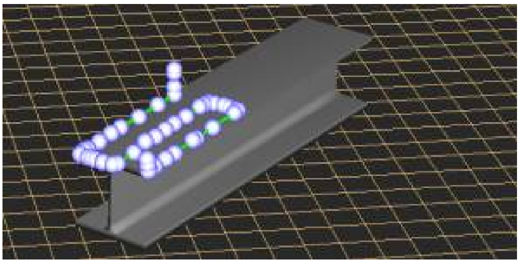

Figure 6. Path simulated in Hammer.

In order to demonstrate the effectiveness of our approach of using two F/T sensors and overload prevention, we carried out an experiment in which an operator guided the robot's tool in contact with a hard surface. This is equivalent to a teaching case in which the operator guides the robot's tool against the work object in order to teach a machining path. Figure 7 shows the environment-robot contact force measured using the wrist F/T sensor (top plot), the human-robot contact forces measured using the teaching module F/T sensor (middle plot), and the scaled handle forces (bottom plot).

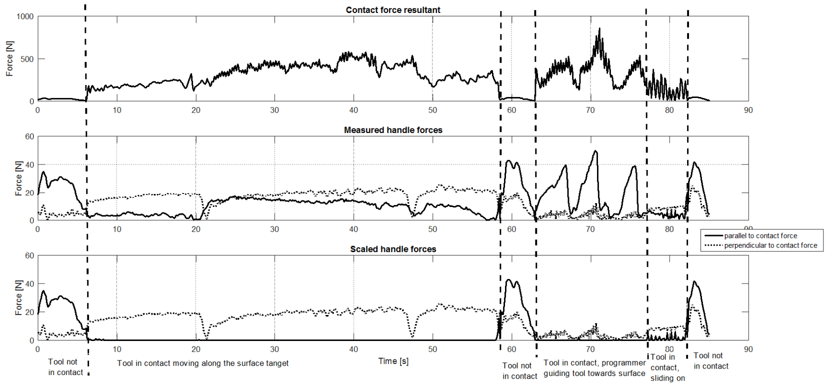

Figure 7. Environment-robot contact force measured using the wrist F/T sensor (top plot), the human-robot contact forces measured using the teaching module F/T sensor (middle plot), and the scaled handle forces (bottom plot).

From 1–6 seconds, the robot was guided and the tool was not in contact with the surface. The top plot shows that the resultant force of the wrist F/T sensor was close to zero. At time 6 seconds, the tool came into contact with the surface and the contact force increased almost instantly to near 200 *N* because of the stiff environment ($K_e \approx 10^6$ N/m). From 6 to 58 seconds, the contact force drifted up to 500 *N*, although the handle force parallel to the contact force was scaled to zero. The drift of the contact force was due to a small calibration error and corresponds to penetration of 0.5 mm. At time 58 seconds, the operator guided the robot's tool away from the surface and the contact force decreased to near zero as the tool come away from the surface. At time 63 seconds, the tool again came into contact with the surface, and the handle force parallel to the contact force was scaled to zero. From 63–76 seconds, the operator guided the tool against the surface three times. From 76–82 seconds, the programmer guided the tool to slide along the relatively rough surface. At time 82 seconds, the operator guided the robot's tool away from the surface.

5.4.4 Conclusions

The robot-based surface finishing has a great potential for boosting small batch production in SMEs, but this application requires easy-to-use and quick robot programming tools. To meet this demand, VTT has developed robust control methods for interactive robot programming by hand-guiding in realistic manufacturing scenarios. We have shown that it is straightforward to interactively program a path for a part to be processed, and then to use this path for specific tasks (i.e. grinding or polishing). Interactive programming of robot paths by hand-guiding can save a lot of time when setting the robot cell.

5.4.5 References

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5.5 VTT Dynamic Safety System and configurator

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We introduce a safety system for large traditional industrial robots to enable work space sharing. With this system we can use large robots without limiting fences and keep the robot working safely even when a person is in close proximity. Optimizing the safety distances manually is almost impossible, and therefore a software has been developed to configure the safety system easily.

5.5.1 Introduction

Traditionally, robots needed to be stopped when a human entered their cage. Many robot manufacturers have brought a collaborative robot model to the market that does not need any safety structures, but these robots lack speed and strength. In this paper, we introduce a safety system for large traditional industrial robots to enable work space sharing. With this system we can use large robots without limiting fences and keep the robot working safely even when a person is in close proximity. Optimizing the safety distances manually is almost impossible, and therefore a software has been developed to configure the safety system easily.

5.5.2 Findings

The safety system that has been developed focuses on large industrial robots and must comply with the standards ISO 10218-1, ISO 10218-2 and ISO/TS 15066 in order to make the system safe. The standards state that the robot must limit the collision force or stop before a human can touch it. As we are dealing with large robots with a lot of moving mass, we consider safety in terms of speed and separation. Thus only independent and synchronous (Marvel et al., 2015) human robot collaboration tasks are considered, and therefore the robot will be stopped before any human can touch it.

The aim has been to generate solutions that can be built according to the current safety regulations. Most of the solutions are based on advanced safety technology. The aim has also been to enable well-functioning work processes. One of the key principles is to avoid unnecessary emergency and protective stops after human attention, and to make the system restart more easily.

Several features of the suggested conceptual solutions have been demonstrated. A core demonstration has been an advanced safety arrangement to enable collaboration between humans and a large industrial robot in a shared work space, in which a human and a robot are working in the same system to perform packaging tasks. The arrangement has a guidance system for a human worker, a monitoring system for the human worker and an advanced sensor-based dynamic safety system. The system detects human motions by two separate systems. The primary system is based on any human detection sensor systems and the secondary system is based on an actual safety sensor. Microsoft Kinects have been tested, which are placed so that they cover the needed approach area in front of the robot and they are used to detect the worker's proximity to the danger zone of the robot. X- and Y-coordinates of the worker location are transferred to the Dynamic Safety Controller and predicted position of the worker is calculated based on the speed and direction of the worker. Speed of the robot can then be reduced according to the predicted position of the worker. The speed can be altered according to the worker's proximity to the TCP (Tool Center Position) or to the closest danger zone border of the robot's permitted moving area. The secondary system, which is the certified safety system, acts only if the primary system fails. We can use either a safety laser scanner or a machine vision-based safety system. The area of the safety sensor is reduced when the speed of the robot is reduced. Here the safety controller is a part of the safety system as it monitors that the set speeds are not exceeded. This enables reduction of the safety areas in the certified way. Figure 1 shows how the emergency stop area is escaping in front of the worker.

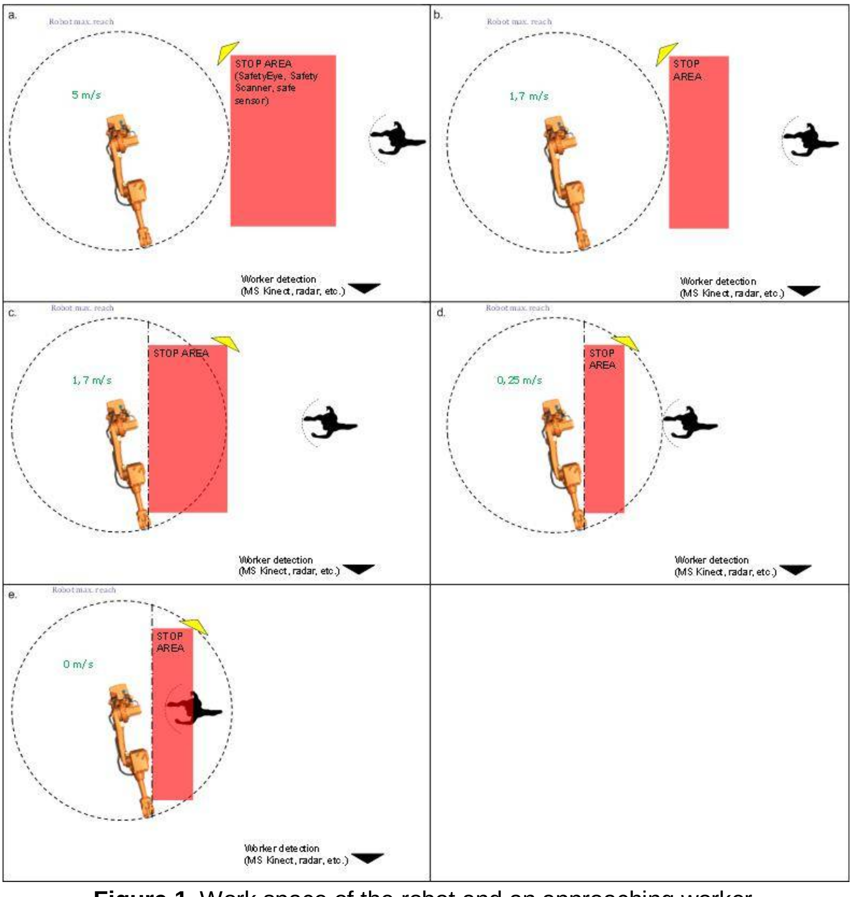

Figure 1. Work space of the robot and an approaching worker.

The safety controller also allows a switch between different permitted work areas of the robot, and thus the separation distance between the worker and robot can be decreased when the robot is working far away from the approaching human. The permitted area of the robot can always be set to the needed space rather than the whole work envelope of the robot. This dynamic safety system can bring the robot to a monitored stop without executing an emergency stop. Automatic recovery to normal speed is enabled when the human has left the danger area. The human worker is informed of the system status via informative graphical displays.

Although using a non-safe sensor (Kinect) to control the robot maximum velocity the system is safe according to the standards, since the safety sensor and safety controller of the robot are linked. The robot signals the safety controller to monitor a certain maximum velocity, which is linked to the size of the safety area (safety laser scanner). If the non-safe sensor should fail it could lead to two scenarios: 1. In case of not detecting the worker or detecting it too far from the robot compared to the actual position, the robot would not slow down when the human is approaching but the safety (stop) zone of the safety sensor would be larger and the worker would violate the area which would lead to an emergency stop. 2. In case of detecting non-existent people or detecting a worker closer to the robot compared to the actual position, the robot would only drive more slowly, not causing any safety issues.

To optimize the safety areas, ergo to minimize the separation distance of the robot and the human, we rely on the formula provided by the standard (ISO 10218-1):

$$S = KR\ (TS + TR) + B\ (KR) + CTol + KH\ (TS + TR + TB)$$

Where B (KR) is robot stopping distance, CTol sensor resolution (low resolution increases distance, i.e. a human hand can penetrate through the sensor detection field without detection), TS and TR are sensor and robot reaction time, Tb is robot stopping time, KR robot speed and KH human walking speed.

When limiting the permitted work area of the robot, we need to take into account the fact that the robot can still penetrate out of the permitted area, and will only execute an emergency stop at the permitted area border. The safety sensors have and the configurations are pre-programed, although it is possible to change between different configurations. Thus, when the robot's permitted area is changed the safety configuration needs to be changed and when the robot monitored maximum velocity is changed we need to change the configuration of the safety sensor. This leads to multiple complex safety area configurations because of all the combinations of permitted areas and permitted speeds of the robot.

To facilitate this configuration, a database of robot stopping distances in different speeds and workloads has been gathered. A tool based on this database has been created to aid in the configuration of dynamic safety systems. In the software tool the user can place different sensors and robots from the library to a layout representing the dynamic environment. The scanning areas of the sensors are shown with generated safety areas. The safety areas are generated automatically against a given robot speed and workload. Several different safety configurations according to different parameters can be automatically generated and configured, in which the parameter can be e.g. speed of the robot or worker locations in robot proximity. Permitted robot work areas can also be defined to make the system even more dynamic. The configuring tool shows the needed separation distance and thus all created configurations comply with the safety regulations. The tool can import and export safety configurations to some devices. The devices that cannot be accessed by the tool are configured manually using the instructions provided by the software tool.

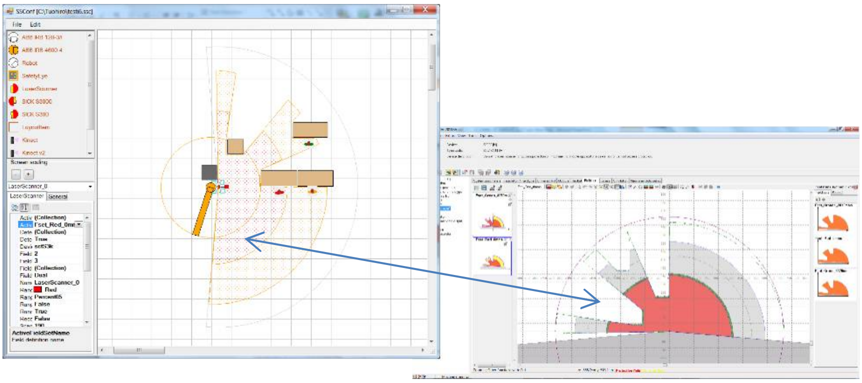

Figure 2. Example layout with area data transferred to SICK Laser scanner setup software. The configuration data can be transferred back and forth between the software tools.

5.5.3 Conclusions

A dynamic safety system for industrial robots to enable work space sharing was introduced. Modern safety devices and new standards enable human-robot collaboration and the presented safety system provides new possibilities to plan production with robot and human working together in closer proximity.

A new easy way of optimizing the safety areas of the safety sensors was also introduced. Safety areas need to be optimized in order to save factory floor space and still be able to bring humans as close as possible to the robot, thus maintaining full capacity of the robot. Complex safety configurations can be created easily with the dynamic safety system configurator.

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5.6 Remote user interface for CyberPhysical Robotics

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Remote service developments are responding to changing and growing needs of customers to improve the return on assets of the systems. We have approached the needs for remote services in robot automation by setting up a pilot system to support setup and maintenance of sensor based robot systems. The main focus has been in user interface design, to support both local field personnel as well as remotely located technology specialists.

5.6.1 Introduction

Remote services use existing and new technologies to support field engineers, irrespective of location. Remote service developments are responding to changing and growing needs of customers to improve the return on assets of the systems. Remote services should ensure that the best knowledge is in the right place, at the right time, to support the clients' assets. With a large number of different types of products, this can be a complex undertaking (Cheever & Schroeder, 2006).

We have approached the needs for remote services in robot automation by setting up a pilot system to support setup and maintenance of sensor based robot systems. Sensor based robot systems, especially with robot vision are contributing to the general production flexibility and agility requirements, e.g., by adapting to variations in part feeding with common and non-dedicated feeders and part locating systems. An essential part of the sensor usage is the calibration between the robot and the sensor. Our pilot system is designed to support such calibrations, but can be controlled and coordinated remotely. The main focus has been in user interface design, to support both local field personnel as well as remotely located technology specialists.

5.6.2 Remote service application: Robot Hand-Eye Calibration

Optical sensors can be integrated to robot systems in a variety of ways. In our case the robot is equipped with a laser profiler sensor, attached to the robot flange. The robot-sensor calibration process determines the exact geometric relationship of the laser profiler sensor with regards to the robot control point, the flange. Basically the calibration procedure is a straight forward flow of motions, where the robot locates the laser profiler in pre-programmed set of points around a regular test object (see figures 1 & 2). The adopted estimation algorithm has been originally introduced by Tsai & Lenz (Tsai, 1989) for calibrating a CCD camera relative to the last link of a robot and we have adjusted the algorithm for calibrating profiler type sensors. Observables include the robot flange poses with respect to robot base acquired from the robot controller, and measured sensor poses with respect to a stationary calibration block, determined by fitting a CAD model of the calibration object to the measured profiles. The calibration algorithm has been implemented in C++ language, running in a PC workstation in the robot cell. Details of our calibration procedure can be found from (Heikkilä et al, 2014).

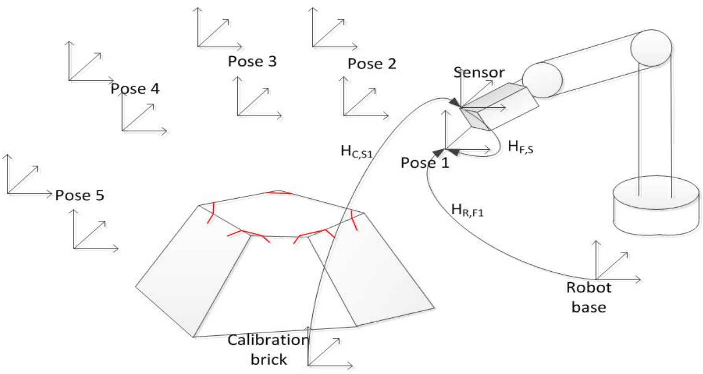

Figure 1. Principle of the robot-sensor calibration process.

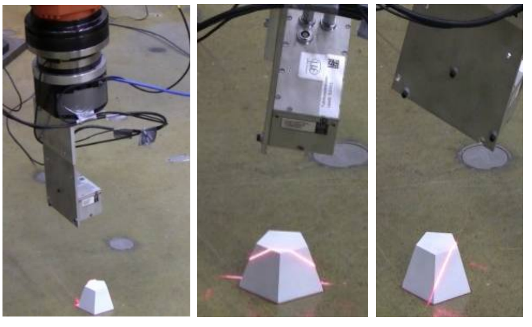

Figure 2. Execution of the robot-sensor calibration process.

5.6.3 User interface (UI) design

In order to support the design and development of the remote robot user interface, the user experience viewpoint was included and integrated in the process. This was first implemented by defining user experience goals. User experience (UX) goals are concerned with how users experience a product from their own viewpoint. The goals should be defined in the early stages of design. Based on our previous studies, UX goals such as 'experience of safe operation', 'sense of control', 'feeling of presence', and 'experience of fluent co-operation' have been relevant in remote operation contexts (Karvonen et al., 2014).

The use case for the remote UI was the remote calibration of a robot, including two user roles: remote operator and local operator (i.e. the person in the same location as the robot). Since actual end users of the remote user interface were not defined more specifically, the UX goals were considered by the development team supported by our previous studies and knowledge on UX goals.

The following UX goals were defined:

- The remote user has the sense of controlling the operation; he knows what he is doing.
- The remote user feels that the operation is safe and the system gives instant indications of deviations and unexpected incidents. It is important to know e.g. that no human enters the robot's movement range at the wrong time.

These goals were well in line with previous studies on UX goals in remote operation contexts. Furthermore, the fundamental problem to be solved in this case was that it is difficult to guide the local operator remotely using the remote operator. For the first version of the user interface, a list of features and functionalities was developed by the development team based on UX goals. The list is presented in Table 1.

From the original list, six items were chosen for implementation in the first phase (see Table 1). Providing a video connection between the local and remote operator was a natural way of supporting the desired user experience. In addition to the connection between the two operators, the general view of the robot cell was seen as important for the remote operator. The status bar (notification of status) was chosen for indicating the process status and possible deviations and alarms, aiming at supporting the feeling of safe operation. The rest of the chosen features were related to the successful performance of the calibration process, including graphs and information on the progress of the process.

Table 2. List of features and functionalities for the first UI version.

Suggested feature / functionality for UI version 1.0	**Feature / functionality chosen for implementation**
General robot cell overview video (full-screen on/off)	X
Local operator helmet video / hand-held video (full screen on/off)	X
Process phase: current phase visible, all the phases with mouse over	
Standard (calibration) procedures to be sent for the local operator	
Textbox for remote operator's comments	
Send procedure button	
Shutter – idle – poses	X (shutter, poses)
Notification of status: Colour codes for different notifications (red - alarm; yellow - deviation; green - normal)	X
Graphs: profile	X
Graphs: parameters	X
Audio / communication buttons for local and remote operator	

Providing an audio connection for the operators was seen as important in creating e.g. the feeling of presence and in supporting cooperation. It was however decided that a phone is a sufficient tool in the first phase of the development. Furthermore, adding an emergency stop button was also considered, but it was seen as a matter for possible further development.

5.6.4 Initial UI

The first version of the remote operator's user interface is seen in Figure 3.

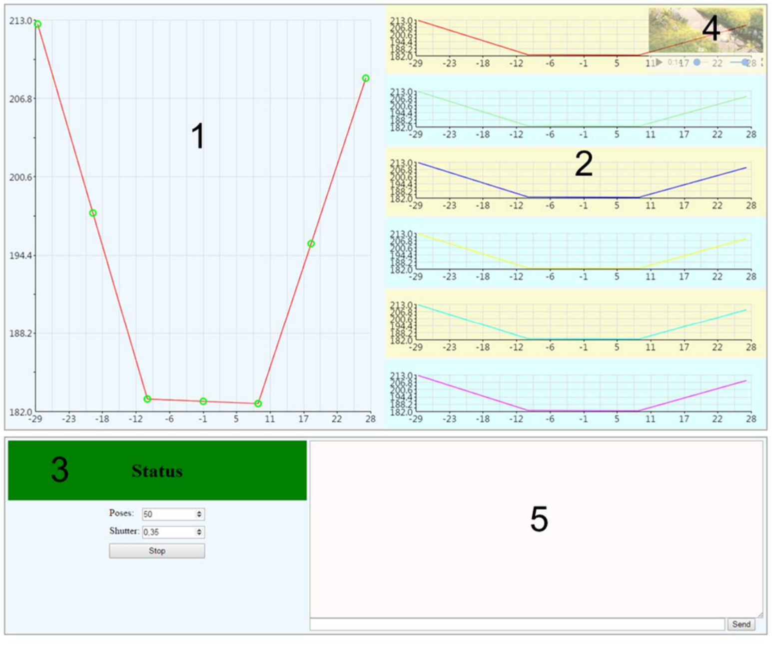

Figure 3. First UI version.

The user interface includes the following features and functionalities:

1) Graphs: The last scanned profile.
2) Graphs: Calculated scanner tool parameters after a number of iterations.
3) Status: General process state indicated with a colour tile, detailed information accessible with a mouse over. Poses and Shutter. Start/Stop –button.
4) Views: Two video views (cell overview and local operator view) and a graph view; can be switched with a mouse over.
5) Area for latest calibration results. Send-button.

5.6.5 Improved UI

The layout and usability of the first UI version was re-evaluated by the project team's human factors (HF) specialists. As a result, a number of improvements were implemented in the next version of the UI (see Figure 4):

- Change of language: From English to Finnish. This is based on the idea that the users' native language should be used when possible (see Nielsen, 1994).
- Titles for graphs (in Finnish): "Profiili", "Korkeus/Leveys", "Asentoa" (etc.)
- Button for switching the video / graph view (top left corner). Video view as a full screen mode.
- Calibration results: Numeric indicator of the progression of calibration process (current poses / total number of poses): <RemoteOperator> Viimeisin tulos (5/50), (10/50)… (50/50).Subsequent paragraphs use the Word style Body Text First Indent.

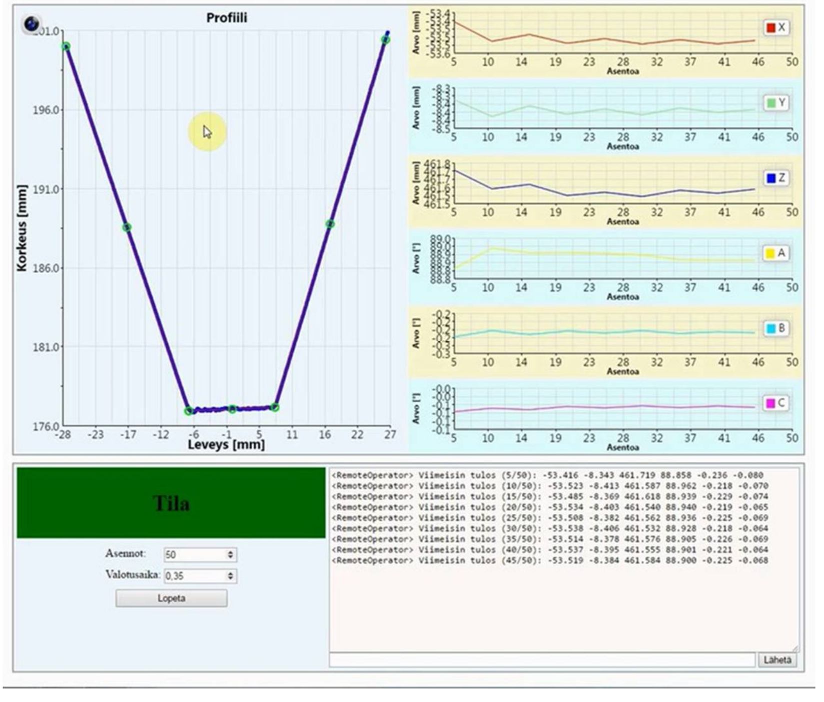

Figure 4. Second UI version.

5.6.6 Final UI with video view

The second version of UI is the currently the latest version. The remote operator's video view can be seen in Figure 5. On the top right corner is the cell overview video, and the larger view is the video connection between the local and remote operators. Additionally, a simplified UI for a local operator was created, including basically only video views for connecting with the remote operator.

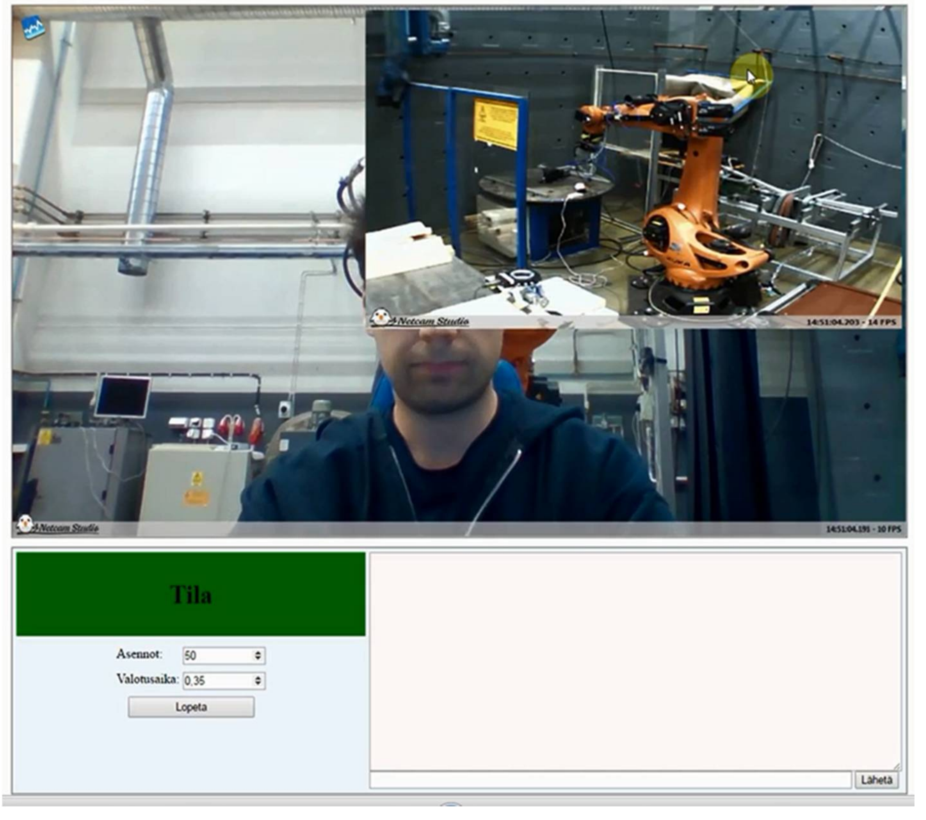

Figure 5. Remote operator's video view.

5.6.7 UI implementation technologies

Because the user interfaces has to work on as many devices as possible, the implementation had to be platform independent. This meant that we had to use the current web technologies, and run the calculations on cloud. Also all communication that go through the internet had to be secure.

Figure 6 below illustrates the implemented software architecture. In the server side, we have the websites, but we also have the calculation process and a

WebRTC signalling server that is used in video conferencing. The robot cell side includes a software component that communicates with the robot and the necessary sensors, and also works as a proxy towards the remote UI. To make a secure video feed visible from the cell, instead of connecting the camera directly to the internet, a streaming server (http://www.netcamstudio.com) was installed on the cell computer.

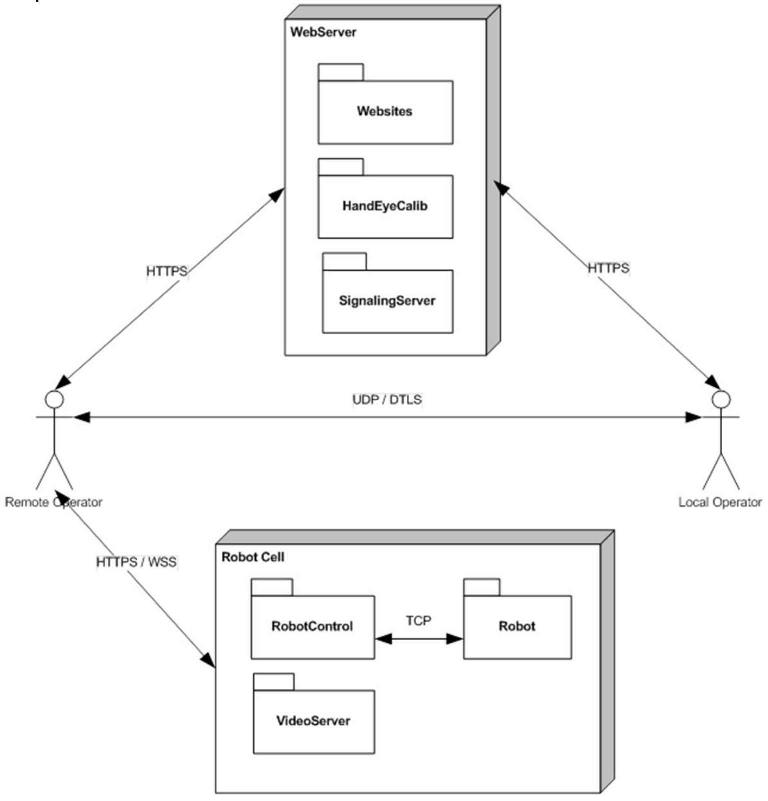

Figure 6. Software architecture.

The user interfaces were implemented by using HTML5, JavaScript, CSS, Secured Websockets and PHP. The HandEyeCalib calculation process was implemented by using Qt, and it is automatically called from the user interface via PHP. The results and requests between the UI and the calculation process are encapsulated into JSON strings. Instead of implementing our own signalling server, we used a free RTCMulticonnection (http://www.rtcmulticonnection.org) JavaScript package that includes a signalling server and also client side libraries for establishing video conferencing. Because the signalling server is implemented by using JavaScript it has to be running on Node.js (https://nodejs.org). Also, instead of implementing our own plotting functions, we used RGraph (https://www.rgraph.net/) JavaScript libraries.

In the cell side, the RobotControl component was implemented by using Qt and the communication towards the remote UI was implemented by using websockets, and the data was encapsulated into JSON strings. The used robot was KUKA's KR120 with KRC4 controller.

The security was established by generating our own SSL encryption key and a root certificate, that is manually installed only on trusted devices.

5.6.8 Remarks

The pilot system was implemented and tested in our own premises. However, the actual user experience and usability was not yet evaluated in the real use situation with external users. According to the previous studies, careful attention should be paid to the auditory information provided by the system from the object environment (Karvonen et al., 2014). A video chat could also be considered. Furthermore, the remote operator's role in safety matters should be elaborated. If there is a need for remote monitoring of the robot's movement area more carefully, and for reacting to sudden problems, what are the features and tools needed for that purpose?

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6. Industrial Internet

6.1 Overview on the Industrial Internet of Things

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The Industrial Internet of Things research module focused on the digitalization of discrete manufacturing processes, in the Finnish SME sector. The leading idea was to study how to create value and a competitive edge from manufacturing data. In addition, issues challenging the progress of Industrial Internet types of applications were the focal point. In the run time of the For Industry programme, alarmingly few research projects matched the set focus. Nevertheless, experiments done in research projects indicate that, with Industrial Internet applications, it is possible to improve the efficiency of production processes, even if the implementation of such systems still faces many barriers. This writing also tries to underline the importance of continued production development.

6.1.1 Introduction

Competitiveness of manufacturing has, at the moment, profound impact on any national economy. Even if developed countries are in the process of deindustrialisation, manufacturing still typically represents about 15–20% of the gross domestic product (GDP) and easily more than half of the exports (EK, 2014). As a rule of thumb, a job in manufacturing creates three other supporting jobs. In developed industrial countries, such as Finland, the competitiveness of manufacturing is directly linked to productivity development, which in turn, is strongly related to digitalisation, and in particular, to the development of working processes, enabled by the introduction of new technologies (Pohjola, 2008). Hence, there is evidently a global competition over manufacturing, which translates to a need for a productivity leap created by the application of digital technologies.

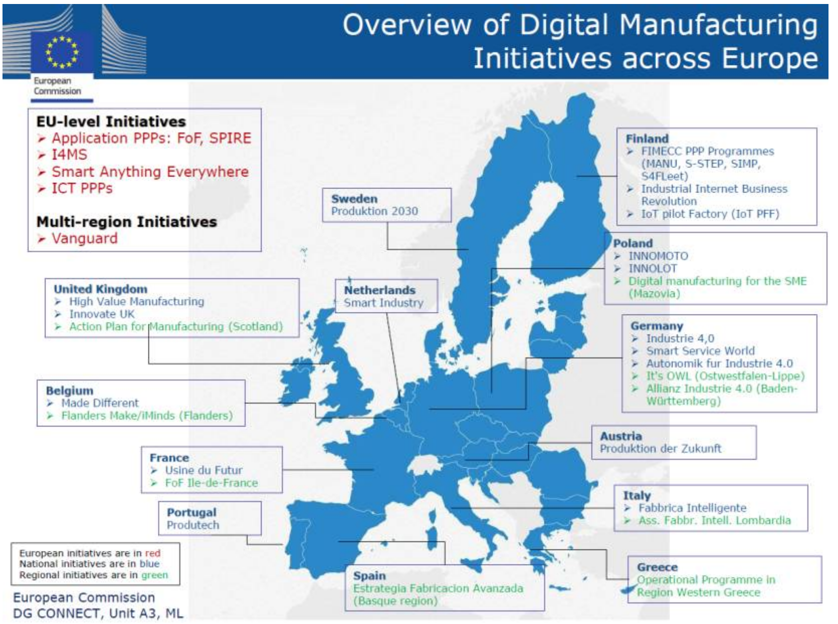

Figure 1. Digitalization initiatives for manufacturing industries in Europe. There are also huge R&D programmes running in the USA and China (DG Connect, 2015).

In order to digitalize the manufacturing industry, the investments in research and development (R&D) are huge, several billion euros per year. This also indicates that politicians, worldwide, have understood the importance of the competitive manufacturing sector and its relation to the sustainability of national economies. Furthermore, it is rather obvious that these R&D investments will create technical innovations, and in connection with political agendas, the entire essence, that is, the location of manufacturing may be in constant change, in the beginning. In some instances, this change is called the fourth industrial revolution, which very much concerns Finland.

In Finland, we have had notable research funding available from the TEKES programmes, SHOKs and the EU Horizon 2020 programme for digitalizing manufacturing industries, and consequently a number of research projects were started. However, when analysing which type of projects were funded, we can clearly see that, with few exceptions, all of the projects focus on developing new technologies for existing products, enhancing the features of existing products or creating digital services based on existing products. Projects aimed at developing the competitiveness of Finnish manufacturing were and are alarmingly rare, or no longer exist, at all. The competitiveness of products is, naturally, the corner stone of any successful manufacturing company and the research done is, therefore, highly relevant. Certainly, there can be successful companies and products without competitive manufacturing. That may well be the core of the Industrial Internet of Things in the digital future, where products can be manufactured anytime, anywhere. But, can the Finnish economy really afford to lose more manufacturing jobs, their multiplier impacts and exports? And, in the long run, R&D and engineering are likely to follow the outsourced production.

In 2014, keeping the previous in mind, when Germany's Industrie 4.0 had just gained worldwide attention and the Industrial Internet was at the peak of a hype curve, the research module Industrial Internet of Things was focused on the digitalization of discrete manufacturing carrying weight, especially, in the SME sector. Product development and product integrated services R&D, such as the conventional Industrial Internet applications (i.e. condition based maintenance (CBM), fleet and asset management and adaptive process control (APC)) were excluded from the module's scope. So was robotics, which had its own research module. The objective of the module was to coordinate research that was directly aimed at improving the productivity of discrete manufacturing processes or recognizing and removing obstacles in the digitalization of these processes.

When considering digitalization of discrete manufacturing, the basic problems have actually remained the same over the last two decades, when attempts have been made to apply more integrated IT systems to factories and supply chains. Firstly, there are issues with connectivity, data interoperability and the legacy of production equipment, as well as he manufacturing of IT systems. Secondly, there is a fair amount of uncertainty in investments and implementation; integrated systems cannot be bought from the shelf, but rather, they need to be tailored to fit each company's processes, used technologies and legacies. Some traditional barriers in the digitalization of the SME manufacturing industry are summarized in Table 1.

Table 1. Examples of barriers in the digitalization of the SME manufacturing industry.

Factory floor automation and robotics	Manufacturing IT systems	Digitalization of processes - CPS
No 'oof the shelf' technology available – no business case	Investment risk – costs vs benefit	Too low technology readiness level
Lack of specialized development resources	Process fit – need of integration and tailoring	Interoperability of systems and devices
Investment risks - no experimentation possibility	Lack of applied standards, legacy systems	Investment risk – speculative benefits

In addition to the above-mentioned problems and barriers, Industrial Internet applications in manufacturing create more issues, such as cyber security, data integrity and data ownership. On the other hand, the hype over digitalization and the Internet of Things is driving a fast development of related technologies. Automation system platforms as well as Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES) are adapting Industrial Internet features at an increasing rate. Also, there are serious cooperated initiatives to solve the connectivity, interoperability, security and integrity problems. Hence, there are strong reasons to believe that, despite all of the problems and challenges, we are evidencing the fourth industrial revolution, even if it might look more like an accelerated evolution, at the moment.

6.1.2 State-of-the-art

Even if considering the Industrial Internet of Things as a subset of the digitalization mega trend, there has not been much progress in the Finnish manufacturing industry. The most significant digital productivity leaps, in manufacturing workshops, were most like gained by applying numerical controls to working machines (~1970 ->) and later the utilizing of personal computers (PC) and ERP systems (~1990 ->) for resource planning and business process control. Further development has been, at least to some extent, gained by the integration of different ICT systems in the order fulfilment process inside of factories and in the supply chains (~2000 –>). The way of working on the factory floor has not changed significantly, during the past two decades, even if different IT systems have been proposed for making production processes more efficient. As a matter of fact, the development trend, in the productivity of Finnish work, has been clearly digressive since 1995 (Tilasto, 2015).

There are, however, some early adaptors of Industrial Internet technologies in the Finnish manufacturing SME sector. It seems that the first Industrial Internet applications, in discrete manufacturing, will aim to connect human workers to production processes and control, with the aid of personalized mobile applications. An example of such a system was implemented at Suomen Levyprofiili, in 2015 (Junttila, 2016). The system collects and analyses data from work in progress, reports the status to the ERP and visualizes personalized control information to operators, logistics and production management.

Figure 2. User interfaces of a mobile welding job reporting and control (source: Suomen Levyprofiili Oy).

A similar application was developed in the FIMECC LeanMES research project, where the LeanMessenger concept utilized smart watches for work progress reporting. This concept also introduced a workstation and operator specific task management system, which is related to the operator's skills and location inside the factory. The concept was designed especially for operators of machine tools and FMS systems and was demonstrated by Fastems Oy.

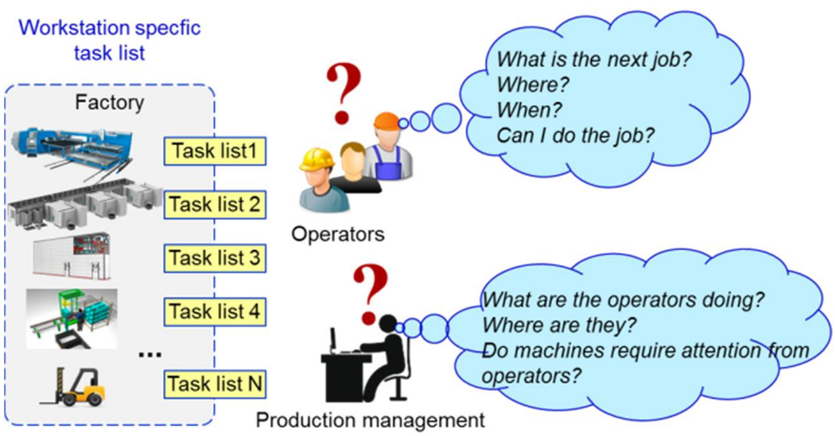

Figure 3. Illustration of LeanMessenger task management system's functionality (source: LeanMES project).

Another realized Industrial Internet applications in discrete manufacturing are real time monitoring systems for production process efficiency and capacity.. In Finland, some manufacturing companies have implemented such systems in cooperation with local software companies that provide the technology for adding external sensors to production equipment, collecting the sensor data to a cloud service and analysing the data for calculation of production key performance indicators

(KPI). Such a system has been implemented and presented, for example, by Stera Technologies Oy, in a Tekes funded project.

There are actually clear reasons why these two application fields, operator guidance and data collection by added sensors, have been the first Industrial Internet applications in Finnish discrete manufacturing. These types of applications can be built and implemented without heavy data integration to control systems of the production equipment and other relevant IT systems, such as the company's ERP or PLM (Product Lifecycle Management). When considering these example applications from an Industrial Internet based manufacturing point of view, they present a feasible starting point. In these applications, the collected data is still unconnected from the production context, which remarkably lowers the usability and value of the collected data. For example, if data read from a sensor attached to a machine tool could be connected to the data available in a machine control system (e.g. active program, active tool, machining parameters, alarm codes, motor torque, etc.) to order specific information from the ERP (e.g. bill of material, routing, customer details, delivery data, etc.) and even to supply chain data (e.g. quality control data, raw material property data, etc.), there would be a possibility of building truly sophisticated analytics systems and KPIs. As a matter of fact, it might even be possible to innovate new manufacturing business models that actually are the core of the Industrial Internet. This would, however, require complete data interoperability between all systems, and is thus, just a utopia, at the moment.

6.1.3 Review of main results

The objective of the module was to coordinate research that aims to increase the performance in discrete manufacturing, by applying Industrial Internet technologies. As the method, the module preferred experiments and demonstrations that would make the research and development results concrete and easy to approach. Research questions were defined as follows:

1) Can data collected from production processes be refined to valuable information and consequently productivity improvements?
2) What new connectivity technologies would allow higher numbers of sensors and measurements in production processes?
3) The data integrity problem: can blockchain technology create new possibilities in manufacturing?

The Predictive Manufacturing project gave some answers to the first research question. In the project, a real data set of factory floor events, from a Finnish SME workshop, was entered into an analytics tool developed at VTT. The analytics identified significant correlations and patterns from the production data, and consequently, many interesting observations about the process efficiency could be made. The project successfully demonstrated the concept of how data collected in almost every job shop, which is hardly ever used at all, has value and can be refined to information that enables development of production processes.

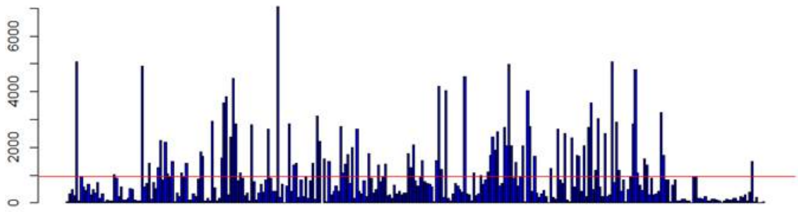

Figure 4. Example of data analysis done from the factory floor event data; deviation of trough-put times per item. Do you know your deviation and the source of it? The analytics tool can answer these questions.
(Source: Predictive Manufacturing project.)

The connectivity issues of the Industrial Internet were also studied in the research module. It seems possible that before all technical specifications, standards and business models of 5G are set and available, LPWAN (Low Power Wide Area Network) may offer a feasible solution to connect a large number of sensors to a wireless network. The advantages of LPWAN technology are extremely low power consumption (hence a long battery life in wireless applications) and much lower communication costs in real-time measurement applications, compared to 3G/4G technology.

Table 2. LPWAN IoT connectivity overview.

Technology	Data rates	Energy consumption	Data pipeline	Technology readiness
SigFox (proprietary)	12 bytes at the time, 144 times a day	very low	Via SigFox cloud system	Good. HW available
LoRa(WAN) (alliance)	10-50 kbs	low	Via LoRaWAN HW provider could or user defined (LoRa)	Good. Existing HW, also in base stations
3GPP (NB-IoT etc.)	Up to 150 kbs	low	Operator	Low. No HW yet available
RPMA (proprietary)	Up to 100 kbs	low	N/A.	N/A
5G	*<1 Mbps*	*low*	*Operator*	*Available after 2020*

In the module project, a wireless sensor node, with versatile sensor and cloud service interfaces, was designed, prototyped and demonstrated at VTT.

Figure 5. VTT LoRa node circuit board developed and demonstrated in a module project.

What concerns the manufacturing equipment and data in Internet the cyber security is a must but in a wider perspective not sufficient. Also the data integrity needs to be addressed. In practise, this means that the source, validity and ownership of data must also be ensured. Blockchains are seen as an emerging technology that has the potential to essentially solve data integrity problems as well as completely change the way digital data and value is handled between different parties. If the Industrial Internet is to create, new manufacturing business models are likely to be a part of the solution. In the research module, the blockchain technology and its viable manufacturing applications were, thus, studied.

6.1.4 Future visions

In the discrete manufacturing industry, development that is connected to investments and lifetimes of production equipment is rather long, in some cases covering decades. It is obvious that large scale digitalization does not happen overnight, but rather, is more of a side product of the normal renewal of production equipment and IT systems. This underlines the importance of investments in the latest manufacturing technology. Manufacturing companies, with a profitable business, are usually open to any profitable investment, if the implementation risks are known and limited. When the Industrial Internet technologies are mature enough, available and tested for the business case, the digitalization of the manufacturing industry will gradually proceed through well planned and considered investments. The question is: how does this kind of digitalization create a competitive edge for Finnish manufactures, compared to any others who are investing in the same technology?

As stated, the Industrial Internet enters manufacturing workshops through investments in the latest machinery and equipment that have the capability to load data to cloud services. This data is really interesting to machine vendors, who are trying to invent new ways to boost their service business. These vendor specific systems can collect very detailed and, also, confidential information from companies' production processes. Modern machine tools are also rapidly adapting the features described in Industrie 4.0, such as improved man-machine cooperation, data collection and improved connectivity and data interoperability.

Furthermore, manufacturing companies are beginning to realize that the data collected from the production processes has value and that integrating the data, with other context relevant data, substantially increases the value of said data. In fact, manufacturing companies should now start to carefully consider the validity, ownership and user rights of their data, as well as the cyber security of data connections.

In the Industrial Internet future visions, platforms will have a central role. Platforms are in the position to solve integration, interoperability and data integrity problems, which standardization has not yet been able to solve. A number of vocabularies, ontologies and formats have been standardized or proposed as standards for data interoperability. Until today, economic interests, technical shortcomings or lack of coverage have prevented any of the standards from gaining real popularity. In consumer business, however, customer needs have resulted in working standards and, thereafter, to platforms that have been able to simplify the technical diversity. Similar development will most likely take place in industrial applications and that is why many technology companies are driving their solutions to standard, or de-facto standard, Industrial Internet platforms. Platforms need to be built on communication standards for which OPC-UA is the strongest candidate in Europe, while the rest of the world seems to vote for MTConnect or both. The platform winners will naturally be such solutions as will be able to attract a critical mass of application developers, compatible hardware suppliers and end-users.

The digitalization of manufacturing has started from factory floor data collection and improved the human-machine and human-process interactions. The next step will be integration of the manufacturing data to other relevant data sources, which will allow the development of sophisticated analytics systems, for the control and optimization of production processes. Finally, the Industrial Internet will also integrate the data of entire value chains throughout the entire product lifecycle, from raw materials to recycling. This, in turn, will enable a real integration of manufacturing, product development and lifecycle management, creating digital data driven processes and feedback loops over organisation and company borders (Figure 6). New ways to develop the efficiency of all processes connected to manufacturing will be open to manufacturing companies. Moreover, new business opportunities for innovative manufacturing equipment and software companies will be available, and maybe, even entirely new Industrial Internet based manufacturing business models will eventually be invented.

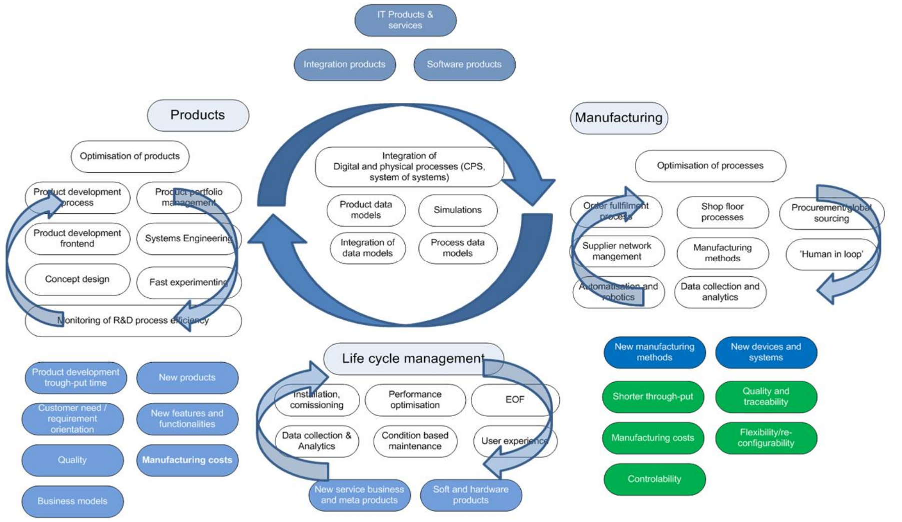

Figure 6. Digitally driven processes & feedback loops in manufacturing.

Nothing is more difficult than predicting the future. Nevertheless, there have been several scenarios presented on the impacts of digitalization in manufacturing. In an idealistic scenario, the digitalization results in distributed manufacturing systems, enabling a more sustainable manufacturing of goods, close to the end-customer. Furthermore, digitalization is considered to make the manufacturing more democratic; developing countries without existing manufacturing infrastructures could more easily start to refine their natural resources into more value-added products. In a more realistic scenario, however, digitalization makes the strong manufactures, that have the required resources to exploit the latest technology development, stronger. Manufacturing would be independent of labour costs and skills, and at this point, the manufacturing industry will simply find locations where the overall profits are optimal (if a political intervention, e.g. rising protectionism, does not prevent this).

What is the scenario for the Finnish manufacturing industry that has a small domestic market, remote location, two decades of low productivity development, a long-term investment depression, and on top of this, practically terminated production and manufacturing methods R&D? There will be some challenges ahead, at the very least.

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6.2 Enabling a productivity leap with production data visual analytics

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The goal of the experiments and prototyping was to study ways to improve manufacturing competitiveness with advanced big data visual analytics. Production managers can use interactive visual analytics to take a deep dive into historical process data, identify patterns and relationships among discrete process steps and inputs, and then optimize the factors that prove to have the greatest effect on productivity. The constructed prototype for intelligent decision support was successfully tested with industrial data.

6.2.1 Introduction

Manufacturing companies are facing global competition, they have to be better, cheaper and faster. In order to manage, they need a productivity leap and eliminate ineffective time and waste in production. Manufacturing companies collect huge amounts of data from their manufacturing processes, which is increasing due to the digitalization of manufacturing and the Industrial Internet of Things (IIoT). Typically, data from a production material flow is stored in different data repositories. If this data is not analysed, the improvement potential is not found.

There is a need for interactive analytics tools that can turn raw data from heterogeneous data sources (e.g. starting from sensor data, manufacturing IT systems) into meaningful information and predictions, and present it on easy-to-use interfaces. For analytics of small series, customer driven manufacturing and flexibility for complicated customized data analytics is needed. The solution is to combine human capabilities to interpret visualizations with automatic data processing and machine learning, e.g. use of visual analytics.

The goal is to go beyond descriptive statistics, monitoring and reporting on what has happened, and learn from previous data using statistical methods, machine learning and customized visualization. In addition, it entails being able to show correlations, patterns, deviations, trends and forecasts, and find and optimize the factors that prove to have the greatest effect on productivity. The end result is to streamline decision-making and produce new insights that lead to better actions.

Manufacturers taking advantage of advanced analytics can reduce process flaws, saving time and money. Gains will likely show up in both labour productivity and resource productivity. Estimations of the impact are presented by the MGI McKinsey Global Institute on Big data.

The next frontier for innovation, competition, and productivity (2011) includes sensor data-driven operations analytics (10–20% operation costs, up to +7% revenue) and “Digital Factory" for lean manufacturing (10–50% assembly cost + 2% revenue).

This chapter presents feasibility studies focusing on the interactive visual analytics of manufacturing data sets carried out at the VTT Technical Research Centre of Finland Ltd. The research question was how to convert manufacturing big data to business and manufacturing advantage? The objectives are twofold: getting experience and guidelines for applying visual analytics in manufacturing and analysing the feasibility of the VTT OpenVA concept, with real manufacturing data.

6.2.2 Visual analytics and VTT OpenVA concept

Visual analytics provides visual and interactive tools to support analytical reasoning and find insight from data. It combines the human capabilities to interpret visualizations with automatic data processing. A visual analytics tool shows the information, in the form of interconnected and interactive visualizations, making the analysis easy for non-experts in data analysis. Behind the visualizations are statistical, data mining and machine learning methods. Users can look for patterns, trends, anomalies, similarities and other relevant features from the visualizations. Visual analytics is an iterative process (Fig. 1 a), where users launch analyses, browse and navigate in visualizations, and highlight and select important areas for further study.

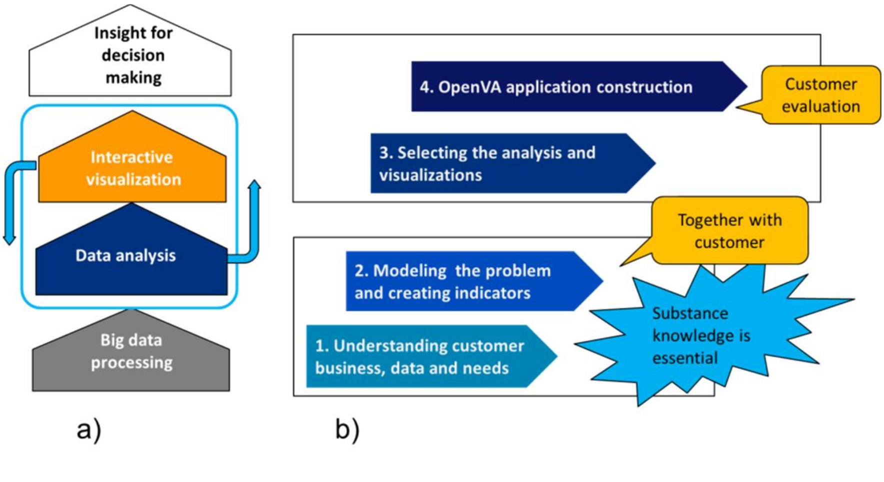

Figure 1. a) Steps in interactive visual analytics, b) VTT OpenVA customer application construction steps.

VTT OpenVA is a visual analytics platform, for measurement data, by VTT Technical Research Centre of Finland Ltd (Järvinen, 2013; Järvinen et al., 2013). It consists of a database, a library of visualization and analysis methods, an interactive user interface and a visual analytics engine that delivers data and analysis requests between the different components. The database stores the application data in a domain independent form. The database contains the data of background variables, measured variables and indicators, and it is populated with application specific metadata. The analysis and visualization library contain a selection of analysis and visualization methods, and it is extendable. The visual analytics tool adapts itself to each application, with the help of the metadata stored in the database. The data to be analysed is loaded from external sources to the databases through a uniform data interface. Visual analytics have been studied at VTT since 2009 (Järvinen et al., 2009).

OpenVA is applied by a step-by-step configuration process (Fig. 1 b). The first step is to understand the customer's business, their analysis needs and find out what data is available. Then, the next step is to define the phenomena that are followed, identify the variables that might explain the system behaviour and form indicators from the variables. In the third step, appropriate analysis and visualization methods are specified. A set of methods is already provided by OpenVA, but new methods can be added. In the final step, the analytics application is constructed by configuring the OpenVA platform and loading the application onto the platform database.

6.2.3 Feasibility studies

The first feasibility study on manufacturing data was carried out in 2015 and is presented in Heilala et al. (2016). The data sets were structured data, from a simulation study, of an automated material handling system. Data was similar to real industrial data that is, typically, automatically collected from automated equipment and robotics, e.g. working time, disturbances, setup and process times, utilization rate, etc. The analysis questions were designed to study the efficiency of the automated material handling system, to predict the production output and find bottlenecks. The selected variables were the utilization rates of the system key resources. The indicator chosen for the system output was finished products/hour.

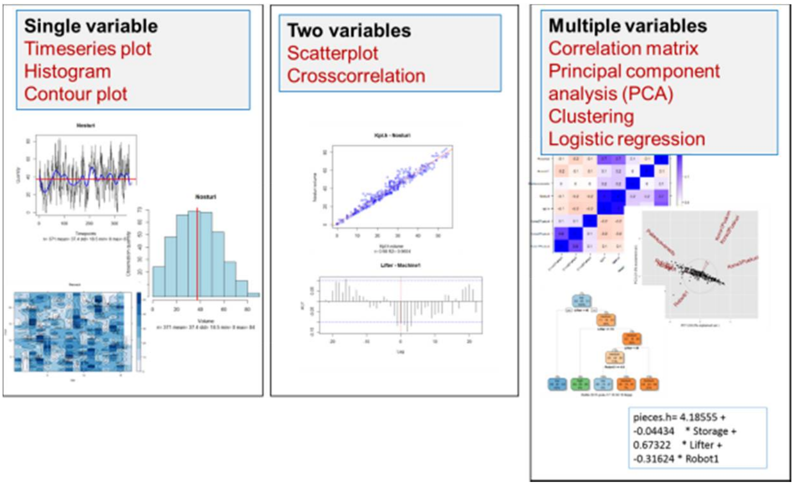

Figure 2. The included set of analysis and visualization methods.

The set of analysis and visualization methods included a time series, histogram, contour plot, scatterplot, cross-correlation, correlation matrix, principal component analysis (PCA), clustering and logistic regression (Fig. 2).

The second feasibility study was carried out in 2016, with real industrial data. The data was from an SME company doing high mix, low volume customer driven manufacturing. The data set was a transfer file from an ERP (Enterprise Resource Planning) system, with 4 months of production data. The data file was an Excel sheet having 152,037 rows and 17 columns. The file had data on items, work orders, planned amounts and start times, planned and calculated workloads for each task, as well as actual task time stamps, from the factory floor, showing the workflow progress. For analytics purposes, some additional parameters were calculated from this raw data.

Regarding data quality, the most difficult data sources are, typically, the humans on the factory floor, which was partially the case, here. There are latencies, delays in submitting progress data to the ERP and the potential need for many human interactions; thus, manual errors are possible. Some of the time stamps from the production phases did have inaccuracies, e.g. the work phases status was entered as being the same time for starting and finishing the work phase or some of the work phase recordings were missing.

The starting point, in this analysis, was that the production process was well functioning if order lead times were stable or had low variability and the planned lead times equalled the real lead times recorded from factory floor. Even if the amount of the data was partially low (e.g. because of low production volumes), the analytics and predictions did give valuable insight into reasons for variability in order or task lead times, as well differences on planned and real lead times.

6.2.4 Using VTT OpenVA

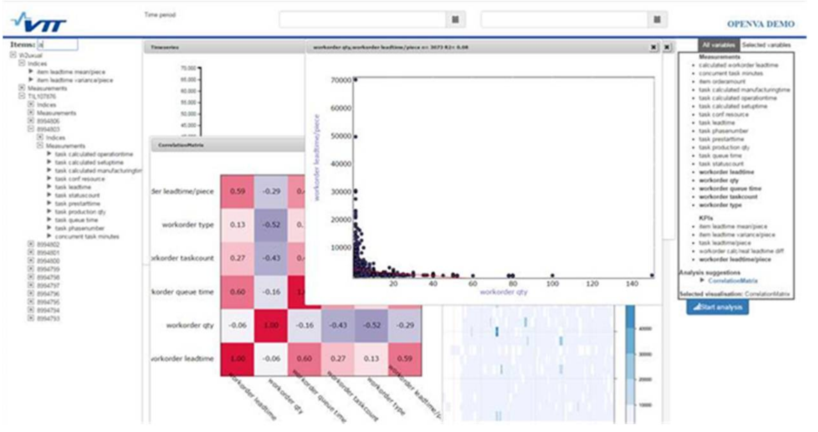

Figure 3. VTT OpenVA has a web browser user interface.

The current prototype of VTT OpenVA is a cloud based tool with a web browser interface (Fig 3.) The analysis with VTT OpenVA is performed as an iterative reasoning process. First, the user is shown the current status of the selected performance indicators and then the most important variables. The user can study the indicators and the other variables, in detail, with the help of visualizations.

The user starts the analysis by formulating an analysis question, e.g. “What explains the variability in lead times?” Next, the user selects the variables and indicators that might give answers to the question. The tool suggests suitable analysis and visualization methods to the user, based on the number and type of the selected variables. Then, the user launches the analysis and gets the results in visual form. The analysis is interactive, deeper digging into the data can be done by directly selecting variables and parameters, from visualizations, using a mouse. The analytics can go up to an item or resource level.

Findings from the presented feasibility studies were promising. In the first small-scale test, relationships, correlations between variables and bottlenecks were identified, and this is a good starting point for optimisation. Visual analytics is also useful for simulation run results analytics or for pre-processing of real manufacturing data before simulation studies. Predictive analytics, future forecasting, was done with logistic regression. The problems of getting data were not studied.

The second feasibility study was demanding, due to the use of real manufacturing data, and that instead of a smaller system, the focus was on the whole factory. Without data on the factory layout or a factory simulation model, analytics was carried out using ERP transfer data. The results show that VTT OpenVA is a suitable tool for monitoring production processes and for productivity analysis. Inside the factory, having the ability to utilize data masses from orders and machine statuses, allows production managers to optimize operations, factory scheduling, maintenance and workforce deployment.

The use of VTT OpenVA is not limited to the manufacturing domain, it has multiple application areas.

6.2.5 Conclusions

As discussed in this chapter, the visual and interactive tools can be used to support analytical reasoning and gain insight from manufacturing data. The visualizations can be chosen, case by case, so that they are focused on the task at hand, and exactly support those decisions that must be made.

The production managers need easy to use tools for finding and eliminating productivity ineffectiveness, e.g. waiting times, bottlenecks and doing manufacturing process improvements. The production manager needs to consider two different time frames, on the one hand, the development of equipment and control principles with longer planning and implementation times and on the other hand, daily operative decision-making. The presented feasibility studies were focusing on finding reasons for poor productivity and identifying areas for improvement.

In the case of daily planning, there are development needs for reliable and real-time access to data from the factory floor, sensors, devices, human operators and manufacturing information systems. Also, analytics needs to forecast potential future events, e.g. the use of predictive analytics (what will happen?) and also support optimization (what action should be taken?), in a near real-time timeframe. To build such an IIoT system, all of the following topics are needed: data access from heterogeneous sources with data preprocessing and transformations, big data management in the cloud, predictive analytics, deep learning and visualization of insights for decision-making and action planning.

For extended enterprise, real-time visibility between suppliers and the production line allows key value chain participants to optimize the material flow and reduce the process cycle time. Furthermore, the use of predictive and prescriptive analytics, using real-time data, allows the enterprise to rectify future bottlenecks and eliminate high costs associated with operational downtime. Developmental difficulty increases, as does value, from use.

Experts at VTT are aiming to continue the development. Potential future development topics, as listed above, are for a daily planning tool with predictive analytics and to enhance scale from factory to extended enterprise. One future research idea could study synchronous collaborative visual analytics in manufacturing. An important objective is to combine the best ideas of collaborative work, with those of Visual Analytics, i.e. to support interactive collaborative visualizations, in multi-party settings.

The ability to analyse large amounts of complicated, heterogeneous data, with custom-written visual analytics will be a key component in future business and industrial intelligence – analytics. Data-driven decision-making, in manufacturing, enables a productivity leap. Predictive manufacturing analytics enables users to:

- Progress from monitoring to predictive analytics, optimization and to “how can we make it happen?”

• Near real-time warnings of potential problems, embedded dashboard to factory floor, etc.
• Analyse production characteristics and business performance.

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6.3 Novel communication solutions in industrial measurement solutions

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Until recently, in the wireless Industrial IoT systems, collected data has been transmitted from the measurement networks to the Internet connected gateway solutions using short range wireless technologies, such as WiFi or Bluetooth. These technologies, however, have range limitations and they have not been able to be replaced by operator network based long range solutions such as 3G/4G technologies, due to pricing and limited energy effectiveness. Current progress, in the field of low-power wide-area network (LPWAN) technologies, is promising to overcome these recent technology limitations. In this short project, an applicability of the novel low-power wide-area network (LPWAN) technologies, for general purpose IoT connectivity, was briefly evaluated and the most suitable technology was selected and tested with the first VTT LoRa Node prototype platform.

6.3.1 Introduction

For some time now, the industrial wireless measurement connectivity technologies have been based on various mature short range (<100 m) ones, such as Bluetooth, ZigBee, WirelessHart etc. Solutions to solve the limitations of short range have been tried, e.g. mesh type multi-hopping network extensions to the original communication stack. Mesh technologies limitations include immature software, an energy hungry complete system and maintenance complexity. The long range wireless technologies, such as 3GPP based ones (2G/3G/4G), are limited by the pricing models, energy consumption and operator network caused delays making them unsuitable for control scenarios with requirements for real-time features.

The current emergence of well-supported LPWAN communication technologies, such as SigFox, LoRa(WAN) and other becoming 3GPP IoT communication technologies, have broadened the possibilities of wireless measurement and control applications. These novel methods would provide up to a 20 km range and low power consumption, with rather low maximum data rates of some tens of kilobytes. (Bardyn et al., 2016.)

VTT Technical Research Centre of Finland Ltd provides research services to companies as well as conducts its own large research projects related to Industrial IoT wireless measurement cases. In most of these projects, some kind of proof of concept or piloting capability is needed. That is why VTT maintains a wireless VTT Node reference and piloting board platform family to be used with various applications and research fields. At the starting point of this project, the VTT Node family included only short range communication possibilities that were limiting the experimentation and research, in various industrial cases. The conclusion was that the

VTT Node should also support some LPWAN technologies. Figure 1 depicts various VTT Node versions.

Figure 1. Three different VTT Node versions (Tiny V3 & V4 and FlexiNode).

6.3.2 Research design

This project focused on surveying and finding the most suitable LWPWAN technology for VTT needs, testing it with initial off-the-shelf development kit testing and finally, based on positive initial testing results, development of the environment setup and building of the first version of the VTT LPWAN wireless node with basic communication and sensing functionality.

6.3.3 Results

The project task was divided in the three phases and are explained as follows.

Review phase

In this phase of the task, the most potential and mature LPWAN technologies were evaluated based on the literature and pre-determined evaluation criteria. As mentioned earlier, the target was to find a versatile technology, suitable to be used in an IoT platform that could be used as a tailorable basic platform for both research and commercial projects. The evaluation criteria were based on following requirements listing that the technology would be fulfilling in an optimal case:

- Open technology
- Flexible and modifiable by the terms of data rate, range and energy consumption
- Tolerable HW and SW support and technology readiness
- Credible consortium or company behind the technology
- Possibility to completely manage the data pipeline from end to end
- Basic security features

The literature review was based on selected peer-reviewed publications (Bardyn et al., 2016; Neumann et al., 2016) and available web material (SigFox web page; Lora Alliance web page; Mangalvedhe et al., 2016) from the consortia backing the technology. Among the reviewed technologies there were SigFox, LoRa(WAN), NB-IoT and RPMA. According the review, the LoRa(WAN) technology was selected for the following reasons.

SigFox is a French originated quite wide-spread operator run, very low power communication technology with a data rate limited to 12 bytes for 6 times an hour. The corresponding data will be sent currently only upstream and it is available only via SigFox dedicated cloud environment using some standard technology like REST. SigFox maximizes the range up-to 20 kilometres in line-of-sight but the minimal data rate and non-flexible data pipeline configuration excludes it from the general purpose wireless communication technologies.

RPMA or Random Phase Multiple Access technology is dedicated on wireless M2M communication. Since RPMA is proprietary technology owned by Ingenu all of the information is based on their reference material. Ingenu reports RPMA to reach 25 miles range with 100 kbs data rate. At the moment, RPMA has about 30 - 40 private networks built to US and they are targeting to cover up to 100 major cities in the states. Unlike the other reviewed technologies that use sub-gigahertz frequencies, the RPMA exploits the band of 2,4 GHz. Due to its proprietary nature, low availability of devices and lack of impartial evidence of functionalities, it was also rejected from the selection.

NarrowBand IoT aka NB-IoT aka LTE Cat NB1 specification was released in June 2016 by 3GPP. NB-IoT devices communicate via current operator networks after the base station SW updates. It will provide up to 150 kbs data rate with up-to 15 km of range. NB-IoT will provide potentially very good communication platform for several IoT use cases but due to its fixed data pipeline via operator network and its current lack of device side HW it was also rejected.

From the requirement specification point of you, the LoRa(WAN) technology was selected to be taken for closer practical evaluation. There are plenty of reasons supporting the selection. LoRa is open technology with a credible alliance behind it. It supports bi-directional communication with a range up to 15 kilometres. LoRa is quite flexible what comes to application specific optimization possibilities between the data rate, the range and the energy consumption. The LoRa scenario, enables complete private networks in case of mission critical applications, but there is already operator driven network growing also in Finland by Digita. Additionally, hardware support is already in place. LoRaWAN also defines all of the OSI layers, except for the physical one. (Neumann et al., 2016.) Table 1 shows some of the compared features of the technologies.

Table 1. Some of the LPWAN technology evaluation criteria and results.

Technology	Data rates	Energy consumption	Data pipeline	Technology readiness
SigFox (proprietary)	12 bytes at the time, 144 times a day	Very low	Via SigFox cloud system	Good. HW available
LoRa(WAN) (alliance)	10-50 kbs	Low	Via LoRaWAN HW provider could or user defined (LoRa)	Good. Existing HW, also in base stations
3GPP (NB-IoT etc.)	Up to 150 kbs	Low	Operator	Low. No HW yet available
RPMA (proprietary)	Up to 100 kbs	Low	N/A.	N/A

Initial testing phase

In this phase, the selected LoRaWAN technology was tested using off-the-shelf development kits. Since some of the available information, in the literature review, was from the non-impartial sources, a brief practical test was conducted in order to confirm the promised performance level of the technology. Figure 2 shows some of the tested off-the-shelf LoRa devices. From the left: Kerlink base station, two Semtech im880A development kits and a Semtech LoRaMote.

Figure 2. Various LoRa off-the-shelf gateway and node development kit components.

The practical testing was realized using off-the-shelf base station and node side components, in a typical urban area, with buildings averaging 5 stories in height. The development kit, shown in the centre of Figure 2, was used as both the base station and the node. The base station was outdoors, on the windowsill of a third-floor office. The node was kept on the same side of the building as the window, in order to avoid initial degradation of the signal, caused by the building the base station was in. 10 different measurements were realized, with directions alternating evenly around the base station and with the node side residing inside the car. Altitude changes were minimal. The sending specs were:

- Carrier frequency 869 524 963 Hz
- Bandwidth 125 kHz
- Spread factor 11
- Error coding 4/6
- Transmit power 17 dB

In this test, the only area of interest was range variation caused by urban structures. Therefore, only small packets (4 bytes of payload) were transmitted with a one second transmission period. The packet reception rate, in the connection ranges between 200 m and 390 m, was 100% (measurement points 1–8) and about 20% in the ranges between 410 m and 520 m (measurement points 9–10). The brief testing proved that LoRaWAN performance was close to what was promised. A better placement of the base station would have been on top of the building and to have moved the node antenna outside of the car. The transmission power was slightly below maximum (20dB) and the antennas on the development kits were not optimal, which explains the lower ranges, when compared to the Semtech documentation.

VTT LoRa Node specification, building and testing phase

Since the initial practical testing proved LoRaWAN worthy of subsequent investments, the designing of the VTT LoRa Node was started. In addition to the communication link related to the general requirements, there were also other applicability related requirements to be taken into account. The requirements included a general purpose, long-range, low power, measurement node with basic sensor settings that included the possibility to use it as part of a hybrid network solution with a subnet of Bluetooth LE, and also have functionalities enabling it to work as a gateway component. Figure 3 shows the targeted communication architecture of the LoRa Node network.

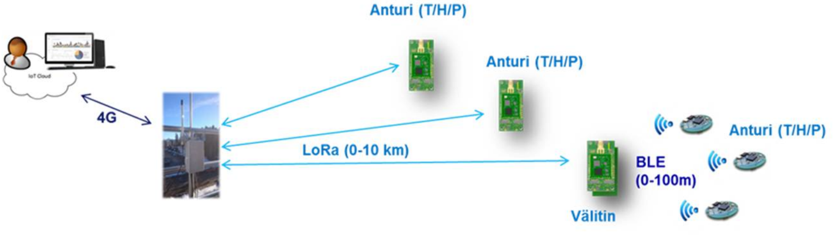

Figure 3. Targeted communication architecture of the LoRa Node.

The design of the developed VTT LoRa is based on an iM880A integrated chip with Semtech's SX1272 LoRa transceiver for communication interface and Cortex-M3 controller for application processing. The SX1272 provides a sensitivity of up to -137 dBm and a maximum output power of +19 dBm, which results in a link budget of more than 156 dB. In addition, the LoRa node contains sensors for humidity, air pressure and temperature, and two connectors for extra attached boards on the top side, and a connector for a Bluetooth LE subnet extension on the bottom side. **Figure** shows what the VTT LoRa Node looks like and its size, as an actual board and the design of the node. The first test had already been conducted and everything was running as it should. The next step in the installation of the set of nodes to monitor the facility air conditioning, in the VTT Oulu premises, has already been started and the results are expected in early March 2017.

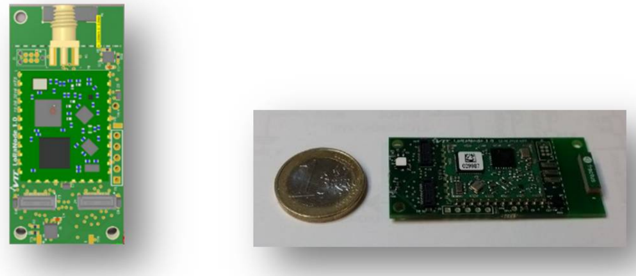

Figure 4. VTT LoRa Node design and actual sensor.

6.3.4 Conclusions

This report describes the evaluation and development path of a general purpose LPWAN IoT measurement node. LoRaWAN was selected for use due to its flexibility, openness and adequate performance features. The developed VTT LoRa Node is now ready for full-scale connectivity, performance and application specific testing.

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6.4 Blockchain technology in the manufacturing industry

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Blockchain and other distributed ledger technologies enable the establishing of trust between two or more parties, without an intermediate, such as a bank or a notary. This innovation may completely change many of the traditional processes of industrial manufacturing, e.g. supply chain networks, logistics and product authentication. Combined with other technological advancements, blockchain may generate novel digital business models. While promising blockchain-powered applications are already being piloted, the technology still needs to prove its capability and maturity, in practice.

6.4.1 Introduction

Blockchain has emerged as a disruptive software technology and it is expected to have a profound impact on the way digital data and value is handled. In short, blockchain is an immutable public record of data that is cryptographically protected and secured by a network of peer-to-peer participants. Blockchain has been described as a database that is distributed, cryptographically protected, incorruptible, and auditable, and depending on the application, the identity of the user can be kept anonymous or made transparent. These qualities make blockchain a distributed ledger that can never be double-spent, double-owned or double-sent. Decentralized networks eliminate single points of failure, as opposed to centralized systems. This distribution of risk among its nodes, makes blockchain much more durable than centralized systems and better suited to deter malicious accesses.

Blockchain may have a significant impact on the manufacturing industry or even change it completely. There are many potential application areas for blockchains in current manufacturing processes, e.g. in managing logistics, providing supply chain visibility and traceability, conducting real-time negotiations, managing product lifecycle data, ensuring product/part authenticity and ensuring audit trails. By using blockchain-based applications, partners in a supply chain can create trusted relationships, without the need for an intermediary third party or, perhaps, even traditional purchasing processes, enabling manufacturers, suppliers, customers and machines to find each other much more quickly and inexpensively.

Combined with advancements in other technological areas, such as the Industrial Internet, additive manufacturing and robotics, the potential of blockchain seems overwhelming.

6.4.2 Method

This report was done as a technology report based on scientific articles, news material and promotional material, and it has not been peer-reviewed.

6.4.3 Findings

Blockchain technology enables the establishing of trust between two parties without an intermediary, such as a notary, bank or public authority. This concept, of removing the middleman, can potentially be applied to a huge number of activities in the manufacturing industry: assets, identities, ownerships, contracts, balances, records and data can be tracked and exchanged on the blockchain, unleashing the global value flow – the Internet of Value. Thus far, much of the attention around blockchain technology has been concerned with the most well-known application of blockchain, Bitcoin. However, blockchain and other distributed ledger technologies hold a vast potential, beyond that of Bitcoin, in many other application areas where trust between actors is an issue, e.g. data management, identity management, digital content management, smart contracts, trading platforms, decentralized notaries and cloud storages. With the help of blockchain, companies may be able to reinvent traditional business processes and areas like supply chains and logistics. On the other hand, blockchain may drive companies – and even entire fields of industry – to discover novel digital business processes.

There's a wide range of extremely interesting business cases for blockchain that are being constructed or already piloted (Table 1). In addition to company-specific efforts, collaborative projects have been initiated to promote blockchain and create common platforms. The Hyperledger project is an open source effort that is hosted by the Linux Foundation and is intended to advance cross-industry blockchain technologies. It is a global collaboration including leaders in finance, banking, the Internet of Things, supply chains, manufacturing and technology.

Table 1. Examples of ongoing blockchain-based pilots and applications relevant to the manufacturing industry.

Everledger	Everledger has built blockchain-based systems to record the movement of diamonds from mines to jewellery stores. Each diamond can be identified by a laser-etched identification code, or if that is removed, by using their records containing dozens of parameters as well as a high-definition photo of each diamond. The company already collaborates with the world's major diamond houses and they are looking to expand to jewellery, arts and other luxury items.
Greats	Sports shoe manufacturer Greats is using blockchain technology with 3D-printed NFC tags that can track their sneakers to the factory, preventing designs from being counterfeited. The tag has a unique identification code stamped on it that links to a specific pair of shoes. Each tag has an encrypted NFC chip that can be tracked by a mobile phone.

Marine Transport International	MTI is deploying the world's first public blockchain solution, in the global shipping industry. The technology will be used to enable secure and open dissemination of shipping container information.
Provenance	Provenance has trialled blockchain technology to track fish from the trawler to the supermarket, in a pilot that could help stop human rights abuses and illegal fishing. At present, the buying and selling of seafood is tracked by paper records and tags on the fish. The new blockchain approach sees local fishermen sending SMS messages to register their catch on the blockchain. This identification is then transferred to a supplier, along with the catch; with any subsequent move, such as processing or tinning, also being recorded.
Raketa	All Raketa luxury watches have a serial number issued in the production stage and applied directly to the products, themselves. For each watch, information will be recorded in the blockchain with regard to the date of manufacturing, its assembler and any repair history, as well as information about the owner.
Walmart	Walmart is running a pilot where they use blockchain to track pork production in China. Every single food product is given space within the public ledger to store information about which farm the product originated from, details about which facility processed it, potential expiration dates, storage temperatures and details about the shipping process.

The "Hype Cycle for Emerging Technologies 2016" reported by Gartner estimates that blockchain technology will become "transformational" across a variety of industries, and it expects that this transition is only 5–10 years away. It further states that the technology is currently being used by less than 1% of its total users and predicts that the technology will advance most quickly in the manufacturing, government, healthcare and education sectors. According to a World Economic Forum report, 10% of the global gross domestic product (GDP) is expected to be stored in blockchain applications, by 2027.

Traditional supply chains have been transforming into more agile, dynamic, often loosely connected networks that are quick to evolve and include or exclude ecosystem partners. As companies are members of several supply networks that are swiftly formed and disbanded, the need to rapidly establish trust between partners is of utmost importance. For manufacturers and their suppliers or logistic partners, blockchain offers a lucrative potential: an individual transaction in a block might contain, e.g. bills of lading for raw materials or finished goods, proof of the origin, quality or operations performed on a part, or instructions for the place and time of a delivery. This information could then be stored, shared and viewed by all partners without delay or cost, or need for separate paperwork or signatures. The integrity of data is assured by the distributed system rather than a counterparty or a costly third party. Not only could this information be used to solve any disputes between partners, but it could significantly help reduce supplier risks, such as fluctuations in lead times, inventories and production capacities, all the way to second- or third-tier suppliers.

In a similar fashion, manufacturers and resellers could provide customers and end-users with the information they are looking for. Currently, consumers have very limited options to assure themselves of the origin or authenticity of a product — even the companies, themselves, sometimes have difficulties ensuring the legitimacy of the entire supply network. While there are programs and certificates, such as Fair Trade, that promote consumer ethics, they are often costly to maintain and still leave the consumer somewhat unsure of the origin of the product. Furthermore, these systems are still vulnerable to misuse and corruption. If the product or raw material was equipped with a unique ID and tracked throughout the supply network, in an open blockchain, consumers could be ensured that the product is legitimate and manufactured to their standards. Blockchain could also be used to store the lifecycle information of a valuable product. For machinery, for example, this might include original blueprints, component and software versions, material information, maintenance data and upgrade information, former owners, usage hours, and so on.

Another potential application area is additive manufacturing, which is proving to be another revolutionary technology that is moving manufacturing closer to users and bringing new life to mass customization. Additive manufacturing is highly digitized, customizable and performed on a small scale. Using blockchain, metadata and intellectual property, rights could be stored and shared easily and cost-effectively, expanding the limits of traditional manufacturing, while also protecting intellectual property.

Not only does blockchain technology create new business opportunities, it also paves the way for completely new business models. It has even been proposed that blockchain cannot fulfil its promise, within the existing business processes and inter-company relations, without massive global changes. In IBM's vision of decentralized IoT, blockchain acts as the framework facilitating transaction processing and coordination among interacting IoT devices – forming the "backbone" for billions and billions of transactions in Internet of Things.

One of the most fascinating concepts of blockchain is "smart contracts". They are actually not contracts in the legal sense, but rather a software-implemented set of instructions that can be used to store, verify or execute agreements or negotiations. Using blockchain to store events and transactions, smart contracts could be applied to run, for example, a fleet of vending machines that keep track of their stock, automatically arrange a call for bids with distributors when stock is low and pay themselves for a delivery, when a restock is made.

While blockchain has massive potential, there are also question marks and downsides involved. As an emerging technology, blockchain holds many risks: the maturity of the technology is still to be proved, work for standardization has barely been initiated, legal regulation may be required at some point and integration with traditional platforms and processes will be a challenge. Because of its disruptive nature, blockchain may face resistance from parties that are established as trust intermediaries, e.g. banks and other financial institutions, or governmental and municipal agencies.

The technical and organizational challenges of building and adopting blockchain-based systems should not be underestimated. Like any other software, blockchain applications need to be developed and sufficiently tested for their purpose. Also, smart contracts require further work before wider application. The fundamental issue with smart contracts is that, by design, smart contracts are immutably embedded in a blockchain, and so cannot be updated. What if it is discovered that a smart contract is – either unintentionally or intentionally – implemented in a way that allows one or more parties to misuse the contract? This capacity may prevent them from reaching maturity, if any non-trivial smart contract can potentially contain defects that cannot be fixed.

6.4.4 Conclusions

Blockchain and other distributed ledger technologies are exciting developments that show a lot of promise. Blockchain technology can potentially change the way digital data and value is handled, by enabling trust between two unknown parties without an intermediary. It has the potential to bring massive improvements to companies and consumers by providing access to detailed and immutable supply chain records, on the level of individual products.

By combining blockchain with other technologies, the business potential seems even more lucrative. It is possible that, in the future, blockchain technologies will inherently develop into a symbiotic relationship with the Internet of Things and today's advanced logistics and supply chain management systems. First, however, the blockchain technology needs to prove its worth in practice.

6.4.5 Further reading

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7. Decision-making in a Complex World

7.1 New approaches to decision-making in a complex world?

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The operational environment of firms is getting increasingly complex. This is due to several factors, such as globalization, new technologies, the size of socio-technical and socio-ecological systems and the systemic nature of the societal challenges we encounter. The complexity follows from the high interconnectedness of various systems, organizations and people at various levels and sectors of society. In the complex world, many problems turn out to be indefinite; there is no "right" answer to them and they can be only partially solved. In such an environment, traditional management becomes obsolete and new perspectives to understand organizations and their operations are needed alongside new methods to acquire information on the rapidly developing technologies, business environments, regulation and values, as well as involved operational opportunities and risks.

7.1.1 Introduction

In all likelihood, nearly every firm has come to think about the difficulties of anticipating developments that relate, e.g. to economy, business-networks, technology or regulation. The difficulty of anticipation and related decision-making comes mainly from the complexity of those relationships that consist of a number of different organizations and people, with their own interests and multi-directional interactions, causing unpredictable developments and impacts within the network. As an example, one may think about current digital information and communication systems, which form huge systems, where various technologies and functions, organizations, legislation, politics and societal values intertwine with each other (e.g. Geels & Schot, 2007). Changing or steering such systems is not easy, as the elements of the systems tend to be "locked" (e.g. Cecere et al., 2014) with each other and introducing new innovations easily necessitates changes in the whole system, which is what is taking place, for instance, in the case of digitalization.

Furthermore, complexity is not only an internal quality of systems, as they form a “system of systems”, where different systems are interconnected with each other. Interconnected systems also increase the probability of operational risks and the vulnerability of the whole society (Helbing, 2013). This has been recently discussed, for instance, in the context of cyber-security as well as with global challenges, such as climate change.

In the following sections, we will discuss the challenges the increasing complexity of our societies sets on decision-making and leadership. The focal claim made here, is that traditional “top-down” philosophy and the idea of organizations as “machines” that can and should be fully controlled, does not function well in a complex and systemic environment. Resilient and agile organizations allow more room for decentralized and lean leadership structures, as well as the independent development of responses, at the grass-roots level, of organizations. This makes creation of new solutions and responses to external challenges, faster and more flexible. The first section contextualizes this need by briefly reviewing the current dynamics of change and our understanding of organizations, which, in turn, affect the way leadership is applied. The second section of the article deals with the new requirements of leadership and the final section, with the information needs of decision-making in a complex world.

7.1.2 A complex and volatile world meets machine-like organizations?

While it is almost a cliché to say that our world is complex, it is still worth stopping for a moment to consider what this complexity means. This phenomenon was already receiving attention in the 1990s, when the term VUCA was developed to describe emerging characters of a socio-economic environment (Lawrence, 2013). In the term, V stands for volatility, U for uncertainty, C for complexity and A for ambiguity. The emergence of a VUCA environment relates, in turn, to various ongoing developments, which can be briefly described as follows (cf. Nieminen & Hyytinen, 2015a):

- We are globally networked and interlinked by economy, politics and new technologies. Especially, ICT-based global networks affect all aspects of our lives (Castells & Cardoso, 2005). Also, the so-called 'grand challenges' reflect and indicate the inter-linkages between various human and natural systems, countries and administrational sectors, such as financial system failures, climate change and migration.
- Technological development has profoundly intertwined with social and economic development (e.g. Freeman & Louca, 2002). Technological development may also have far-reaching impacts on, e.g. biodiversity, sustainable development and human identity, emphasising the need for assessment of the social, ethical and political aspects of technologies (Guston & Sarewitz, 2002).

- Due to described inter-linkages and challenges, any significant societal changes or breakthroughs of radical technologies requires systemic change, which means concurrent technological, economic and social change, including, e.g. the development of organizations, technologies, services, networks, funding, regulations and education (e.g. Geels & Schot, 2007).
- This is also reflected in the work that is increasingly information intensive, and thus, multi-dimensional and complex, requiring the combination of different information and know-how on network, organizational and personal levels.

In this context, firms and their operational environments can be seen as complex systems characterized by the multi-level and multi-directional interactions of various actors and system elements creating unanticipated developments and impacts, in the organization and business environment (e.g. Mitleton-Kelly, 2007). As an example, one may consider production processes in the manufacturing industry and the various factors affecting it, from new technologies to price pressures and business relationships between firms. There is neither a definite or single solution to the emerging challenges. These kinds of problems can be described as "wicked" (Rittel & Webber, 1973; Vartiainen et al., 2013); meaning, among other things, that the nature of the problem is persistent, due to the constantly changing situations, the complexity of the environment and multi-actor involvement with various perspectives. An everyday example could be product development in a firm, which needs to take into account, e.g. diverse and shifting customer needs and images of products, price factors, production possibilities, digitalization of processes, delivery and resale, public regulation, as well as social and environmental values. In doing so, the firm may also collaborate with a wide network of actors, from public research to other firms and public authorities. In other words, there are various perspectives that need to be taken into account, negotiated and fitted to the constantly changing situation, over and over again.

Under these circumstances, highly centralized or hierarchical control and management of all the factors and developments becomes more or less difficult due to the simple fact that there are too many issues to be controlled, and if controlled, operations may become slow and rigid. Despite this, it seems that organizations are still widely treated as machine-like entities (Morgan, 1977), which are mainly top-down managed.

The evident question that arises from this discussion is that, if a centralized and linear leadership and management approach does not function well in a complex world, what kind of approach would fit better? One possible solution is based on the idea that organizations should be seen as complex adaptive systems (CAS, e.g. Mitleton-Kelly, 2007; Holland, 1995). Such organizations are characterized by a constant internal and external interaction that "produces" organizations. As this interaction involves numerous people, processes and development paths that cannot be fully identified or controlled, organizations, in many cases, "co-evolve" with their environment rather than consciously develop.

In this view, development is usually based on self-organized learning and interaction. Instead of being "machines", organizations are instead "organisms" or “systems of change and flux” (Morgan, 1977) and include the idea of organizations consisting of sub-systems (such as groups, individuals), which are embedded in a wider ecosystem of other organizations and institutions. Change is not only a controlled phase in the organization’s lifecycle, but a continuous process in which the whole organization and its people, participate.

7.1.3 Leading complexity

Many researchers, who have obtained complexity thinking as their starting point, emphasize that instead of control, leadership should strengthen such elements and principles in the organization, which support dynamic self-organization like continuous learning, freedom of action, democratic engagement of the whole personnel, intensive communication and interaction within the organization, and even breaking existing rules, if it supports the organization’s adaptation ability and renewal potential. Change is something that organizations should strive for, not store. (E.g. Clarke, 2013; Biggs et al., 2012.) Decision-making is, thus, decentralized, “lean” and engaging. The basic idea is that “the experts know better”, and new action models and solutions should be co-created rather than given “from above”, as no one can master all of the issues of a complex environment alone.

It is evident, however, that alongside self-organization, organizations also need traditional rules and management, to maintain everyday vital and bureaucratic functions in the organization, to create continuity and stability in the organization - such as economic, legal and personnel related functions. These more traditional forms of management can be maintained alongside new and more dynamic forms of leadership and management. This is one of the major points made, for instance, by Mary Uhl-Bien and her colleagues (2007). They think that creativity and dynamic change necessitate support from stability creating leadership and management, and that leadership, in the information age, should consist of three elements (Nieminen et al., 2017):

a) Administrational leadership, includes all of the functions that relate to decision-making, planning, coordination, and the raising and allocation of resources. This traditional form of leadership is necessary for the survival of any organization, but one should also be cautious in applying it. For instance, excessive efficiency may endanger needed diversity and creativity in the organization.
b) Enabling leadership that supports such conditions in which new action models may evolve. Enabling leadership supports interaction within an organization and makes dissemination of new innovative ideas possible.
c) Adaptive leadership, which refers to all of the functions and actions that makes change and adaption possible. It supports the organization’s internal diversity, the actors’ interdependencies and interactions, mutual competitions and creative tensions, which may increase creative capacity, new innovations, and thus, adaptive capacity. The relationships should not be

based on hierarchy and power, as it hinders dynamic interaction and development of new ideas.

Distributing responsibility, hierarchically and horizontally, in the organization increases its opportunities to react meaningfully to complexity and rapid changes. A prerequisite is, however, that the personnel have a clear and shared idea of the organization's strategic targets and organizational culture, which supports independent action and shared responsibility. Therefore, strategic leadership, as a shared process and dialogic development, is emphasized in leadership. Inclusion and participation in the creation of a firm's "story" are of importance. (Mantere et al., 2011.) This is not necessarily easy, as traditional procedures, in society and organizations, do not support this kind of operational model. For instance, general regulations and traditional ideas of employment contracts, alone, may cause limitations to the idea of shared responsibility. There are, however, current examples of successful firms that operate by using the principle of self-organization and decentralized leadership.

7.1.4 Enhanced strategic intelligence

As these developments put more emphasis on strategic leadership, they also increasingly emphasize a need for a holistic understanding of the complexity of networked systems. In addition, the introduction of new innovative services and products also necessitates the increasing "orchestration" of the whole socio-technical system or major elements of it. Radical innovations are "systemic" by nature, meaning that their implementation needs more or less extensive changes in the existing system, before they may "take over" the system and markets (e.g. Geels & Schot, 2007). As an example, one may take electric vehicles. Together with the still developing technology and relatively high car prices, systemic questions, such as the existing infrastructure (mainly built for the combustion engines), community structures, service and regulation related deficiencies, public support and customer expectations, affect the breakthrough of the new technology (cf. Auvinen et al., 2014; Nieminen & Hyytinen, 2015b). The, now predicted and much hyped, transfer to robotic and self-driving cars can be seen as necessitating even more radical changes in the whole system, not only technologically, but also, e.g. in policy-making, regulation, and peoples' attitudes towards robots and transportation as a whole.

In the VUCA environment (volatile, uncertain, complex and ambiguous), the ability to analyse both the current situation and future developments of the system become of utmost importance for sound decisions and strategic leadership. Thus, during recent decades, various methodological solutions have been developed to meet this challenge. Common to these approaches is that they all emphasize the necessity to take the systemic nature of the operational environment into account. This has been pointed out, e.g. in various evaluation related methodologies and studies. Assessment of impacts and measures requires understanding of system dynamics, instead of simplistic cause-effect and linear descriptions, which have been commonplace in many evaluations (e.g. Merrill et al., 2013). While foresight methodology has been used in various strategies, technology foresight and policy processes for a long time, it is only recently that researchers have paid attention to the fact that foresight methods are also highly descriptive by nature, and that a more systemic and dynamic view of foresight should be developed (e.g. Andersen & Andersen, 2014; Saritas, 2010). In addition, modelling, in various forms, has become a methodology, which has been developed to analyse the complex dynamics of the operational environment of organizations and innovations (e.g. Ruutu et al., 2017; Hyytinen et al., 2014; Sternman, 2000).

While there are a number of variations in these methods and how they can be used for enhancing a firm's strategic intelligence, e.g. in anticipating emerging technological opportunities, developing markets and associated risks, as a further example, we briefly introduce a future-oriented impact assessment method that we have recently piloted and are continuing to develop (e.g. Nieminen & Hyytinen, 2015ab; Hyytinen, 2017). As the operational environment is multi-dimensional and includes temporal dimensions (past, current and future developments), we have ended up suggesting a multi-method approach that is based on the systematic integration of evaluation, foresight and system dynamic modelling to provide a holistic analysis of the situation. We need information of the current dynamics (how the system and our organization is developing within current structures, practices etc.) of future developments in order to prepare ourselves for it and a more profound understanding of the complex interaction and feedback loops within a system, to understand the impacts of our actions.

In the approach (Nieminen & Hyytinen, 2015ab), the evaluation provides systematic information on the historical and current state of affairs in the organization and its operational environment, the impacts of the actions the organization has taken and identifies possible lock-ins, in the development. Evaluation especially addresses the interdependencies between the organization and its environment, as well as the broader interaction within the operational environment. Foresight, in turn, deals with the future developments of the organization and its operational environment, and helps to set long-term targets. It is also a participatory process providing concrete and shared options, for the firm and stakeholders, on alternative futures and how they might be achieved. Evaluation is combined with foresight in order to reach a holistic analysis on the development paths and impacts of the decisions and chosen operations, and to create commonly shared ideas of them within the organization, and distribute them more widely among the stakeholder network. System dynamic modelling and simulation, in turn, complements this analysis by providing a formal analysis of elements that enable or hinder the achievement of targets (impacts). Modelling enhances learning and decision-making in complex systems, especially by making visible the complexity and multitude of connections.

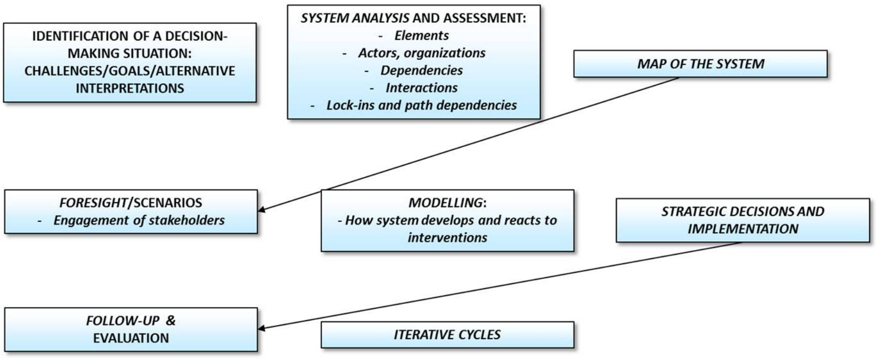

Figure 1. Future-oriented impact assessment and decision-making.

Figure 1 depicts, in a simplified linear form, how the future oriented impact assessment functions in relation to decision-making. In the first phase, there has to be an identified situation, with an approximation of challenges and targets for action, which makes it possible to delineate both the evaluation perspective and the starting point for the foresight process of creating alternative future paths. The analysis is complemented by modelling the system's development in alternative cases. In reality, the evaluation, foresight and modelling may also intertwine with each other, so that there are no distinct phases. The combination of this multidimensional information creates a holistic basis for decision-making and implementation. As the operational environment constantly changes, the chosen strategy and its implementation needs to be assessed continuously and changed if the whole strategy, or parts of it, turn out to be obsolete or inoperative. As the main point is to ensure the organization's sustainability, the process is an iterative cycle to increase the organization's resilience and adaptability. An essential part of the whole process is to engage the whole organization, and its stakeholders, in the process to create commitment and boost the organization's capacity, by collective intelligence.

In addition, as discussed earlier, if the firm is introducing new innovations, many times a systemic change is needed to make a successful innovation possible. Sometimes, this concerns the ecosystem in which the firm is embedded, including, e.g. interdependencies among innovation partners, subcontractors, or dependencies of wholesale business and other firms, which makes the introduction of innovation possible, by providing complementary services etc. (e.g. Adler, 2012). Sometimes the introduction of innovation requires wider systemic changes, including, e.g. regulation, organization, infrastructure and service related changes. These processes can be supported by engaging the relevant stakeholders and users in the process, early on. Integration of various interests and perspectives in the process makes it possible to develop it as a "collective endeavour". The implementation process can also be supported by a method called societal embedding (Nieminen & Hyytinen, 2015ab; cf. Loorbach, 2007). Its target being that of explicitly supporting collective dialogue among stakeholders and other key actors, in the implementation of innovations, it supports increasing the quality of innovation, by taking advantage of co-creation and collective intelligence.

7.1.5 Conclusions

As our operational environment is increasingly complex and changing rapidly, the outcomes of the operations of firms and organizations are also becoming increasingly uncertain. There are no definite solutions for the emerging problems, but they are often time and place sensitive, and cannot be generalized in a constantly changing and complex environment. This emphasizes the need to take into account the systemic nature of the operational environment, the limited ability to know of and anticipate its development, and, following from this, the limited capacity of traditional "top-down" planning and decision-making.

Instead, the complex operational environment emphasizes the importance of strategic leadership and the ability to create decentralized leadership practices and collective intelligence in order to make the organization more adaptive and resilient. This approach shifts the focus to collaborative multi-actor systems, which supports the engagement and inclusion of various actors and perspectives, in the processes. The engagement provides an opportunity to create new and more effective innovative solutions, both in terms of products and services, as well as in terms of strategic choices. Inclusive processes increase creativity as well as the commitment of personnel and stakeholders in the processes that are systemic and challenging to manage.

Systemic and complex environments also emphasize the role of such analytical approaches in the strategy and management of processes that enhance the holistic understanding of system developments and the organization's impacts and performance. An example is future oriented impact assessment. The approach systematically integrates evaluation, foresight and system dynamic modelling into a methodology providing comprehensive information of the current system and its alternative development paths.

Altogether, the principles of leadership in complex environments could be summarized as follows (Nieminen et al., 2017):

- Trust in an organization's ability to self-organize and create sensible solutions,
- Appreciate diversity and multi-voiced organization as a source of creativity and resilience,
- Accept surprises and tensions as a part of the organization's ability to regenerate itself,
- Make sure that the personnel share the organizational goals and understand them,
- Increase the strategic intelligence in the organization by using versatile information and holistic approaches.

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7.2 Enhancing risk awareness of new and emerging technology implementation, case circular economy

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In this study we describe the need for risk management approaches that facilitate studying major economic changes and taking into account the impacts of new and emerging technologies. We took circular economy as a case study because the current change from a linear economy to a circulation economy creates positive environmental, economic and social impacts. However, circulation economy creates, in addition to opportunities, also new risks. The results show that industry already works in the field of circular economy. However, the managing of risks and opportunities are not at the conscious level, but rather exist randomly.

7.2.1 Background

Major economic changes involve many actors and various risks. New and emerging technologies are often involved in these changes increasing the number of risks. The aim was to study the need for risk management approaches to support various industrial actors and authorities. We took circular economy as the case study because the current change from a linear economy to a circulation economy creates positive environmental, economic and social impacts.

In order to realize the benefits of a circular economy, it is important to develop new solutions for production and discarding processes together with recycling processes for raw material flows. In many cases, the management of new types of health, environmental and other risks is vital. When developing new solutions for a circulation economy, it is important to carefully analyse the risks of each process stage and find solutions to ensure their effective management.

A circulation economy enables the utilization of new ways of cooperation. The development of existing business networks or the extension of cooperation into new lines of business will bring a whole new range of possibilities for the provision of goods and services. New approaches may also hide new risks. Combining expertise is one way to manage risks. Closer co-operation between different actors and a better understanding of the risks involved can lower the threshold for testing new solutions. On the other hand, lease-based co-operation requires an active transfer of information between different actors. The open sharing of information requires a high degree of confidence between the parties.

7.2.2 Methods

The methods used in the project included literature research and project reviews, to explore different approaches for risk assessment in a circular economy, and interviews of representatives of four companies, to receive a deeper understanding of the challenges and needs. The companies represented manufacturing, energy, waste management and environmental expertise fields of business.

The results were analysed by using NABC analyses. NABC comprises the four fundamentals that define a project's value proposition: Needs, Approach, Benefits and Competition.

7.2.3 Findings

The literature consisted of reports dealing with future and circular economies made by the Prime Minister's Office (VNK), SITRA (A fund operating under the Finnish Parliament), the Finnish Environmental Centre (SYKE) and the European Union. The main finding was that there were very few discussions about risks, uncertainty or safety. However, authorities and companies find it challenging to identify the risks that are related to new technology and the operation of business networks. The main issue was how to manage the risks of fast piloting. The VTT projects, SustainValue (EU) and StraSus, offer tools for sustainable business evaluation, but they do not focus much on risks.

The performed interviews pointed out that, inside the manufacturing industry, circulation economy is not a part of business, yet. The strategies to enhance circulation economy will be done after there is a clear economic benefit in sight. The market is not yet large enough for this, and in any event, customers' needs are strongly seen as a main driving force for moving towards circulation economy, in the short-term. Instead, the companies speak about "remanufacturing", which helps customers lengthen the lifecycle of the product.

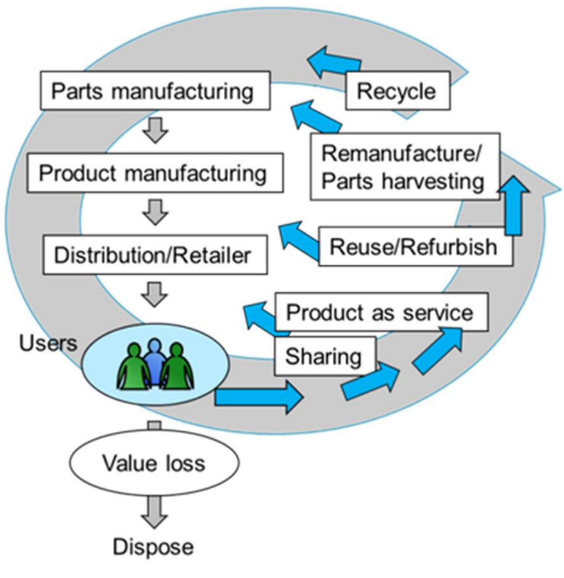

Figure 1. Circular economy strategies (Modified from Saswitha, 2016).

The risks included in a circulation economy were seen as being decidedly equal to the risks of normal production processes, including environmental, health and safety risks (EHS). However, new risks emerge such as: is the circulated material of good quality, does it include hazardous remains, etc. For example, remanufactured products are not equal to original ones, and therefore, you cannot be sure of what they consist of. In addition to this, a circulation economy has a broader risk perspective when dealing with the world economy, sustainable development and humanity aspects. For example, the availability of rare earth elements can cause new risks in relation to the availability of needed components.

Quite many processes of circular economy involve environmental licenses that may be very demanding and long-lasting for companies to sort out, especially if there are no practical examples of new processes and plants. This may reduce the interest to enter new business.

The anticipated political steering may raise new risks. There may be high recycling levels for recycled materials and at the same time, the applications of recycling products may be restricted. If the market for recycled products and materials is not predictable, it will restrict the development of novel innovations.

Products utilising recycled materials and raw materials compete with other products in companies' decision making processes and hence, solutions with highest value creation end up to final implementation. Through public administrative control and steering actions development can be guided to desired directions.

Among the industries, there is a need for "community roadmaps", roadmaps that are focused on a specific business sector (for example, companies who use the same kind of materials, raw materials, processes etc.), and which see the world from their sector's point of view. These roadmaps should include both the short-term and the long-term state of the world and ask what are the main issues to which circulation economy will create value, how can it be utilised during the lifecycle of the product, what are the new expected regulations, and what kinds of opportunities and risks will it create, etc.?

7.2.4 Conclusions

According to the study, it seems that the manufacturing industry is following a circular economy, but it does not discuss it when preparing strategies or politics. However, they are already inside the circular economy (see Figure 1) when they, for example, provide remanufacturing services.

The study demonstrated the need for more diversified risk identification and evaluation. New and emerging technologies include traditional risks like environmental, health and safety risks. In addition, risks connected to political steering, change of legislation, and market prospects affect significantly the implementation of new and emerging technologies. Wide-ranging and tailored risk assessment method takes into consideration risks from many viewpoints. This is essential when analysing processes and methods which are still in planning phase or from which there are not much experience.

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7.3 Digitalization and future industrial knowledge work

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The digitalization of industry is changing many work roles making them knowledge-intensive. The work focus is increasingly on virtual data related to physical objects, rather than on the manipulation of those objects, in the physical world. This implies that there is an increasing need for tools that support the analyzis and translation of data into knowledge, and thus, the better understanding of the context and situation in order to make informed decisions and actions. People, in different work roles, will need appropriate contextual knowledge, i.e. situationally relevant information in a contextually relevant form that is accessible by contextually relevant interaction tools. The underlying postulation of this article is to highlight that, to fully utilize the emerging possibilities of digitalization both work processes and work tools need to be developed in parallel, targeting improvements in both productivity and work satisfaction.

7.3.1 Introduction

Enabled by advanced digitalization, the Industrial Internet and smart technologies, such as the Internet of Things (IoT), it is expected that the 4th industrial revolution, often referred as Industry 4.0, will soon be on its way (Lasi et al., 2014; MacDougall, 2014). In essence, Industry 4.0 will integrate the physical and virtual worlds, thus, bringing into focus various information and data that is related to physical objects, throughout their lifecycles. In general, it is expected that Industry 4.0 will result, e.g. in shorter development periods, individualization in demand for the customers, flexibility, decentralization and resource efficiency. At the moment, the Industrial Internet and the IoT have been widely studied from the viewpoints of management, business and technology, in which the research focus is mostly on digitization, i.e. the creating and transferring of digital data. To gain the full benefit from big data, there should be more research that addresses the analysing of data, combining it with human knowledge and making contextually relevant knowledge more easily available to people in different work roles.

Future work will be mediated between the virtual and the real worlds, i.e. it will increasingly focus on the virtual data related to physical objects rather than on the manipulation of those objects, in the physical world. In the manufacturing industry, the competence demands will increase for all members of the workforce, in terms of managing complexity, abstraction and problem-solving (Kagermann et al., 2013). For industrial workers, the revolution is expected to provide opportunities through the qualitative enrichment of their work, e.g. by posing a more interesting working environment, greater autonomy and opportunities for self-development. Subsequently, the employees are much more likely to act on their own initiative, possess excellent communication skills and organize their personal work flow, i.e.

in future factories, they are expected to act as strategic decision-makers and flexible problem-solvers (Gorecky et al., 2014).

In this chapter, we will first describe the content of future industrial knowledge work and the central changes in work that it will introduce. Then, we will describe how new interaction tools can support workers in getting access to situationally relevant knowledge. The next chapter 7.4 continues the themes of this chapter, by focusing on data visualizations that explicitly support decision-making in different work tasks.

7.3.2 Industrial knowledge work

According to MacDougall (2014), many industrial jobs are anticipated to become knowledge-intensive and new work roles are expected to emerge. Industrial work roles are becoming increasingly knowledge intensive, as people are dealing with data and information related to physical objects rather than the physical objects, as such. Work will be increasingly mediated between human and machine, and between the virtual and the real worlds, as the work tasks are transformed from manual work to monitoring machines and the data produced by them. There is an increasing need for tools that support analysing and translating the data into knowledge, sense-making of the situation and decision-making, in order to understand the situation better and make informed decisions and actions. People in different work roles will need appropriate contextual knowledge, i.e. situationally relevant information, in a contextually relevant form that is accessible with contextually relevant interaction tools. To utilize the possibilities of digitalization, both the work processes and the work tools need to be developed in parallel, targeting improvements in both productivity and work satisfaction.

In future industrial work, it is expected that the work tasks will be shared flexibly between the automation systems and the human workers. Future workers will monitor and supervise autonomous systems, which necessitates that the employees possess multifunctional skills and take more responsibility in the content of their work. The digital transformation is often seen as a need to train workers in ICT. This is too narrow a view, as it should be noted that ICT technologies and new interaction tools are just tools for humans and that the main transformation will take place in the nature of the work, itself. It is expected that, for a long period of time, industrial work will still require an in-depth understanding of the purpose and objectives of the work. For instance, operating a welding robot does not just require computer skills, but that the worker should also deeply understand the welding process, all of the elements it includes and how a successful outcome is recognized. When the tasks of current workers are changed from manual work to monitoring automated machines, it is central that they still have hands-on experience of the work. This is essential because the industrial workers should always experience the feeling of being in control, that they are in the loop and can fluently intervene in the process, whenever needed (Kymäläinen et al., 2017). Naturally, the situation may change in the more distant future, when we see workers who begin their work careers with mediated work and have never experienced the manual work environment. When considering industrial labour, it is expected that new approaches will be needed to train new workers to have a thorough understanding of the purpose and objectives of the work, in all of its transformation phases. In this mediated work, there are two important aspects that need to be acknowledged, the decision-making process and situational awareness of the surroundings and available services.

Decision-making is seen as the process of gathering information needed for making a decision, devising possible courses of action, analysing them and assessing them against each other – and eventually selecting a particular course of action. Decision-making, under perfect conditions, has conventionally been considered as a rational process using all of the necessary information available. However, in dynamic complex systems, especially in time constrained situations, where the stakes may be high and situations are rapidly changing and evolving, decisions are not made as described in the rational decision-making literature. Instead, in dynamic situations, decision-making is based on the recognition of features in the situation, the matching of these features to situations that have been solved in the past and the application of expert strategies that have been demonstrated to be suitable, in the past.

Especially in dynamic systems, the goal of sense-making is often achieved by an appropriate level of **situation awareness**, which in turn supports effective decision-making. Situation awareness is often described as the perception and comprehension of the current situation and the projection of the future status. Three levels of situation awareness have been described: 1) the perception of elements in the environment, 2) the comprehension of the situation and 3) the projection of the future state, based on the understanding of the situation. Situation awareness can, therefore, be seen as a triad between three psychological constructs: perceive, integrate and predict. In the current state, it is fundamental that more research will be allocated to understanding the different aspects of situation awareness and its contributing factors (Endsley, 2015).

Expectations for Industry 4.0 include many positive changes to industrial work (Kagermann et al., 2013). At its best, the changes can lead to meaningful and interesting work roles that provide new possibilities for continuous learning and competence development. Individual worker differences can be taken into account and the workers can participate in designing or configuring their work. Digitalization will open the global work market to anyone, and will make work independent of time and place, by supporting alternative ways to organize work, e.g. by better fitting together working life and private life.

However, the promises may also include challenges: Are the future working roles really meaningful? What kinds of competences do future workers need? How can current workers be trained in the required new skills? How to address the issue of resistance to change by current employees? Will future industrial work be interesting enough for young talented people? How to manage in the global work market?

7.3.3 Interaction tools for contextual knowledge sharing

The anticipated industry transformation will affect all worker groups, but at the forefront of the change there will be the mobile workers and especially those who work in the field, with customers. In the DIMECC S-STEP programme, VTT has led studies on industrial maintenance work and focused on how it could be developed (Kaasinen et al., 2017). The core idea has been that contextually relevant information, related to different maintenance tasks, can be made easily available for the maintenance technicians with augmented and virtual reality technologies as well as other new interaction tools and techniques. The information includes measured data, documentation and knowledge shared by peers. The DIMECC S-STEP programme developed, in parallel, new work practices and new tools for gathering, sharing and presenting information. While earlier studies have mostly focused on individual demos for a particular maintenance task, in S-STEP work, we aimed to cover maintenance work on a larger scale, from preparing a maintenance visit to reporting the results. Our research took a broader-spectrum stance, being that in order to succeed, Industry 4.0 requires more than the mere introducing of new technologies for maintenance work. This research confirmed that, in essence, to develop sustainable solutions, there is a need for a shared vision of the future, which requires a clear and extensive view of how the new technologies will be utilized and what kinds of new work practices will, thus, be developing.

As stated, the new advanced human augmentation solutions will strongly influence future industrial work tasks. In Figure 1, we illustrate VTT's more explicit vision of the future, the Augmented Superworker (Kymäläinen et al., 2016). Basically, the figure exemplifies how the focus of the employee's wearable enhancements will shift from mere safety and security, towards connectivity, comfort and efficient co-operation with intelligent automation. In this vision, future industrial work is expected to move towards a shared awareness with autonomous systems, where location becomes inessential. Future workplaces are not limited to the company's premises, and instead, co-operation takes place between different facilities and people, outside of its premises. Accordingly, the content of the work moves from distributing the workload and observing the workers, towards a co-evolving human-autonomous system partnership. From the workers' point of view, these new ways of working indicate that they need to trust their systems; they need to experience control over their tools and ownership of their work processes, and primarily, they require advanced and efficient tools for working in their new operational environments (Kymäläinen et al., 2014).

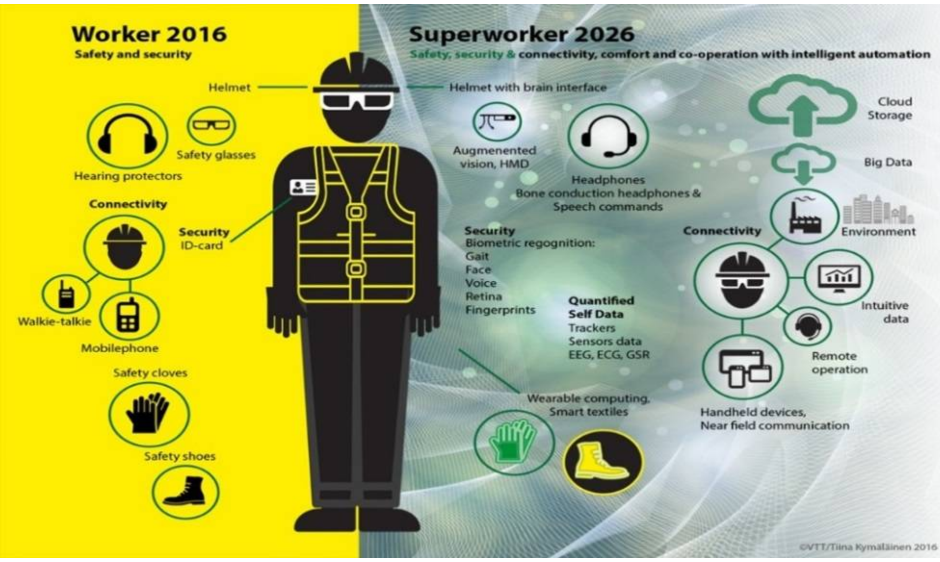

Figure 1. VTT’s vision of the future Superworker (Kymäläinen et al., 2016).

7.3.4 Conclusions

This chapter discusses the issue of the evident transformation of industrial work, where digitalization changes alter work to become increasingly knowledge intensive. For the industrial worker, the transformation means that his/her work includes decision-making, based on situational information and data from multiple sources. Novel interaction tools, such as augmented reality, can support situation-awareness and further decision-making by making situationally relevant information more easily available. This chapter has firmly striven to underline the fact that the best solutions are developed by simultaneously focusing on both work practices and tools. One of the most important research challenges in this domain lies in the consideration of how to visualise the data and information from multiple sources and services, in order to best support decision-making. This issue will be the focus of the next section 7.4.

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7.4 Data visualizations to support decision-making

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Appropriate data visualizations can improve human performance in the control of dynamic, large and complex industrial systems. We describe and discuss the findings from a review on research dealing with the user experience and human factors of data visualizations. We argue that this field has considerable potential for the future, where industrial work is becoming knowledge intensive. This review is intended to inform and inspire future work in this area.

7.4.1 Introduction

Many industrial jobs are becoming knowledge-intensive and mediated, as work tasks are transforming from manual work to monitoring machines and the data from them, sense-making of the situation and decision-making. There is an increasing need for tools that support analysing and translating data into knowledge, and thus, provide a better understanding of the situation in order to make decisions and take actions. Tools for visualizing the data to support decision-making are an essential part of this. In this Section, we present the main findings and conclusions from a literature review and interviews at VTT, where we focused on the background and state-of-the-art research dealing with the user experience (UX) and the human factors of data visualizations. The motivation for the work is in the hypothesis that appropriate data visualizations can improve human performance in the control of dynamic, large and complex industrial systems. A user-centric approach addresses such matters as how to interpret the visualizations, discover the fundamental information and relationships that need to be visually represented in order to support system state assessment, problem formulation, diagnosis and decision-making. Our purpose is, essentially, to inform and inspire future work related to this area.

In the following, we will first introduce the most conventional types of visualization presentations and describe the basic tenets of the information visualization discipline. From this background, we then extend the discussion into interactive information visualization and modern visual analytics. Finally, we will concentrate on the literature supporting situation awareness and sense- and decision-making, with real-time information visualization. We will also introduce data visualization research at VTT.

7.4.2 Information visualization and the conventional types of presentation

Visualization, in general, is the process of turning data into images that allow easier comprehension of information. In this context, data can refer to a range of things, from mental concepts to data as numbers and text.

In the manufacturing industry, visualizations are currently used in process control, manufacturing, maintenance, mining and energy. Visualizations are studied and developed actively also in fields, such as cyber security, business management, finances, military domains, smart cities, smart homes, bioinformatics, health and wellbeing, transport, weather and climate, as well as social media and web analytics.

Many application domains have emerged to facilitate visualization research, e.g. information visualization, visual analytics, scientific visualization, geographic visualization and various graphic design areas, such as typography and illustration. Information visualization (InfoVis for short) and information display design have been increasingly active areas of research and practice for the past few decades.

Presentation is the most obvious aspect of visualization. In a very conventional case, information is visualized as a static 2-dimensional graph (scatter plot, histogram, bar chart, etc.), whose main function is to illustrate and communicate information that is already known to its creator, e.g. a statistician illustrating the results of his analysis. In general, the most common visualization techniques can be categorized into treemaps, hyperbolic trees, heat maps, graph drawings, dendrograms and cladograms (ACM classification).

From early on, the information visualization discipline has recognized the significance of understanding human cognitive processing (and its limitations), in the design of information visualizations. In this way, the visualization sciences expands from mere presentation into the area of representation. Representation is concerned with discovering an understanding of what kind of relationships lie within the phenomenon or data that are important, and what needs to be communicated (Bertin, 1967). Bertin describes a process by which data can be transformed into visual representations of the phenomenon, i.e. how the visual elements can be constructed, organized and visualized. Classic information visualization draws from the knowledge of human visual perception and cognition, to derive guidelines and best practices for visualizing information. Tufte (1983), in his classic work, provides many examples of how data can be visually displayed and the principles by which the visualizations can be more effective at communicating understanding.

From the beginning, the role of information visualization, in exploring data and information, has been recognized. Perception-based (vision-based) design of information visualization takes into account the properties of the human visual system (i.e. how we perceive colours, shapes, forms, space, regions, patterns, motion, distances, similarities and differences etc.), when representing data and information visually. Tufte (1983), among others, presents many examples of “lying with visualizations” (intentionally or accidentally), showing how different types and designs of visualizations, of the exact same data, can lead to wildly different interpretations and conclusions, about the data or information.

In the case of static visualizations, the vision science based approach to infoVis utilizes the knowledge of human visual perception and cognition to mainly derive optimal ways of visually presenting and communicating information. In dynamic and interactive visualizations, on the other hand, the human perceptual and cognitive abilities (that currently exceed those of machines, in many ways) are put to use in detecting patterns in the visualized data and guiding the interactive data exploration process. From the domain of complex systems, interesting approaches have been developed to identify and model the key relationships that human operators need to understand in order to effectively diagnose and manage system operations, malfunctions, and recovery (Wong, 2016). Effective utilization of the powerful human perception system, for visual analysis tasks, requires careful design of appropriate human-computer interfaces. In thinking with visualizations, visualizations are used as part of the decision-making processes. (Keim et al., 2008.)

7.4.3 Interactive information visualization and modern visual analytics in making sense of complex phenomena and situations

Big data has been widely touted as a source of new kinds of opportunities. However, the effective use of big data also poses considerable challenges, many of which have not been properly overcome, in practice. To address these challenges relating, e.g. to information overload, there are interesting new visualization methods and approaches. According to Keim et al. (2008), the information overload problem refers to the danger of getting lost in data, which may be: 1) irrelevant to the current task at hand, 2) processed in an inappropriate way and/or 3) presented in an inappropriate way.

In many application areas, the importance of having the right information available at the right time is emphasized. Beyond the acquisition of raw data, one needs to be able to identify suitable methods that can turn the data into reliable and provable knowledge. According to Keim et al. (2008), technologies that claim to overcome the information overload problem have to provide answers to the following questions:

- Who or what defines the “relevance of information” for a given task?
- How can appropriate procedures, in a complex decision-making process, be identified?
- How can the resulting information be presented in a decision- or task-oriented way?
- What kinds of interactions can facilitate problem solving and decision-making?

The overarching driving vision of **visual analytics** is to turn the information overload into an opportunity. Thomas & Cook (2006) define visual analytics as a multidisciplinary field that includes the following focus areas:

- Analytical reasoning techniques that permit users to obtain deep insights that directly support assessment, planning and decision-making;
- Visual representations and interaction techniques that exploit the human eye’s broad bandwidth pathway into the mind to let users see, explore, and understand large amounts of information simultaneously;

- Data representations and transformations that convert all types of conflicting and dynamic data in ways that support visualization and analysis; and,
- Techniques to support production, presentation and dissemination of analytical results to communicate information, in the appropriate context, to a variety of audiences.

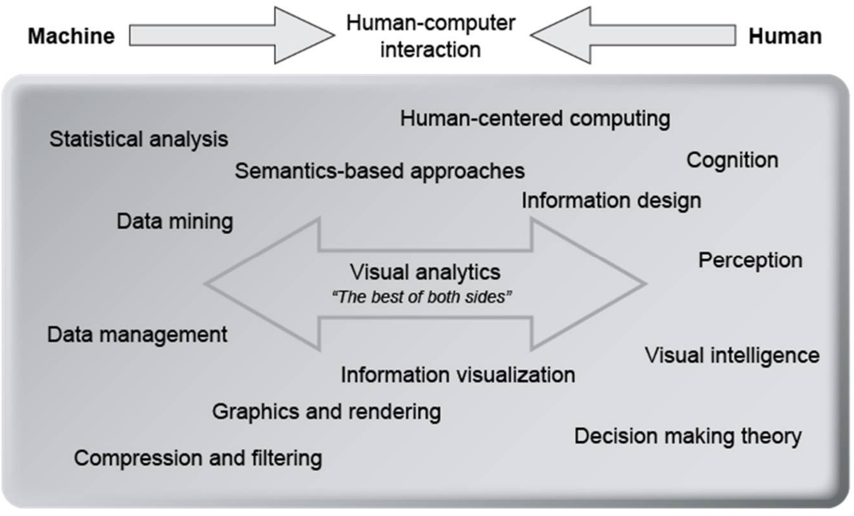

Figure 2. Visual analytics seeks to integrate knowledge and methods from multiple scientific disciplines, to improve the division of labour between human and machine. Adapted from Keim et al. (2008).

Information visualization and visual analytics commonly state the **creation of insights** as one of their central goals. The idea that visualization should lead to insight seems logical, but researchers have been slow to build on the concept, because insight, as such, is difficult to define. In cognitive neuroscience, where insights have been studied rigorously for the past few decades, insight is understood as a less ambiguous term, which specifically refers to what is commonly called an "aha" or "eureka" moment. In an interactive information visualization context, the insight generally has a wider and vaguer meaning. In this context, insights incorporate aspects of continuous problem solving in which a person moves through a series of steps towards a solution or increased understanding of a situation or phenomenon. This process involves iterative building and confirming of mental models and knowledge through interaction, as depicted in Figure 2. From the perspective of evaluating visualization systems, insights have, in some cases, also been treated as units of accumulated knowledge that can be counted and used as a measure of the usefulness of the visualization system.

Rather than seeking to exactly define what an insight is, it may be more useful to examine *how* people gain insights into **sense-making processes** involving interactive visualizations, what kinds of human factors are involved and how to design visualization systems that best support the sense-making processes. It should be noted, that sense-making has been examined in numerous contexts, in areas such as organizational research, educational research, military domain and decision science. In general, sense-making has been described as a motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and, consequently, act effectively. This particular definition shows that sense-making is often connected and intertwined in an iterative manner, with the process of decision-making.

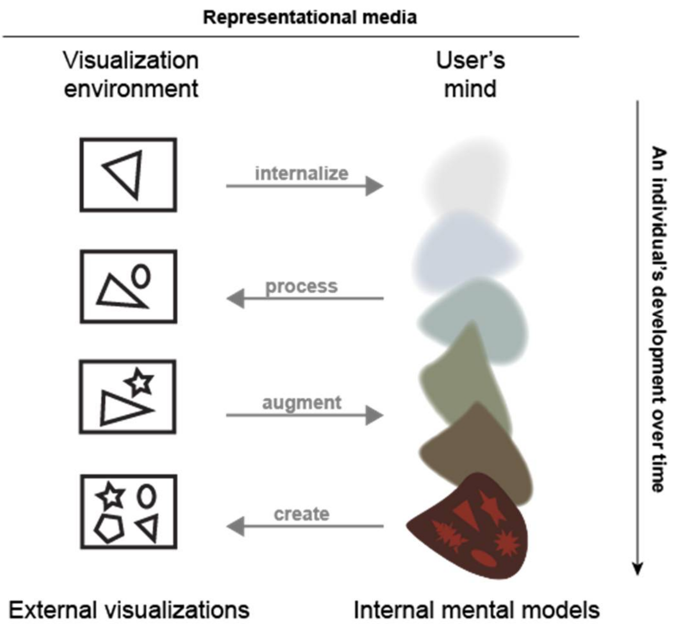

Figure 2. Visualization as an interactive process in which an individual's understanding develops over time. Adapted from Liu & Stasko (2010).

Figure 2 illustrates the high-level dynamics between the external visualizations and internal mental models of users, highlighting the fact that the mental models evolve throughout the interactive visualization process. From a cognitive point of view, the user first *internalizes* a visualization or visualization system as a mental model. Internalized mental models can, in turn, be used to *process* and make sense of new visualizations and other external phenomena. External visualization can *augment* the internal visual models, supporting sense-making and reasoning. Finally, mental models can serve as the cognitive basis for *creating* and innovating new concepts and designs, including novel visual representations.

7.4.4 Supporting situation awareness and decision-making with real-time information visualization

In an optimal situation, visualization constituents provide conditions for users to make real-time decisions, by allowing users to “play with data”, i.e. interact with different visualizations, perspectives, and levels of detail. In achieving the optimal situation, it is important to study how people interact with, and how they perceive and experience, a visualization system (e.g. interface or tool), which can strongly influence their understanding of the data as well as the system’s usefulness. Human factors studies and user research significantly contribute to visualization research and it should, therefore, play an important role in the design and evaluation of the visualization systems. The human-computer interaction (HCI) design strategy for visualization systems should focus on inherent *playfulness,* when interacting with visualizations and data, and also on the important cognitive characteristics related to the visualization systems. The challenge in this is that, in general, the implications of cognition processes and information seeking behaviour on effective sense- and decision-making are under-represented in contemporary literature on interactive visualizations (Tory & Moller, 2004; Ferreira et al., 2016; Plank & Helfert, 2016).

As relevant a topic as the effective use of big data is in the information visualization context, real-time requirements pose considerable challenges for processing data and presenting visualizations of the information. Computational methods can improve the scalability of visual analytics by providing compact, meaningful information about the input data. However, in practice the required computation time often hinders real-time interactive visualization of the big data. By addressing discrepancies between these computational methods and visual analytics, researchers have proposed ways to customize them for the visual analytics (Choo & Park, 2013).

While one of the central promises of the Internet of Things (IoT) is to make our world smarter, it can only happen when the right information is provided at the right time. Augmented reality (AR) technology, which can be used to visualize data from hundreds of sensors simultaneously, overlaying relevant and actionable information of the environment, through a headset, offers a potential solution. For example, AR technology can increase the efficiency and productivity of industrial facilities, by enabling staff to see the most pertinent sensor data in a dashboard-like view.

Despite the challenges in real-time interactive visualization, IoT data is considered integral to the future visualization environments aiming to support situation awareness and decision-making, in complex dynamic systems. In essence, the IoT ecosystem has four critical functional steps, including: data creation, information generation, meaning-making and action-taking. Among practitioners and experts, the visualization techniques and technologies, such as AR, are expected to play a central role in benefitting from the data provided by the IoT and IE (Intelligent Environments). Microsoft, in particular, has proclaimed that its HoloLens technology is especially suited for a broad range of use cases in these domains.

Furthermore, it has been announced that companies ranging from Autodesk to NASA to Volvo are currently testing the Hololens augmented reality platform. However, in the case of AR visualizations, the usability and user experience seem to have received only a little attention in the scientific literature, to date, with even less having been paid to visualizations, in general. This is perhaps because, until recently, development in AR has been mainly technology-driven. Especially, there seems to be a gap in the research in the field of developing HCI guidelines and presenting results from formal HCI studies.

VTT has been actively trying to fill this gap, in data visualization research. Siltanen (2015), for example, has presented several case studies relating to augmented reality solution development through user involvement, although the focus in her dissertation has been more on the technical framework and viable business ecosystems. Olsson, who has worked on many research projects with VTT, has also published a dissertation "User expectations and experiences of mobile augmented reality services" (Olsson, 2012), which introduces four case studies targeted for mobile augmented reality services. The strength of Olsson's approach is in the postulated design implications for the context and, especially, the way that he contrasts the results with general UX research. In the DIMECC S-STEP programme, VTT has lead the work of developing AR- and VR-based knowledge sharing solutions for industrial field maintenance workers, focusing on fluent work practises, in addition to the AR/VR solutions. The work continues in the DIMECC DYNAVIS project, where the focus is on creating novel dynamic visualization concepts for presenting lifecycle data and information to different actors.

7.4.5 Conclusions

In general, industrial work is currently transforming from manual work to monitoring machines and the data from them, sense-making of the situation and decision-making. This is creating an increasing need for tools that support the analysing and translating of the data into knowledge, and thus, the better understanding of the context and situation, in order to make informed decisions and take appropriate actions. This review highlighted the fact that tools for visualizing the data are a fundamental part of support in the decision-making process. It also acknowledged that visual analytics provides methods to combine machine-based data analysis and the understanding of human perception, cognition and decision-making, as both are needed for efficient visualisation solutions. In addition, this review proposed that to support the human decision-making process, visualization solutions should be interactive. This may be supported, e.g. by a visualisation system in which a machine asks for advice from the (human) user to support the decision-making process, e.g. by fine-tuning a visualisation or innovating new ways to visualise knowledge.

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8. Conclusions

8.1 Concluding remarks

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Although the ***For Industry*** programme ended in 2016, the revolution of the industry has not. Very new disrupting technologies, such as Artificial Intelligence, Blockchain, etc., are rapidly rising to challenge the manufacturing business. Therefore, it is evident that the companies need effective R&D actions and ecosystem, in the future. The For Industry programme has created a strong platform that enables the Finnish industry to tackle future challenges. This platform consists of multidisciplinary expert networks, company partnerships, business models, technology solutions and agile co-operation models, all of which are critical success factors of the future.

The mission to boost the competitiveness of the Finnish manufacturing industry is at the core of VTT's new strategy, which is in effect from 2017 onwards (VTT, 2017). This mission is concretized in Industrial Renewal lighthouse, which promotes the new opportunities for industrial competitiveness. Through the lighthouses, we aim to inspire ourselves, our partners and our customers to think boldly, now and in the future, so that together, we can find and turn future challenges, into beneficial opportunities.

The future is for winners, so, let's create winning capabilities for the upcoming challenges. Together with the For Industry platform created ecosystem and the challenge driven thinking of the lighthouses, we can keep the Finnish manufacturing industry competitive and also ensure Finland's welfare, in the future. VTT is committed to this mission and we welcome all new partners to join this mission and the related ecosystem.

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VTT Technology 288

Title	**Towards a new era in manufacturing** Final report of VTT's For Industry spearhead programme
Author(s)	Edited by Jaakko Paasi
Abstract	In order to boost the competitiveness of the Finnish manufacturing industry, a spearhead programme, called For Industry, was run at the VTT Technical Research Centre of Finland Ltd, in 2015–2016. The programme focused on key technologies that would make new solutions available to the Finnish industry to maintain domestic manufacturing as well as create new products and services for international markets. These key technologies include the Industrial Internet of Things, automation and robotics, additive manufacturing and digital engineering, at large. In addition to technology, For Industry focused on how to create successful business from new technology. These considerations included studies on business ecosystems and business models in manufacturing, and decision-making in complex business environments. For Industry placed special emphasis on increasing the competitiveness of SMEs. This VTT Technology report summarizes the main results and research highlights achieved in the For Industry spearhead programme, in each of its six modules: Manufacturing Ecosystem, Business Models, Digital Engineering, Automation & Robotics, Industrial Internet and Decision Making in a Complex World. The approach of the report, however, is to not only look retrospectively at the results of completed studies, but also to envision the future of manufacturing. We are in the middle of a rapid transformation towards a new era in manufacturing, and that is why the envisioning of future research topics has been emphasized in this concluding report of the For Industry programme. Although the For Industry programme ended, the revolution of the industry has not. For Industry has created a strong platform from which Finnish industry can tackle future challenges.
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VTT Technology 288

Nimeke	**Kohti uutta tuotantoaikaa** VTT:n For Industry -kärkiohjelman loppuraportti
Tekijä(t)	Toimittanut Jaakko Paasi
Tiivistelmä	Teknologian tutkimuskeskus VTT Oy käynnisti vuoden 2015 alussa kärkiohjelman nimeltä For Industry, jonka tarkoituksena oli merkittävästi parantaa Suomen valmistavan teollisuuden kilpailukykyä. Ohjelmassa keskityttiin avainteknologioihin, joilla saadaan Suomen teollisuuden käyttöön uusia, kotimaista valmistusta tukevia ratkaisuja ja joiden avulla voidaan kehittää uusia tuotteita ja palveluja kansainvälisille markkinoille. Näitä avainteknologioita ovat teollinen internet, automaatio, robotiikka, 3D-tulostus ja digitaalinen suunnittelu. Teknologiatutkimuksen lisäksi ohjelmassa keskityttiin keinoihin, joilla voidaan luoda menestyvää liiketoimintaa uuden teknologian avulla. Keskeisiä keinoja tässä ovat liiketoiminnan ekosysteemit, liiketoimintamallit sekä päätöksenteko monimutkaisissa liiketoimintaympäristöissä. For Industry -ohjelma painotti erityisesti Suomen valmistavan teollisuuden pk-yritysten kilpailukyvyn kehittämistä. Tämä VTT Technology -sarjan raportti kokoaa yhteen vuoden 2016 lopussa päättyneen For Industry -kärkiohjelman keskeisimmät tutkimustulokset. Ohjelman tutkimus toteutettiin kuudessa eri tutkimusmoduulissa: Manufacturing Ecosystem, Business Models, Digital Engineering, Automation & Robotics, Industrial Internet ja Decision Making in a Complex World. Tulokset esitetään tässä raportissa ohjelman rakennetta noudattaen moduuleittain. Sen lisäksi, että raportti esittelee jo päättyneitä tutkimuksia, se luotaa vahvasti tulevaisuuteen. Valmistava teollisuus on keskellä suurta murrosta, ja siksi raportin jokainen luku sisältää tutkimusteemoittain katsauksen tulevaisuuden näkymiin. Vaikka For Industry -ohjelma päättyi, teollinen vallankumous jatkuu valmistavassa teollisuudessa. For Industry loi Suomeen vahvan alustan, jonka avulla suomalainen teollisuus voi kohdata tulevaisuuden haasteita.
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Towards a new era in manufacturing

Final report of VTT's For Industry spearhead programme

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