Smart Industry Roadmap
Onderzoeksagenda voor HTSM en ICT en routekaart voor de NWA

van Keulen, Fred; Ahsmann, Bart; van den Akker, Evert ; Habraken, Milou ; Burghardt, Paul ; Jayawardhana, Bayu; Van Lente, Harro; Meinders, Timo ; Thuis, Bert; al., et.

Publication date
2018

Document Version
Final published version

Citation (APA)
van Keulen, F., Ahsmann, B., van den Akker, E., Habraken, M., Burghardt, P., Jayawardhana, B., Van Lente, H., Meinders, T., Thuis, B., & al., E. (2018). *Smart Industry Roadmap: Onderzoeksagenda voor HTSM en ICT en routekaart voor de NWA*. Smart Industry.

Smart Industry roadmap

Onderzoeksagenda voor HTSM en ICT en routekaart voor de NWA

5 februari 2018

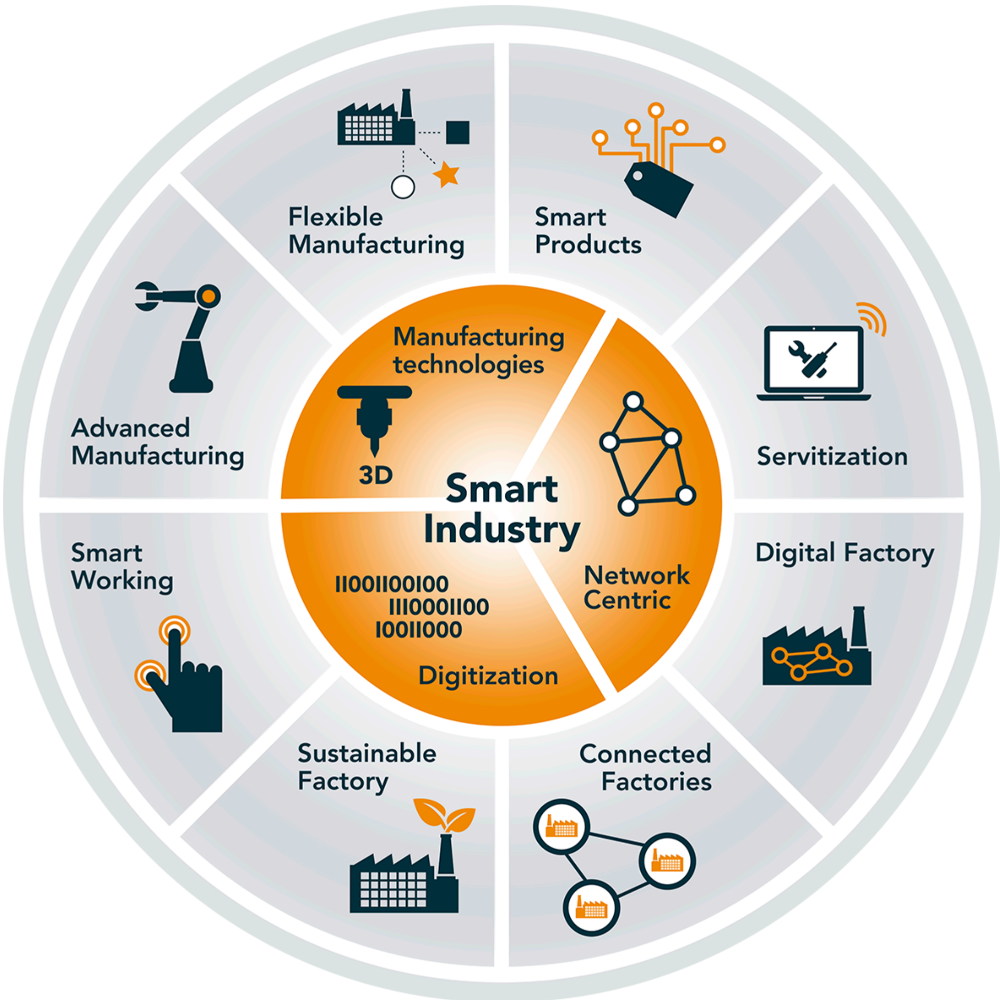


Table of Contents

Part 1 Korte Nederlandse Smart Industry beschrijving 3
Part 2 Roadmap from research to transformations (English text) 9
1. Introduction 9
1.1 Definition of industry and smartness 9
1.2 Impact on Society, Business and Technological developments 9
1.3 Smart Response 11
1.4 Smart Industry knowledge challenges 13
2. Smart Industry challenges 15
2.1 Smart Design & Engineering 15
2.2 Integrated Life-Cycle Management 17
2.3 Additive Manufacturing 17
2.4 Advanced Manufacturing 18
2.5 Robotics & Mechatronics 20
2.6 High Precision Equipment 21
2.7 Cyber Physical Systems 23
2.8 Digital Twin 24
2.9 Mass Customization 25
2.10 Production Management 26
2.11 New Business Models 28
2.12 Condition-Based (Predictive) Maintenance 29
2.13 (Trusted) Data Sharing 30
2.14 Cyber Security 31
2.15 Human Centered Technology 32
2.16 Employee Management 33
2.17 Smart Response 34
3. Transformations 36
3.1 Smart Manufacturing 37
3.2 Flexible Manufacturing 37
3.3 Smart Products 38
3.4 Servitization 38
3.5 Connected Factories 39
3.6 Digital Factory 40
3.7 Sustainable Factory 40
3.8 Smart Working 41
4. International developments 42
5. Contributions 44
6. Documents used (References) 45

Part 1 Korte Nederlandse Smart Industry beschrijving

Dit NWA/HTSM/ICT[1] document bestaat uit twee delen. Deel 1 beschrijft Smart Industry en de transformatie uitdagingen voor bedrijven. Het is in het Nederlands geschreven voor ondernemers en algemeen geïnteresseerden, van nationale overheid, regio's en steden die de productiviteit willen vergroten tot aan het algemeen publiek met de indieners van de vele NWA vragen uit 2016.
Deel 2 is in het Engels en is bestemd voor onderzoekers en programmaleiders. Het beschrijft de kennisvragen of onderzoeksagenda (*knowledge challenges*) voor de wetenschappelijk wereld die nodig zijn om de transformaties mogelijk te maken.

Inleiding

Smart Industry is een cruciale ontwikkeling voor de industrie. Het is dé basis voor het versterken van onze toekomstige welvaart en concurrentiekracht alsmede het leveren van oplossingen van maatschappelijke vraagstukken. Het gaat daarbij om het realiseren van economische en maatschappelijke meerwaarde. Economische meerwaarde in de vorm van het verhogen van de productiviteit en toegevoegde waarde van bedrijven, gezamenlijk door alle bedrijven verhogen van het Bruto Nationaal Product, het behouden en creëren van nieuwe werkgelegenheid en gezonde winsten voor ondernemers. Maar het gaat ook over maatschappelijke meerwaarde zoals verminderen van grondstoffen en het verbruik van energie, het produceren van de nodige producten voor duurzame energie, betaalbare medische hulpmiddelen, veilig, duurzaam en betrouwbare mobiliteit, etc.

Smart Industry wordt gedreven door de versnelling van de digitalisering van de industrie. Het gaat ook over een systeemverandering met vergaande gevolgen. Internationaal spreekt men over de vierde industriële revolutie (Industrie 4.0 in Duits of Industry 4.0 in Engels, soms afgekort tot 4IR). Gedreven door technische ontwikkelingen in de ICT als Internet of Things (*IoT*), 5G, blockchain, big data, kunstmatige intelligentie (*AI: artificial intelligence*) en straks kwantum computers, ontstaan er nieuwe economische mogelijkheden die uiteindelijk ook maatschappelijke gevolgen hebben. De kennisvragen omtrent deze ICT-ontwikkelingen, de nieuwe producten en diensten alsmede de kennisvragen omtrent de maatschappelijke gevolgen als werkgelegenheid worden in deel 2 beschreven. Dit zijn uitdagingen voor bèta, engineering, sociale en economische management wetenschappen.

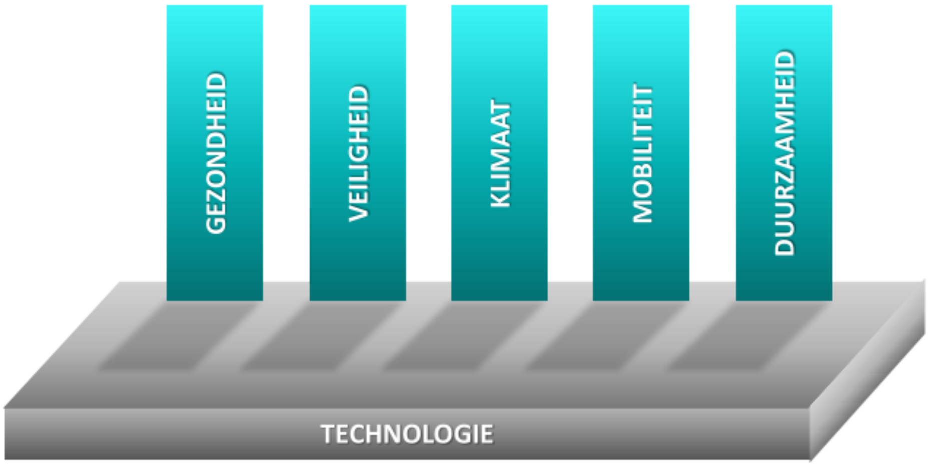
Wereldwijd probeert ieder geïndustrialiseerd land haar hele industrie en in het bijzonder het MKB te stimuleren tot het versnellen van investeringen in nieuwe technologie. Na de crisis van 2008 kon men weinig investeren, terwijl de technologische ontwikkelingen door zijn gegaan en er nieuwe markt en maatschappelijke vragen bij zijn gekomen. En juist door de versnelling van de digitalisering zien alle landen nu dat het voor MKB-spelers te snel gaat en zij niet alles tegelijk kunnen aanpakken. Landen en regio's die daar, in de gemeenschappelijkheid van ondernemers, kennisinstellingen en overheid, beter samen werken dan anderen ontwikkelen daarmee een voorsprong.

Het Nederlandse Smart Industry programma is in 2015 van start gegaan als samenwerking van FME, KvK, Min EZK en TNO. Dit actieprogramma heeft geleid tot een brede beweging met internationale uitstraling, 32 fieldlabs als zichtbare wapenfeiten en een totale publiek/private (60/40%) investering

[1] NWA = Nationale Wetenschapsagenda, HTSM = topsector Hightech Systems & Materials

van reeds 160 Miljoen Euro. Na 3 jaar wordt dit actieprogramma omgezet in een implementatie-programma rondom een 8-tal bedrijfstransformaties, 9 versnellingsprojecten en een verdere ontwikkeling van regionale hubs van fieldlabs voor innovaties en skills ontwikkeling. Een belangrijk facet voor de kennisagenda zijn de bedrijfstransformaties.

De maatschappelijke impact van Smart Industry



Figuur 1 De verbinding van Smart Industry met de maatschappelijke thema's

De technologie die schuil gaat achter Smart Industrie kent een groot maatschappelijk belang die tot uiting komt in een veelheid van halffabricaten, producten en diensten zoals apparatuur voor de gezondheidszorg, de energietransities, automobiliteit, etc. en natuurlijk de dienstverlening waarin internet en cybersecurity een belangrijke rol speelt. In feite speelt Smart Industry bij alle momenteel relevante nationale thema's, zie figuur 1, een belangrijke rol bij het efficiënt afleveren van technologie rond processen, producten en diensten. Daarnaast zorgt Smart Industry ervoor dat deze efficiënt en local-2-local geleverd kunnen worden waardoor de innovatie en realisatie daarvan dicht op elkaar zitten. Dit bevordert de interactie en daarmee de innovatie tijd en dus de time-to-market.

De sociale aspecten van Smart Industry uiten zich in werkgelegenheidsaspecten als de ontwikkelingen van digitale vaardigheden bij mensen van boven de 35 jaar, de verwachte schaarste (van technici) op de arbeidsmarkt en een uitdaging om de productiviteit per werknemer de komende 20 jaar met een factor 2 a 3 te vergroten. Waar nu een lasploeg van drie mensen van bijv. 20, 40 en 60 jaar het werk verrichten moet over 20 jaar de dan 40-jarige samen met twee a drie slimme robots of machines aansturen. Van 2008-2018 is door de crisis de werkloosheid fors toegenomen[2] en is er relatief weinig geïnvesteerd. Nu trekt de markt aan en wordt er weer geïnvesteerd. Het aantal banen groeit weer. Ondertussen keert de uitstroom van babyboom generatie ouderen terug naar de omvang van vroeger, terwijl het aantal jongeren is verminderd. We kunnen voorspellen dat dit eerst in specifieke segmenten, maar uiteindelijk in de hele arbeidsmarkt spanning op gaat leveren.

[2] Door het verhogen van de AOW leeftijd is tijdens de crisis de gemiddelde pensioen leeftijd van 61 naar 65 verschoven. Al dit tijd zijn oudere werknemers langer blijven zitten. Dit heeft de werkloosheid vergroot, maar nu deze mensen ouder zijn en wel uittreden wordt de omslag van arbeid overschoot naar arbeidstekorten extra versterkt.

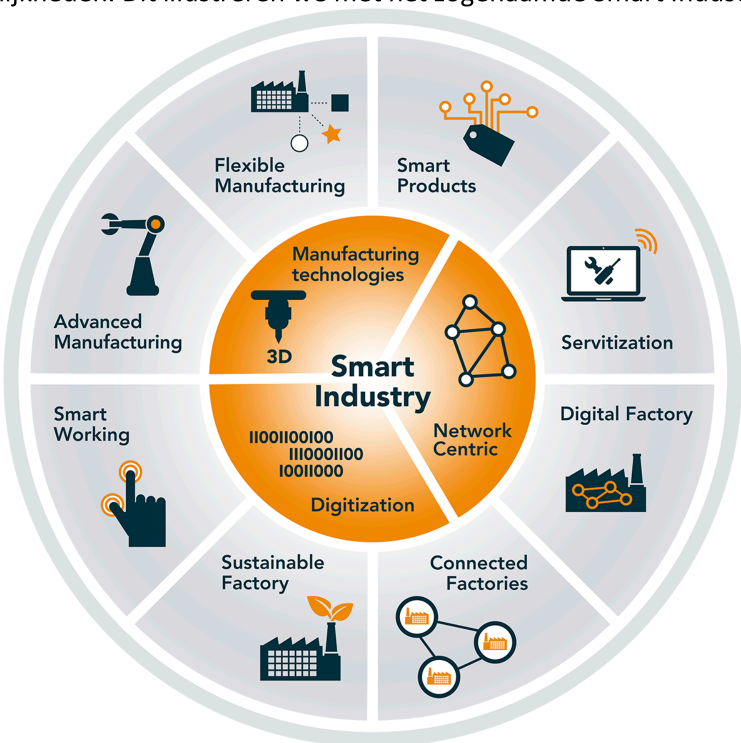
Om dezelfde omvang van onze welvaart te behouden, de kosten van klimaat maatregelen, de groeiende ouderenzorg en andere maatschappelijke uitdagingen te kunnen betalen, zal onze BNP ieder jaar groeien. Dit kan door de productiviteit per werknemer fors te laten groeien. Op lange termijn, 20 jaar, wanneer de verhouding werkenden-gepensioneerden van 4-1 naar 2-1 gaat, zal bij een gelijk bevolkingsomvang zal het aantal werkenden verminderen en moet de productiviteit van werkenden zelfs een factor 225-300% meer bedragen dan nu. Dit kan niet alleen door fors te investeren in Smart Industry technologieën, maar ook in de scholing van werkenden. Let wel iemand van 35 nu is dan 55 moet kunnen omgang met iets van Internet-of-Things, blockchain, kunstmatige intelligentie, kwantum computers en nog onbekende digitale technologieën, terwijl diezelfde persoon 20 jaar geleden op school nog geen Internet had.

De impact op bedrijven en de nodige transformaties

Smart Industry gaat niet alleen over technologie en leven-lang-leren met rollen voor publieke onderzoekers en onderwijs instellingen. Smart Industry gaat over het vergroten van de productiviteit van bedrijven. Bedrijven en ondernemers worden geconfronteerd met uitdagingen als

- andere, slimmere producten voortbrengen met gebruik van minder energie en hergebruik van materiaal,
- in kleine series, sneller en betrouwbaarder leveren en
- werknemers betere en meer productieve hulpmiddelen bieden en daarvoor opleiden

Een onderneming zal zich steeds aanpassen aan en nieuwe oplossingen bieden voor veranderingen in de markt. Nieuwe kennis en vaardigheden van mensen en nieuwe, betaalbare technologie bieden daar toe vele mogelijkheden. Dit illustreren we met het zogenaamde Smart Industry wiel, figuur 2.



Figuur 2 Het Smart Industry wiel

In het oranje deel van het Smart Industry wiel staan drie sleuteltechnologieën (*smart technologies)* in de vorm van de versnelling van de digitalisering van de industrie (*digitization*), meer, beter en veiliger connectiviteit (*connectivity*) en nieuwe product- en productietechnologieën (*manufacturing technologies*) centraal. In het centrum van het wiel staat een Smart Industry bedrijfsteam van de juiste kundige mensen (*skills*) uit een onderneming die Smart Industry in hun bedrijf moeten realiseren. In de grijze ring bevinden zich de transformaties. Buiten het wiel bevindt zich de markt, de maatschappij en haar behoeften.

Een onderneming kan niet alles tegelijk veranderen. Het is wel mogelijk om de huidige en een gewenste positie van een bedrijf t.o.v. anderen en de best-in-class bedrijven te bepalen. Middels een Smart Industry assessment wordt dit uitgewerkt om vast te stellen waar de grootste transformatie van huidig naar gewenste positie nodig is. Het is dan aan de bedrijfsleiding en haar Smart Industry team om te bepalen welke transformatie gewenst is en welke implementatieprojecten het meeste resultaat zullen opleveren.

Op basis van internationale ontwikkelingen (i.h.b. Vlaanderen en Duitsland) en eigen ervaringen in Smart Industry fieldlabs (i.h.b. RoSF (Regions of Smart Factory) fieldlabs) blijkt de uitdaging van Smart Industry te bestaan uit een achttal transformatierichtingen. Een Smart Industry transformatie betreft een verandering in een industriële organisatie om tot een beter, duurzamer product of dienst of om tot een beter presterend proces of organisatie te komen door de inzet van nieuwe slimme technische mogelijkheden en de kennis en kunde van mensen in die organisatie. Slimme producten en servitization (andere op diensten gebaseerde businessmodellen), maar ook automatische, gedigitaliseerde productie en een efficiënt gekoppelde waardeketen, duurzamer produceren en slimmer werken, en in kleinere series, op order en minder op voorraad sneller en foutloos leveren zijn voorbeelden hiervan. Hieronder worden deze transformaties toegelicht.

1 **Slim Produceren** (*Smart Manufacturing)* (apparatuur niveau)
Een Nederlandse fabriek levert steeds meer 100% foutloze producten door dat iedere productie stap 100% gecontroleerd wordt. Door altijd (100%) van de tijd voor (100%) binnen specificatie te blijven aan de uitgangzijde van een productie stap, zijn de ingangscondities van iedere vervolgstap steeds hetzelfde. Niet alleen is verdere automatisering en bijv. robotisering dan mogelijk, maar belangrijker is dat foutloos produceren (*zero defect*) veel vervolgkosten vermijdt. Foutloos produceren heeft gevolgen voor alle equipment, vereist hogere nauwkeurigheid (micro/nano niveau) en uitgebreide datalogging. Indien gerealiseerd dan is een volgende stap naar *mass customization* mogelijk omdat instel- en aanloopverliezen dan ook kleiner worden.

2 **Flexibel Produceren** (*Flexibele Manufacturing*) (fabrieksniveau)
Nederlandse fabrieken realiseren vooral kleine series, enkelstuks (n=1) en maatwerk, realiseren productie op order i.p.v. voorraad en kennen betrouwbare en veelal korte levertijden. De *high complexity-low volume* industrieën, zoals in de high-tech systems en maritieme sector, vormen een belangrijke Nederlandse sectoren van wereldklasse. Kostprijsverlaging impliceert zero-programming van robots en equipment, grote schaal inzet van 3D printing, maar ook first-time right (geen aanloopverliezen zoals met direct printing van electronics en direct zero defect). De ambitie is om tot een zeer flexibele fabriek te komen waar een team mensen steeds in staat is om andere producten te realiseren in de kortst mogelijke doorlooptijden (van offerte tot levering en van order tot levering).

3 **Slimme Producten** (*Smart Products*)
Nederlands ontworpen producten zijn in 2020 gebruiksvriendelijk en aantrekkelijk (human touch), slim en altijd digitaal verbonden en zijn ontworpen op minimale totale levensduurkosten (in energie, materiaal, transport). Producten zullen ingebouwde intelligentie hebben, eventueel door middel van flexibele elektronica zodat ze met hun omgeving (gebruikers, maar ook eventuele remote beheerders) kunnen communiceren. Tevens zullen producten klant specifiek (kapitaalgoederen) of zelfs ultra-gepersonaliseerd (consumentenproducten) zijn. Ook zullen deze producten ontworpen zijn voor hergebruik van componenten en flexibele (n=1) productie.

4 **Slimme Diensten** (*Servitization*)
Nederlandse productleveranciers ontwikkelen zich tot een serviceprovider die producten als dienst leveren of hebben de verdienmodellen van haar serviceorganisatie uitgebreid. Voorbeelden zijn lease diensten met bijbehorende financieringen van hardware producten, maar ook voorspellend onderhoud (*condition-based of predictive maintenance*) met behulp van remote monitoring van installaties. Het eerste geval wordt steeds meer mogelijk door o.a. de toepassing van Internet of Things (IoT), 5G, blockchain technologie, etc. zodat een leverancier die zelf hardware/software bouwt, beheert, onderhoudt of terugneemt alles kan volgen. Ontwikkeling van (digitale) platform oplossingen waarin meerdere toepassingen en meerdere componenten samen komen spelen hier een belangrijke rol. Een voorbeeld is de inzet van kunstmatige intelligentie (*AI*) op de verzamelde data van (vele) sensoren voor remote monitoring t.b.v. voorspellend onderhoud.

5 **Digitale Ketens** (*Connected Factories*)
Nederlandse bedrijven zijn in 2020 digitaal verbonden en kunnen veilig data uitwisselen via internationale standaarden voor gekoppelde ICT-systemen en zijn voorbereid om integrale keten optimalisering mogelijk te maken. Offertes, tekeningen, orders, transportinformatie, rekeningen, productie/kwaliteitsdata vanuit machines, etc., zijn digitaal geïdentificeerd/beschreven conform open industriestandaards en kunnen zonder *vendor-lockin* veilig worden uitgewisseld. De uitdaging is om over de gehele waardeketen tot optimale inzet van middelen (minder kosten, sneller en foutloos leveren) van offerte tot levering/betaling te komen (bijv. blockchain gebaseerde automatische marktplaats onderhandelingen). Cyber security, IoT koppelingen, maar ook inzet van glasvezelverbindingen en 5G (grote data en korte responsetijd) maken dit mogelijk, maar vergen de juiste juridische contracten (copyrights on sensor data, databankwet, privacywetgeving, gebruiksrechten op software in equipment).

6 **Digitale Fabriek** (*Digital Factory*)
Een Nederlandse fabriek is intern digitaal naadloos (en veilig) verbonden, van kantoor, design, productie, logistiek tot aan onderhoud en beheer toe. Van alle producten, processen, equipment is een digitale twin beschikbaar van/voor ontwerp, visuele (AR/VR *augmented/virtual reality*) en procesmodellering, simulatie, control, onderhoud en beheerregistratie. Dankzij de verzamelde data zullen met kunstmatige intelligentie (AI-)algoritmen steeds meer processen automatisch verlopen. Naast de CAD-versie van een object zijn ook big data management, IoT koppeling en data storage (proces- en onderhoudsdata) van het gebruik van belang. Met behulp van al deze digitale modellen, data en koppelingen is het mogelijk de toestand van een fabriek te bewaken, te optimaliseren en veranderingen te simuleren. Ook kunnen vanuit de verzamelde historische waarden AI-algoritmen worden getraind. Veel sensoren, equipment en systemen verzamelen meer data dan momenteel worden gebruikt. Door AI-toepassingen zal dit (snel) veranderen. Nederlandse ondernemingen zorgen ervoor dat deze data, modellen en algoritmen binnen eigen beheer blijven.

7 **Duurzame Fabriek** (*Sustainable Factory*)
Een Nederlandse fabriek werkt zo zuinig mogelijk met energie en materialen. Ze verbruikt zoveel weinig mogelijk en alleen maar duurzame energie en (recycled/refurbished) materiaal en de geproduceerde producten zijn zoveel mogelijke geschikt voor reuse/refurbishing/recycling. Er is een relatie met totale levensduur ontwerp van smart products (1), servitization businessmodellen (2), maar ook met de flexibele fabriek (8) omdat een flexibele fabriek die in staat is enkel stuk te produceren, als duurzame fabriek op termijn ook in staat moet zijn om een product in omgekeerde volgorde weer te demonteren in de meest herbruikbare componenten.

8 **Slim Werken** (*Smart Working*)
Werken in een Nederlandse fabriek is leuk en motiverend en bereikbaar voor jong en oud, onafhankelijk van vooropleiding. De werknemers worden maximaal ondersteund door technologie die ze begrijpen, waarvoor ze indien nodig training hebben gehad en die ze productiever maakt en gezond houdt. Dit noemen we mensgerichte technologie. Denk aan exoskeletten en robots die zware en gevaarlijke klussen lichter, schoner en veiliger maken, en aan de ondersteuning met AR/VR (*Augmented Reality of Virtual Reality*) om complexe handeling foutloos uit te voeren, of aan robots en machines die intuïtief te bedienen zijn. Deze technologie maakt mensen eerder en langer inzetbaar en zorgt dat ze waarde in hun werk ondervinden en er meer plezier aan beleven. Het vergroot ook het aanbod op de arbeidsmarkt beschikbaar voor een industrie die schreeuwt om werknemers, en maakt de bedrijven competitiever. Verder draag dit bij aan leven lang leren, en brengt het met zich mee dat aandacht besteed moet worden aan de organisatorische aspecten van de inzet van technologie op de werkvloer.

Met de transformatie naar slim produceren is het wiel weer rond.

Bovenstaande uiteenzetting van de Smart Industry transformaties is een hulpmiddel voor bedrijven om, in de veelheid en snelheid van veranderingen, de meest geschikte implementaties te prioriteren. In deel twee wordt ingegaan op de kennisvragen die met deze transformaties verbonden zijn.

Vanuit de brede NWA route Smart Industry en de meer technische georiënteerde topsector HTSM roadmap Smart Industrie, alsmede het ICT Commit2Data programma is deze 2018 update voor een gemeenschappelijk onderzoeksagenda opgesteld. Deze agenda moet passen bij het implementatieprogramma met de acht transformaties van het Nederlandse Smart Industry programma. Daarmee wordt een situatie gecreëerd waarin door publieke kennisinstellingen structureel wordt gewerkt aan de invulling van een Smart Industry roadmap. Voor private partijen biedt dit duidelijkheid over de meerjarige publieke inzet. Daar kunnen zij hun private bijdrage in samenwerkingsprojecten met die kennisinstellingen op afstemmen. Overigens zal een deel van deze invulling (data delen, digital twinning, smart working) ook van toepassing zijn in de luchtvaart roadmap van HTSM en de topsectoren Agro/Food alsmede Chemie en Creatieve industrie.

Samenvattend in een zin:
De ambitie is dat Nederland in 2021 het meest flexibele en het beste digitaal verbonden productienetwerk van Europa heeft voor het ontwerpen, produceren en leveren van slimme producten en bijbehorende diensten, waarmee de betrokken ontwerp- en maakbedrijven ook een substantiële energie- en materiaalbesparing in productie en levensduur realiseren en werknemers continue hun (digitale) kennis en kunde op peil (kunnen) houden.

Part 2 Roadmap from research to transformations (English text)

1. Introduction

This part provides a description of the knowledge and technology challenges underlying the Smart Industry program, as motivated and explained in the previous part. This will be done in a few steps: starting from the definition of key terms, and an impact analysis on society, business and technology comprehensive overview of knowledge challenges is presented in a table. Consequently, each challenge will be considered more in depth, mapping out routes for future knowledge development programs.

1.1 Definition of industry and smartness

Smart Industry is the Dutch strategy to develop the Dutch industry fit for the future (see http://www.smartindustry.nl). *Industry is defined as* our value creation activities that ultimately result in value created for customers and society. *Smart can be defined as* possession of intelligence, and intelligence (Wikipedia) has been defined as one's capacity for logic, understanding, self-awareness, learning, planning and problem solving. Intelligence or smartness can be more generally described as the ability or inclination to perceive or deduce information, and to retain it as knowledge to be applied towards adaptive behaviors within an environment or context. To realize intelligence in products and manufacturing systems one needs embedded computing or computational devices with network connections.

1.2 Impact on Society, Business and Technological developments

Today's Smart Industry implementations might seem simple in the context of the above definition of smartness. Nevertheless, internationally it is stated that we are entering the fourth industrial revolution. In this roadmap, we envision solutions that can be applied between today and 5-years from now and the knowledge questions/research questions for solutions for the next 10 years. Already within this time frame, it will have huge consequences for technology, business and society. In this introductory paragraph, we define smart industry and describe the consequences in terms of technological development, business transformations and smart societal responses.

Smart Industry is about future-proof industrial & product systems; these are smart and interconnected and make use of Cyber Physical Systems. Digitization, connectivity and new manufacturing & product technology are drivers for this:

1. High-quality, network-centric communication between organizations, humans and systems, in the entire value network, including the products or services used by the end-users.
2. Digitization of information and communication among all value chain partners and at all levels in the production process.
3. Granular, flexible, and intelligent manufacturing technologies, adjustable on the fly to meet highly specific end-user demands.

In the coming decade, a network-centric approach to production will replace linear production processes with intelligent and flexible (regional) ecosystem approaches. These networks will interconnect parts, products and machines across production plants, companies and value chains at a highly granular level. The network-centric approach will radically optimize production in existing value chains and, more importantly, the notion of network-centric production finally spells the end of the 'value chain' and the birth of the 'value network'.

One of the key enablers of the third industrial revolution was the digitization of information and communication. The Internet was instrumental in this, as was further software development. Smart Industry raises digitization to another level. Not only will it enable communication between all partners in the value chain, but digitization of, for example, product quality, user-characteristics and production parameters based on sensor systems (Internet of Things, Blockchain registration and Artificial Intelligence) will also be crucial to new innovations in the production process, products and services and business models.

Within the Smart Industry domain, ICT, Mechatronics, Robotics and Manufacturing are enabling technologies essential to tackle the big challenges our society is facing. Proper design of machines is necessary for production and manufacturing, semiconductor fabrication, healthcare, etc. and will soon involve functional integration (with e.g. AM), distributed mechatronics (in CPS), active (metamaterial) structures (product design), and further miniaturization. Novel robot technologies, precision motion systems, and energy-efficient drive techniques can, for example, constructively help to address problems we are facing in Climate Change (environmental monitoring, but also more efficient production), Energy (efficient design of machines), Health (novel diagnostic or robotic intervention), Mobility (coordinated intelligent transportations) and Security (Monitoring and Intelligent prevention or Screening).

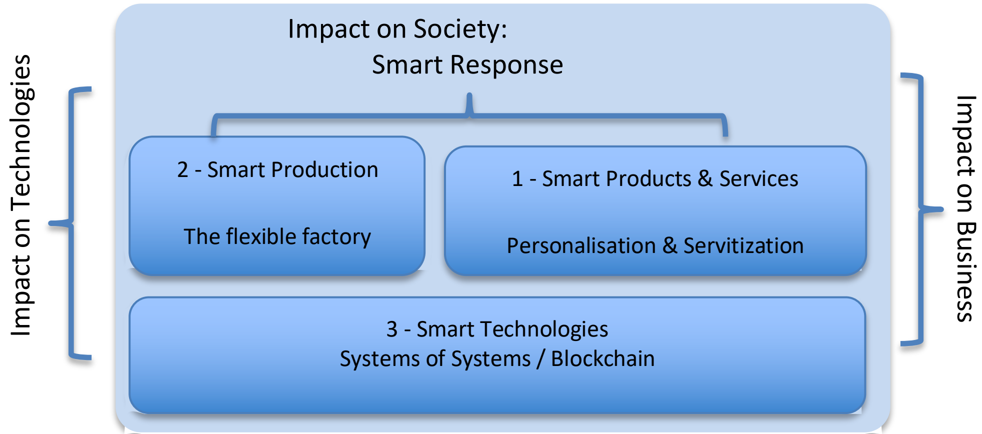


Figure 1 The NWA 2016 Smart Industry route model

The technology that lies behind Smart Industry has a great social importance that manifests itself in semi-products, products and services such as health care equipment, energy transitions, automotive etc. and of course the service in which internet and cyber security plays an important role. In fact, Smart Industry plays an important role in all currently relevant National themes in the efficient delivery of technology around processes, products and services. In addition, Smart Industry ensures that these can be delivered efficiently and local-2-local, speeding up innovation and realization by a close connection of them and thus the time-to-market.

In 2016, the NWA (Dutch: Nationale Wetenschapsagenda) route Smart Industry was formulated around the topics as shown in the figure with the impact of Smart Technologies, Smart Production, Smart Products and Services on Technologies themselves, on Businesses and on Society. At the same time, the topsector HTSM (High-Tech Systems & Materials) roadmap in Smart Industry was constructed with a narrower focus. In this NWA/HTSM 2018 Smart Industry document, both the NWA route and HTSM roadmap are merged and extended with the ICT topsector contributions. This results in a broad range of topics, both beta/technical as well as gamma/social sciences. Based upon a SWOT as well as discussions in the regions - national and international - eight transformations will make Dutch industry fit for the future.

The developments that come together in Smart Industry concerning smart products, smart production, and smart systems, offer many opportunities as a game changer. However, it is also clear that capitalization on these opportunities will not take place automatically, since it will involve a massive reshuffling of production systems, business models and urban and regional organizations. Without a 'smart response', SI developments may have a disruptive effect on Dutch industry, similar to the effects the failure to catch on to a transition had on Detroit and Manchester.

1.3 Smart Response

Smart Response deals with the response of the economy and society to the changes caused by Smart Industry and the disruptive technologies (robotics, AI, embedded sensors and Internet of Things) used to bring it about. The question is not only how we respond to the acceleration of the digitization process but how we can anticipate these developments to realize the desired economic and social impact or avoid the negative effects for specific groups. Smart Response covers: technologies, business and society. Which technological choices need to be made? How do we adapt businesses? What is possible and desirable from a societal point of view?

Smart Industry has a societal impact and leads to radical changes in production processes, business models and consumption patterns. It is important to *explore* the potential societal effects. How do the concepts opened up by Smart Industry affect society? On which points will they put pressure on the existing social order? How will economic ecosystems/networks, sectors, business models, organizations and jobs change? Besides exploring the effects, attention needs to be paid to the question in which areas the Netherlands can develop *unique positions* (points on the horizon) and how these ambitions can be realized (Smart Industry, Smart Society). What 'smart response' or smart interaction can be brought about by consumers, employees, politics, media, etc.? On which aspects should we be more offensive and on which aspects do we have to be more defensive? Examples are cyber security in open complex systems, or involving ethical, privacy and social values into the early stages of innovation to increase acceptance, but also changes in organizational, managerial, HRM and labor market practices.

A proactive response calls for exploration of possible scenarios. Society as whole has to find ways to deal with and respond properly to digitization. It also involves questions about desired social directions (smart society) and economic growth within ecological boundaries up to and including affordable care in an ageing society and the impact on the need for smart products and services for which smart business may provide solutions. Resilience and employability of employees are also important.

For years, outsourcing and offshoring were the ways in which companies strengthened their competitive positions and increased their profits. The first signs of a reversal of this trend are visible. Smart Industry allows production of small series, whereas offshoring to China is only profitable at very high volumes. Automation and robotizing are also making labor cost less relevant. Wage rises in China make production closer to the markets more attractive. This is the general trend, although the picture for individual sectors and products is not yet clear. If it continue, value chains will change and affect production and location decisions.

Digitization of industry, all value chains, the whole economy and all of society has led to the emergence of the 'platform economy'. The rise if new monopolies whose size and power increases through positive network effects points to the advent of a new economic order. Companies like Google and the like are so rich that they can buy any new competitor and thus smother future competition in its early stages. Consumers and businesses become increasingly reliant on a small number of American players for major functions (e.g. Amazon Web Services). We therefore also need a smart response to avoid a situation where all value is capture by a few (USA-based) platforms.

But Smart Industry also has a regional and spatial impact. While towns and cities in the Netherlands and Europe grow and flourish, the countryside and peripheral regions face demographic and economic decline. Smart Industry offers new opportunities for new regional development and growth. Many industrial SMEs are deeply rooted in their region and want to stay there, but they have to find a way to cope with international competition. Smart Industry brings the productivity increase that is needed to stay competitive. This not only leads to better jobs and higher incomes but to new business initiatives thanks to agglomeration effects. Smart Industry can also have big impact in cities: 'metropolitan manufacturing' stands for small-scale, ecologically sound and flexible production close to consumers.

There are also major developments with regard to sustainability that require a smart response in the context of Smart Industry in the need for eco-efficient production. Additive manufacturing is the best-known example of a technology that allows production with less raw material. Less waste, closed cycles and automatic disassembly are the key words. Local, regional, integrated value chains and closed cycles are inherently more efficient than the globalized traditional production processes.

The development of Smart Industry also requires analysis and exploration in a wider sense to establish the impact on economy and society. It is assumed that companies that embrace Smart Industry timely and completely will survive longer and achieve a better, more competitive position than companies that do not. There is every reason to investigate this in more detail. In connection with this, it is also necessary to investigate if and what kind of relationships there are between investments in Smart Industry and regional and national economic development and export positions.

What are the effects on different kinds of jobs and on employment as a whole? Not only technology changes fast, so does the Dutch working population. The increase of the retirement age and the ageing working population force employers and governments to think about new forms of sustainable employment. Flexibilization of the labor market also plays a role and has a clear impact on policy. Keeping and continuously training of existing technical employees will become critical because labor shortage in technical disciplines are expected to become worst.

Technology can make people redundant, but it can also be used to support people in the labor process. The development of cobots (robots that safely work with human within the reach of the robots) and expert systems that support people in the performance of their tasks and make it possible for people to participate longer or at a higher level in the labor process. The accelerated development if inclusive technology, for instance for older employees, is an important priority.

In the next years/decade, 10 to 50% of the jobs and companies in this sector will disappear (disruptive innovation) or will change dramatically. Training and re-training young people and existing employees will involve quite an effort. History shows that adaptation is usually successful but this will not take place automatically: rapid development of new business models and new skills are required. We need to develop new learning environments that respond more rapidly to new developments than traditional education is able to do, in particular for employees who got less initial education as they were less successful at school and who now face a world of lifelong learning. We need a smart response such that those people can be successful in acquiring new knowledge and digital skills.

1.4 Smart Industry knowledge challenges

The question therefore is *what is needed to ensure that the Dutch economy and Dutch society benefit from the opportunities offered by Smart Industry?* The answer is worked out in the matrix below and provides a basis for research into Smart Response options as part of the SI program.

	IMPACT/development areas		
	Technologies	Business	Society
	Smart Response		
Smart Products & Services			
Smart Manufacturing & Processes			
Smart Systems			

Table 1 The NWA/HTSM Smart Industry 2018 Model

The above matrix gives and overview of developments required for a successful Smart Industry development in the Netherlands. On the horizontal axis, Smart Industry is split up into smart products, smart production, and smart systems. The vertical axis shows the three development areas that determine how the opportunities of Smart Industry can be taken in the Netherlands: Technologies, Business, Economy and Society. The first area focuses on technology development. Which priorities need to be set? What are potentially successful Dutch contributions to the worldwide technological effort? The second development area is concerned with business conditions. Are sufficient properly trained employees available? Which business models are required? What is the impact of Smart Industry on liability? The third development area considers the social adjustments and the conditions for successful deployment of Smart Industry. What is the role of consumers? How does Smart Industry fit into the urban landscape? Which legal adaptations are needed for new value chains? Are new standards required? Is venture capital available? What about the recyclability and possible waste?

2. Smart Industry challenges

This section discusses the knowledge and technology challenges. The order of the challenges is arbitrary and does not reflect priority in any way.

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

2.1 Smart Design & Engineering

An integral part of the Smart Industry roadmap is the Smart Design and Engineering challenge. The challenge addresses the lifecycle phase of design and engineering, responsible of translating customer requirements into product and manufacturing process specifications. With increasing variations in customer demands and increased automation of the factory, the design and engineering organization has to be able to address more input variations and deliver more information to the factory, while pressure on time-to-market requires faster delivery more than ever before.

The trend of work in industry is moving away from conventional manufacturing to design and engineering (“Praetimus, ‘Productization of supply chain companies’, white paper, 2016”). One of the key conclusions is that the added value of the manufacturing function is decreasing while that of the design and engineering function is increasing. The way design and engineering is performed will change considerably due to increased complexity and reduced lead times. The processes will become highly integrated and automated. The challenge is to extend the current state-of-the-art in design engineering with smart capabilities. This requires attention for custom-based design for products that can be manufactured in a smart way. In fact, we are heading towards mass-customized designs that must be produced first-time-right. Consequently, we require tools for mass-customized design that strictly ensures manufacturability.

The focus of this roadmap is on adding intelligence and the use of the internet to existing solutions in design and engineering capabilities. Four fundamental areas of improvement are identified. First, intelligent add-ons to existing models need to be developed to realize the model-as-a-service while meta languages will be developed to support rapid (re)development and (re)configuration of models. Second, system integration and standardization of interfaces will be of key importance. Methods are required to flexibly integrate and reconfigure models across disciplines and organizations. Standards for data exchange and communication to support flexible, integrated, reconfigurable processes across disciplines and organizations are needed as well. Third, new control paradigms are necessary to enable experts to control operations of these complex and highly automated systems, including integrated verification and validation methods. Finally, means need to be developed to reuse data and models beyond the original scope of application. Develop methods to extend data and models with meta data to support future reuse.

This challenge is linked to other challenges in the roadmap. Integrated lifecycle management is linked to this challenge because, as the application lifecycle becomes shorter, the design and engineering organization has to focus on the knowledge lifecycle behind the application. Also Cyber Physical Systems have connections to this challenge, since the multi-physics design aspects and system engineering way of working will require even stronger interaction to deliver high-tech system solutions. Human Technology Interaction is required to enable users to address the far more complex and dynamic design and engineering process. New business models support the new collaboration strategies required to enable the integrated design and engineering process across organizations.

Mass customization and personalization does not imply that more variations of one product will be made. Industry can focus on creating more personalized added value for stakeholders, end-users and society at large. Ultra-personalization enables us to be better equipped with made-to-shape products and services, for example based on 3D scanning and anthropometric databases. Such a parameterized design offers more comfort and greater emotional attachment than any standardized size systems, enabling to better produce to sales than bulk production. This is now common for hearing aids and dental solutions, which in turn have transformed from product delivery to product service combinations – infused by big data and additive manufacturing. Similar opportunities arise for other domains that depend on human capabilities (ranging from supporting professionals to people with special needs).

Smart industry redefines the profession of design and engineering. New creative profiles are being developed such as the societal complex system designer, personal value designer, critical mass designer, advanced production designer, and intelligent interactive system designer. Although the notion of human centeredness will remain, adaptation of new methods is required, ranging from software engineering (agile, version management), robotics (reasoning/intelligence, augmented awareness), towards organizational sciences (critical system thinking).

Smart Design starts with reflections on societal changes and looks for a balance between collectivity and individuality. Uniqueness is a great good and part of the achievements of modern society, but has a downside that can negatively impact solidarity. It is becoming increasingly easy to develop custom-made products and services, but what will be their impact on sustainability? How do we create products and services that meet the need for a personalized offer? How can we create value for the end-user through digitization and information in production, content creation and design? The creative industry views this as a challenge that contributes to the Inclusive and Innovative Society; it builds on the technological challenges of the Smart Industry program and ties in with desired and desirable solutions. In doing so, it connects with the NWA Smart Industry route and offers fertile grounds for the NWA route to Art and human oriented Research and Innovation.

2.2 Integrated Life-Cycle Management

Over the past years, the requirements made of industrial manufacturing companies have increased enormously due to ever changing market situations. Companies have to respond to external changes (e.g., increasing globalization, increasing market orientation, growing model variance, increased quantities, shorter product cycles, decreasing target costs) and internal changes (e.g., growing product complexity, increasing modification frequency of parts). New technologies like cloud computing, 3D printing etc. as well as the influence of cyber physical systems will intensify this trend towards the future. New and complex products will be developed for a customer-oriented market.

The production of highly customized products with short life cycles addressing volatile markets will require new structures and operational strategies from their supply chains. Future supply chains will need to reconfigure dynamically as customer-specific products will be based on an increasing number of specific components. This calls for new technologies, structures and ICT systems to establish ad-hoc supply, manufacturing and de-manufacturing networks for customer-specific products. These networks support decision makers in finding and establishing the best possible supply chain solution for any specific order. New supply chains that address globalization and the integrated offering of products with services will require new approaches that take into account movement of material, exploitation of clusters of manufacturing excellence alongside an ability for local customization.

Process design is gaining in significance. It is critical to the long-term success of a manufacturing company in the intensifying global competition. Processes are dynamic and call for adaptation to the changing external and internal requirements as well as for the integration of new technologies and the complexity caused by the cyber physical systems. The goal is flexible and continuous processes support the entire product life cycle from product planning and generation in engineering, procurement and production to distribution, service and recycling/end of life. In this context, information develops from a production factor with increasing meaning into an important success factor.

2.3 Additive Manufacturing

Additive Manufacturing (AM) is a promising and rapidly progressing field that provides unsurpassed design freedom and opens up many favorable possibilities in system architecture when combined with design optimization. AM has numerous advantages compared to conventional subtractive manufacturing. It enables efficient manufacturing of complex, personalized and customized products built up layer-by-layer with high precision, resource efficiency (near-net shaping) and cost effectiveness. AM offers the possibility to create multi-material products (combination of, e.g., metals, polymers, composites, ceramics) and parts with material gradients. Typical AM technologies are 3D printing, tape placement, braiding, laser cladding, friction stir welding, etc. Technological advances in AM will reduce the manufacturing accuracies of micro and nanoscale features, while at the same time increasing production speeds.

Integration with design tools and CAD software will allow AM to have a significant impact on both time and cost savings, as well as weight, storage, tooling, assembly, transportation, supply chain management and maintenance. By utilizing numerous state-of-the-art technologies such as pick and place, dispensing of viscous materials, sintering, etc., additive manufacturing can leap itself from merely producing bespoke dump parts to building smart objects printed locally. AM will be an smart industry

enabling technology for many applications, such as embedded and smart integrated electronics, complex high-tech modules and submodules and human centric products like dentures, prostheses, and implants.

AM requires additional technology development to improve on cost, speed and quality, and therefore developments are needed in the field of new concepts for multi-material, multi-technology digital manufacturing, and high-speed continuous AM technology. Multi-scale computational material and process-level models are required to capture textured and multi-property functionality. New models need to account for the influence of printing process parameters on the resulting mechanical behavior and functionalities. Different length scales will be relevant for proper macroscopic characterization. These can be used to investigate aspects such as three-dimensional topography, surface texture and porosity, as well as residual stresses and delamination to improve AM accuracy and quality. AM provides an overwhelming design freedom for complex 3D structures. This freedom can only be exploited to its full extent via advanced topology optimization techniques.

AM equipment should enable first-time-right manufacturing, higher throughput, better precision, larger dimensions and more versatile processes. These process developments should be accompanied by progress in advanced materials, with an emphasis on the related areas of laser and printing technologies, real-time in-line metrology, control technologies and machine learning protocols. Besides standards for materials, new design programs, machine processes, and qualifications for built parts have to be developed to turn AM into a mature production technology. Also required are protocols for intellectual property rights in part designs for a digital workflow in many locations (encryption, standard file format, security for defense).

Finally there are challenges in new “smart” AM materials. These can be used for new levels of manufacturing such as 4D printing, higher reliability trends as well as recycling, end-of-life aspects such as easy disassembly, etc., and also for advanced functions realized via structuring by combining proper material selection and structuring in e.g. sensing and actuation. These smart materials include metamaterials. Connected to structuring are integrated manufacturing, functional integration in smart devices and design. Instead of a focus on isolated material structures, there is a focus on application, integration, design and manufacturing.

2.4 Advanced Manufacturing

Advanced manufacturing technology contributes to the realization of three major trends in production systems, i.e. increased efficiency, quality and reliability. It requires process monitoring and modelling approaches, associated with novel optimization and maintenance strategies. Improvements in manufacturing technology will be data-driven and can be based on measurements or models (deep-learning techniques, statistics, and physically based models).
Research on integrated computational engineering in the past decades has resulted in many complex models, reaching ever higher levels of accuracy and maturity. In most cases, these models are used to create a better understanding of the constitutive behavior of the material in question and the related production processes. However, reduced tolerances on product properties require higher accuracy of the current (simulation) models, whereas a higher level of maturity is required as well to make them useful on the factory floor as part of the control system.

The final properties of many products are the result of a sequence of production steps, where preceding steps influence the current production step. Full-process-chain simulation is still in its infancy. The design of highly accurate multi-stage manufacturing processes requires the development of efficient full-process simulation tools. Automatic (mathematical) optimization based on process models is reaching a level of maturity that is acceptable for industry. After optimization, processes tend to perform better, but also become more critical. Therefore, robustness of processes has to be included in virtual process optimization, taking account of natural and uncontrollable variation in material and process properties. A challenge for the next decade is to integrate the evolution of variation in product properties in a full-process simulation for multi-stage manufacturing processes.

Modern production machines are already equipped with a multitude of sensors and actuator systems and this is expected to increase further in the near future. The use of feedback and feedforward control systems has been essential in every automated process stage in advanced production systems to fulfil tight and rigid product specifications at each stage. Yet, such systems cannot handle natural variations in material properties and process conditions very well, which may lead to waste due to nonconformity with the specifications and may cost millions of euros a year in product, labor and energy waste for manufacturers. With the increasingly strict requirements for modern high-tech products, a new intelligent control strategy is needed that can take into account material variations in the complete control system, allow for flexible tolerances at each stage and meet the final product specification. The increasing use of ICT and Internet-of-Thing sensors in modern manufacturing has opened a new way for the development of novel control systems design that can lead to drastic improvements in production accuracy, leading towards zero defect.

Current control strategies control the tool movements, temperatures, etc., but not got the state of the product. Advanced model-based control algorithms be developed to control the product properties directly and create a zero defect manufacturing systems. Standard metrology and feedback control is not yet able to adapt to high frequency (product-to-product) variations that are observed in practice. Data processing and translation into corrective actions, adjustments and active control must be improved to bring the desired performance improvement. Improved metrology includes accurate and absolute reliable measurements, measurement setups and measurement methods. Relations between the measured signals and product properties are extremely nonlinear and are described by the process models. Since these process models are usually very time-consuming, lower order models are required for application in control loops. These reduced-order models can then be used to optimize the process or can be incorporated into a control system in a factory platform. A number of issues are very important, i.e. the simulations platform must be very robust and stable, data processing must be fully automatic and standardization plays an essential role to create platform robustness.

Advanced model-based control can contribute to all three main trends: accuracy, flexibility and efficiency improvement. Enhanced control will drive defects to near zero levels. These technological developments enable industrial principles such as Zero Defect, Lean and Just-In-Time manufacturing to reach their full potential, while dramatically reducing cost and impact on the environment.
This approach can be used in zero defect, high-volume production but is also very useful in flexible robotics to speed up the implementation on the factory floor. The adaptive learning process of the emerging flexible robotics could be based on data both from physical modelling and sensors, in combination with adaptive control. This combination will lead to more innovation speed in process development and implementation on the factory floor.

2.5 Robotics & Mechatronics

Mechatronics integrates electrical, precision mechanical, sensor, thermodynamic and control engineering and software for the design of products, systems and manufacturing processes. It relates to the multi-physics and multidisciplinary design of systems, devices and products aimed at achieving an optimal balance between all basic disciplines. Within the smart industry context, mechatronics systems are pervasive both in the realization of smart processes, as well as, smart products. The current level of mechatronics expertise in Netherlands belongs to the top in the world, based on many years of development in various application areas such as semiconductor equipment, healthcare systems, printing systems, but also mass production equipment, consumer product design, advanced scientific instrumentation, and automotive systems.

Smart Industry themes such as high mix, high complexity, low volume manufacturing, introduce new challenges to robotics and mechatronics. The added value of mechatronics and robotics innovations is potentially very big, e.g. through integration of many sensors, wireless networks, and information technology (artificial intelligence and control algorithms) across the industrial environment (but also other sectors such as food processing, and smart agriculture). This typically leads to integration of more feedback and feedforward control approaches and production automation/robotics technologies into the manufacturing and assembly environment. In addition, handling technology related to gripping, manipulating, complex assembly, and precise component placement can be of great value, but also, and adaptive/learning or robust control loops.

To achieve zero defect manufacturing, more data will become available at all steps in the manufacturing and assembly process. To begin with, this implies integration of many sensors, e.g. for in-line inspection of parts, supervising correct processing, placement, assembly etc. Fast communication of the resulting data and measurement signals will be required to have a clear status overview of the manufacturing and assembly process. An intelligent processing platform and decision-making system is required to initiate corrective actions to specific production equipment, manual repair actions, compensation at other stages of the manufacturing and assembly line, etc. This calls for the development of novel sensor technologies and metrology, vision integration, in-line inspection and monitoring, fast data processing and transport. The integration of machine learning with adaptive and learning control strategies will also play an important role for enabling autonomous reconfiguration of control algorithms and decision- making systems.

To enable flexible manufacturing of high-mix, high-complexity, low volume products in a competitive way, it is essential to switch fast from producing small series of one product to producing the next product. Re-programming, unproductive ramp-up, and similar production-time loss factors destroy the competitive position and need to be eliminated through smart innovations. Effective flexible manufacturing will be enabled in both a feedforward and feedback manner. Feedforward in the sense that a priori product information (e.g. CAD data, design documentation, assembly instructions) directly leads to the optimal configuration of the manufacturing and assembly environment, including all internal communication and reprogramming of robotic manipulators for handling new parts for a new type of product (self-configuration). A self-learning process evolves when feedback derived from continuous monitoring of critical production parameters through continuous sensing and metrology leads to adaptation of machine settings or replacements of tools when quality parameters start drifting (self-learning).

In Smart Industry scenarios, smart robots will take on a range of production tasks (production, inspection, transportation) and will behave as smart production entities based on local intelligence that reacts to data from sensor-rich production environments. However, the state-of-the-art task control strategies in manufacturing facilities still lack the flexibility needed for this future scenario. Research should focus on decentralized and mixed control strategies that will enable maximum flexibility and extensibility of systems of cooperating production robots. Mobile robots need to move in 2D and 3D through known and unknown, static and dynamic, structured and unstructured environments. Besides, they must be able to deal with unfavorable conditions for sensing, mobility and manipulation, like varying light conditions, water, dust, mud, etc. This relies on the robot's observation of the world through its sensors and data acquisition through other robots and systems, such as surveillance cameras. They need to localize themselves, navigate to target destinations, while avoiding obstacles in a safe and efficient way. Intelligence and autonomy are key in this sense.

Physical interaction between users and robots is getting increasingly important. Tele-operation and haptic feedback are examples of robotics technology to deal with more complex, more diverse robots, so that they can be safely controlled by non-trained, non-professional users.

A robot needs to be able to adjust itself to changing environments and changing tasks to work efficiently. Creating flexible and intelligent robots that are able to use and update databases and knowledge about their environment requires developments in many areas, in hardware, as well as in control software. Robots need to be able to learn from humans, their environment and from other robots. Especially robots working on repetitive tasks, which is often the case, can benefit a lot from learning, while optimizing their performance. There is a need for reconfigurable systems allowing self-adjustment, learning and adaptation, correction, and control as well as networking to bring about a significant impact on changeover time/cost, tooling, programming and energy usage of those systems. Research should include aspects such as improved methods for engineering processes, communication structures, and generic resource description for 'plug and play' machine integration.

Software development for integration and control of machine controller software is often time-consuming and expensive. Considering robots alone, the costs of integration are three to five times the cost of the robot hardware alone. The reuse of robotic software artifacts is a key issue in decreasing the integration costs and can be promoted by domain engineering, components, frameworks and architectural styles. The interoperability of hardware and software components for robotics is also important in forcing a breakthrough in the development of robots. And innovative robotics design might create new solution too.

Business and consumer interests and technological advancements will lead to wide diffusion of robotic technology into our everyday lives, from collaboration in manufacturing to services in private homes, from autonomous transportation to environmental monitoring. Building an early awareness of the resulting ethical, legal, and societal issues will allow timely legislative action and societal interaction, which will in turn support the development of new markets.

2.6 High Precision Equipment

To survive global competition, high precision and high quality products need to remain a differentiator, which will demand continuous improvements in process control and system accuracy in many aspects. The existing mechatronics competence base needs to be brought to the next level in the area of precision motion and handling systems, and thus requires significant progress in control systems theory, dynamics, thermal management, sensor technology and precision metrology, fast and efficient actuation, advanced control theory, motion control implementation platforms for high bandwidth control and data processing. This holds for both motion systems and robotic manipulators for picking and placing components and handling subassemblies.

Distributed actuation, identification and control are mechatronic challenges in high-tech systems with a high numbers of carefully selected distributed sensors and specially designed electromechanical actuators, with both continuous and discrete dynamics, and with systems and control technology that is able to handle this high level of complexity. Also driven by the availability of massive computing (massive parallel systems) new avenues for control become viable. Systems may possess many sensors and actuators and all information passing through the control can be used to estimate performance and disturbances at different time and spatial scales simultaneously. Multi Input-Multi Output control and systems that are adapting to disturbance or system variations will become industrially relevant, and so will distributed control approaches to deal with the ever increasing complexity of high-tech systems and their control architecture. Such distributed systems will allow multi-rate control solutions to be designed, lifting some of the limitations in present day equipment. Diverse types of measurement data must be combined to take the right decisions and actions. Research into the numerical processing, merging 1D, 2D, and 3D metrology, data fusion, and wireless transmission of this information will also be needed.

Technologies have to be developed for mass reduction and increased speed of operation, while maintaining accuracy. New systems have to be really lightweight, able to cope with deformation (e.g. quasi-static, dynamical, thermally induced), extended actuation and metrology topologies, and operating under extreme conditions. Further increase of amplitudes and speeds of systems into the nonlinear regime can be enabled with more advanced methods for controlling their nonlinear dynamics.

Higher speeds and accelerations are required to increase productivity, leading to large driving forces introducing more disturbances and heat loads. This calls for high force-density actuation, efficient power conversion technologies advanced drive electronics, distributed magnetic structures, high precision and high power switching amplifiers, and alternative actuation principles. Furthermore, structural stability should be guarded by advanced thermal control, spatial and deformation metrology, advanced materials with favorable properties, wireless machines, both for data and for power transmission, eliminating the parasitic influences of cabling. Miniaturization will increase operation speeds and frequencies, and will simultaneously increase the demand for high-bandwidth sensing, actuation and control of the dynamics of systems at the micro and nanoscale.

The field of systems and control is a strong enabling technology that ensures robustness to uncertainty of many feedback control systems in high-tech systems applications. Model reduction for multi-physics systems and hybrid system theory are also relevant topics. Modeling interconnections of multi-domain (physical/chemical mechanical) dynamical systems in one and the same framework is needed to derive new concepts to exploit the combination to the full benefit of system performance. A similar aspect is found in the integral optimization of mechanical design, topology, disturbances and controller solutions for high performance systems. In cases like these, developments of novel mathematic approaches or complete new paradigms will be needed.

Solving multi-criteria, complex design problems will be the key to really exploiting the potential in novel system architectures. This probably will quickly go beyond human mental capacity. Shape and topology optimization provide a very promising enabler in this respect to find breakthrough solutions. In the longer term, this will call for methods to design and manufacture multi-material systems. For high precision equipment, the production of complex high precision compliant mechanisms is very important.

2.7 Cyber Physical Systems

The digitization trend at the industrial level leads to a merger of the physical world of production with the virtual digital world of information, data and computational power. A cyber physical system (CPS) is a system (or a system of systems) featuring integration of, and interaction between the system's digital/computational and physical elements, the system's environment, within the application constraints. This calls for the development of open, networked, flexible and interactive systems that exploit this cyber physical combination.

The importance of cyber physical systems of systems in the context of Smart Industry is increasing. It involves integrating digital information technologies in products, processes and factories and connects them to perform a certain function, provide a service or produce a product with the goal to achieve better quality and to adapt automatically and instantly to, for instance, changing material conditions or customer demands.

Obviously, the networked and information intensive nature of CPS, brings about big challenges. Design, development, maintenance and control of these cyber physical systems of systems will not be possible with theories and tools from the traditional field. Collaboration between scientific disciplines to manage this development is therefore essential.

Semantically interoperable systems collect and process detailed data about embedded and physical states, events and processes, where data ownership and privacy are important. The resulting integrated approach towards design and implementation allows an increase in the overall adaptability, autonomy, scalability, efficiency, performance, functionality, predictability, reliability, safety and security. To integrate networking, computation and physical processes, wireless networked systems for sensing and control are of key importance. Examples of CPS include communicating manufacturing systems/lines, systems to track and analyze emission, communicating (wireless) sensor systems, and systems to provide situational awareness.

Management of both hardware and software (distribution of time-critical tasks, locations of processing) during their life cycles need much better mechanisms and support than currently available. Future CPS should have plug-and-play components, both the physical and cyber elements, where the overall control can cope with scaling-up of the networked systems and reconfiguration Independently developed subsystems need to support collective applications by making individual components aware of the overall CPS applications and vice versa.

The current development cycle of CPS that follows a consecutive design of physical systems, of control algorithm and of information technology has limited the potential of CPS as disruptive technology. Bringing out the potential of CPS requires an integrated co-design method within an engineering science that brings together physics modelling across various domains (mechanical, thermal, electro-mechanical, etc.), complex control algorithms, communication protocols, and computational platforms that can guarantee safety, performance and robustness.

Internet-enabled decentralized monitoring and control algorithms, using wireless sensor systems, are required to improve process and product performance and enable proactive maintenance strategies using local and global information. The CPS will utilize effective, reliable, real-time and secure data collection, multi-physics predictive modelling, and data analytics under industrial conditions. Modularity of CPS will play an important role in enabling a seamless interconnection of new CPS and/or removal of existing CPS from the network. In these CPS, next to the (wireless) sensor systems, there is also the actuation systems to interact with their environment. The design of automation, control and information technology must provide assurance of safety, reliable operation under normal and abnormal conditions, while guaranteeing performance. Self-monitoring and self-repair techniques are important. Obviously, the networked and information intensive nature of CPS, brings about big challenges with respect to security. This is covered by a separate challenge 'Trusted Data Sharing'.

2.8 Digital Twin

Process and product development are organized in cycles. The structuring, management and the accuracy, applicability and reliability of information is of crucial importance for the efficiency and effectiveness of these development cycles. These cycles, combined with the different stakeholders/perspectives that are involved at different levels of aggregation are so complex, that virtual models are required to provide the essential understanding for optimal product and process development. Data that is collected through the entire life cycle of the product has to feed the virtual models to improve overall understanding and furthering of the cyber physical system.

A digital twin is, roughly speaking, a virtual copy of physical processes, systems, materials, products and assets. It provides a (high-)fidelity representation and abstraction of their physical "twin" in the digital world. For the past decades, the use of the (old-fashioned) digital twin has been crucial in modern engineering systems and it has taken various different forms. For instance, during the design/systems engineering phase, CAD/CAM and FEM models are generally used for model-based design and virtual prototyping of high-tech systems, transfer function or state-space models are used for the control algorithm development, circuit models for the electronic analysis and realization of the final electronics using electronic design automation (EDA) software and finally various different computer-based formal models are used for monitoring and maintenance of the assets. In the aforementioned examples, these models are typically based on fundamental physical and mathematical laws. Moreover, they are usually formulated a priori, i.e., the models are developed and made available before the actual products/systems are realized. For such a scenario, interoperability between these different models is already identified as a key technical challenges in maintaining, reusing and exchanging information among them.

Complementary to the physical model-based digital twin, the ubiquity of Internet of Things sensors and hyper-computing capabilities have enabled engineers to directly create a data-driven digital twin based solely on data collected from the realized processes/systems/products. This approach can thus be regarded as the a posteriori approach since they are only available after the underlying physical systems are realized and operational. The models are typically used for monitoring, real-time process control and maintenance of the assets. Similar to the physical model-based approach, these different data-driven digital twins also face interoperability problems and do not allow the support of design cycles of non-existing products or processes.

A digital twin, based on real data or data from physical based models of the process, will be stored in a statistical model using Artificial Intelligence like neural network (NN) based deep learning algorithms, or on other statistical models approaches. The physical based simulations can either be analytical, phenomenological or even very complex micro-mechanical based non-linear FEM models. Of course, the digital twin can also be based on the combination of different model concepts and even the physical models can be calibrated based on real-time production data.

Processes addressed are e.g. raw materials manufacturing, product design & development, production systems engineering, process & production planning, production execution, production intelligence, closed loop optimization, and digital transformation business modeling. Simultaneously, different perspectives (like quality, sustainability, logistics, cost, …) are addressed for all such processes. The challenge is to seamlessly connect all building blocks in such a way that stakeholders can have meaningful interaction with the definition of the cyber physical product (e.g. by VR/AR Technology) at the right level of aggregation. Stakeholders should be provided with perspective-dependent ways to access the available information. The way in which the different stakeholders can interact with information and models is of crucial importance for the efficiency and effectiveness of a digital twin. Currently, the structuring, management, accessibility, connectivity, cyber security and accuracy of the building blocks in digital twinning are under developed. What is more, the fundamentally new ways of working that come within reach based on the use of digital twins are unexplored, which means that the working methods and tools have yet to be developed in the context of new business models. Therefore, the product and process development cycle is currently far from optimal and hence zero defect, zero waste, customized production for products that fulfill the highest quality requirements is not in reach yet. Research on all levels is required to allow for building full-blown digital twins of the product development cycle, the resulting products or the production environments.

The digital twin, includes a number of sub domains:

1. Physical constitutive models of the materials, including validation
2. Meta models based on this information and the application
3. Real-time sensor data including sensor analyses
4. Industrial statistics creating the Artificial Intelligence of the Twin
5. Interoperability

2.9 Mass Customization

In mass manufacturing, the optimization of production processes is the primary driver for price competitiveness. Drawbacks of this approach are that it leads to “one-size-fits-all” products with standardized components, conservative product designs, limited shapes, rigid supply chains and pressures to minimize product variety. If customer satisfaction is not primarily driven by price but also by the variety to choose from, a fast but more responsive manufacturing infrastructure is needed. Modern industry has to produce smaller lot sizes efficiently, enabling more variety in products against an acceptable price level. The globalized market and new business models require the ability to launch streams of new products with a high degree of personalization, for instance adapting to an individual’s biometric parameters or satisfying specific customer preferences.

Customization is a game changer in high-value manufacturing and requires a much closer integration of design with manufacturing. At a local level, higher responsiveness needs to be developed to meet customer demands, and mass customization should be implemented in such a way that high product variability can be offered with a flexible combination of limited sets of modules. To achieve this, the manufacturing companies and their production systems must combine flexibility and efficiency. Future factories will be smaller, closer to their customers and increasingly modular. Mass customization will be supported by computational design tools and tools for mass customized design which strictly ensure manufacturability to ensure first-time-right as you don't want any scrap or unnecessary material waste.

Manufacturing equipment is modularized in units of the size of containers and even smaller (tabletop factories). Each unit contains a smart, Internet-connected piece of manufacturing equipment like a 3D-multi-material printer, a CNC machine, assembly robots, test equipment, etc. With these units, one can produce all kind of products in small series. Most important for the suppliers/manufacturer is that the production system consisting of these units can manufacture different product orders without the need of changing the physical configuration. If the product mix or order volume changes substantially, the system has to be reconfigured and/or extended with more or different units. Product and production information can be uploaded to the production facility by the customers themselves or by their solution providers. The suppliers/manufacturers are able to offer a larger variety of parts/assemblies or even complete products in smaller batches. Previously, they got the order if they offered the lowest price. Nowadays they have to invest in flexibility. Any moment orders can change, product designs change and, at the same time, zero defect quality is required. The future factory is situated in a personalized customer-centric world. It combines high performance and quality with cost-effective productivity, allowing small series customization at large series manufacturing cost level. The limit to customization will no longer be set by technology but by the extent to which customers are willing to be involved in the design of their own products.

The challenge for suppliers/manufacturers is to make their factories smarter but, above all, more flexible and closer to the market [Smart Industry - A vision for Dutch Industry fit for the future]. It is expected that ultimately smart factories will be smaller than before, integrated in metropolitan areas: "Industry as a friendly neighbor". Economies of scale is no longer the paradigm, but the scale economies of networking become the rule of the game. Next-generation applications require technological breakthroughs like new printing technologies, new materials, multi-materials and advanced manufacturing concepts, and a high-level of integration. Future manufacturing systems deal with big sets of personalized data caused by the network-centric approach for single product/small series manufacturing, IP and copyright protection. The integration of Internet and Industrial automation has created a bright future for the smart factories of the future.

2.10 Production Management

Production management primarily addresses the decisions made for configuring a production system, either green or brown field. It considers both structural decisions (production capacity, facility design, production equipment selection and configuration) and infrastructural decisions (quality polices, supply chain logistics, production planning and control, production scheduling). The challenges for the coming 10 years are a direct consequence of three following trends:

- Firstly, producers of industrial equipment and production technologies are integrating an increasing number of hardware (i.e. sensors and automated calibration technology) to prepare their equipment to handle Smart Industry production paradigms.
- Secondly, markets are becoming much more dynamic, pushing companies to offer mass-customized products, production services systems at faster time to markets rates. Furthermore, emerging markets are expected to surpass established markets in developed economies in size and capacity in the coming 10 years.
- Thirdly, industrialized nations are tightening environmental regulations in a coordinated way in order to achieve a large reduction in CO_2 emission and a substantial increase in the material reutilization rates.

These trends require production systems to become much more flexible and resilient to uncertainties in terms of production volumes and product characteristics. In order to achieve this, the following challenges need to be addressed. First, more flexible and intelligent methods for production planning, control and scheduling need to be researched and developed in order adapt to changing demand patterns, small production batches and disruptive market events.

One challenge consists of developing methods that combine available sensor data and optimization algorithms while keeping human decision makers in the loop. Furthermore, this also calls for improved coordination between producers and suppliers, requiring more flexible contracts and increased information sharing.

Secondly, new technologies to enable reconfigurable production cells have to be developed to enable fast changes in production layouts and to maximize the product variety by minimizing investment in production technologies. Such technologies include hardware solutions that (1) enable setting-up production cells by manipulating basic production equipment building blocks, (2) control-engineering/mechatronic solutions that minimize setup times by automatically determining process parameters and machine controlling protocols, and (3) design automation tools to quickly determine feasible production cell configurations and layout characteristics. Thirdly, create symbiotic relations between the inputs and outputs of different production systems to optimize energy and material utilization rates. The main challenge is how to integrate the facility layouts and material flows of different companies producing different products in a way that waste energy and material can be reutilized.

Finally, educate a technical workforce so that they have the capacity to operate and maintain this increasingly complex production environment. In this context, both engineers and technicians need to be trained constantly so that they can cope with production systems that are not only becoming more complex, but also much more susceptible to sudden changes.

Solving these challenges will result in competitive and sustainable production plants using innovative technology-based approaches that drastically change rigid supply chain mechanisms and product-based business models into collaborative and robust production networks capable of delivering innovative products and services in time in a very dynamic and unpredictable, global environment. Solving multi-criteria, complex design problems will be the key to really exploiting the potential in novel system architectures. This will probably go quickly beyond human mental capacity. Shape and topology optimization provide a very promising enabler to find breakthrough solutions. Future computational optimization tools should provide competitive customized design including the required manufacturing conditions.

2.11 New Business Models

Smart Industry challenges the validity of established business models. Reconfigurable, adaptive and evolving factories are needed to face the uncertain evolution of the market or the effect of disruptive events. Manufacturing enterprises are pushed to take metropolitan actions, i.e., thinking globally but acting and staying economically compatible with the local market. Increasing customer-market orientation and the resulting problems of varying diversity and product complexity correlates to the complexity of business processes in manufacturing companies.

The management of complexity in product and processes, the growth of servitization business models, as well as the decentralization in case of smart factories is a real future challenge. The speed of corporate reactions towards changes to obtain or maintain a stable process situation depends on product, process transparency and open interfaces. The development of integrated, scalable and semantic virtual factory models will enable the implementation of decision support tools and optimization methods to address strategic decisions such as the location of new production sites, production technologies, and the selection of products and services to be offered in the market. These models should allow a fruitful interaction among all the relevant stakeholders in the design of manufacturing strategies.

Besides, new business models that provide a fully closed loop circular economy rather than a linear economy approach need to be designed, i.e., models that reduce, reuse, remanufacture, recover, recycle and redesign. To successfully combine the use of new production technology, digitization and a network approach, companies are challenged to adapt the four interlocking elements of their business model, i.e., customer value proposition, profit formula, key processes, and key resources.

The establishment of a network-centric production system that spreads throughout the entire asset life cycle may lead to the emergence of new forms of collaboration that are characterized by a co-creation approach to value creation. Customers play a predominant role among the collaboration partners. They become an integral part of the Smart Industry by providing information on their individual needs and use, which is critical input for optimizing existing and creating new network-centric production systems. Future key research lines are servitization as the design and implementation of new business models that allow the active integration of customers, to evolve business models into efficient and effective mechanisms based on co-creation competences, customer intimacy within an information-based business approach and the contribution of co-creation approach to the creation of customer intimacy. Future manufacturing enterprises collect customer requirements, analyze them and make the right product and service model. Enterprises are also expected to offer a comprehensive range of after-sales product services. New tools, methodology and approaches for user experience intelligence (i.e., social networks, crowd sourcing, social science methods, qualitative and quantitative, to generate insights, models and demonstrations, etc.) need to be explored and used.

Smart Industry is on the agenda in many countries, hence, managing inter-company relationships in *coopetitive settings, i.e., contexts in which competition and cooperation merge together*, have to be advanced. Since competition and cooperation may not be considered as secluded spheres, the development and adoption of new technologies required for Smart Industry solutions (e.g., automation, digitization, flexibilization, etc.) may benefit from a network approach to innovation among various competitive firms. Existing business models will change because of the introduction of big data and new applications using this data. Innovative business models are based on a dynamic network of companies, continuously moving and changing in order to afford more and more complex compositions of services. In such a context, there is a strong need to create distributed, adaptive and interoperable virtual enterprise environments supporting these ongoing processes. The establishment of coopetitive settings to foster the development of a smart industry have to be pursued. Business models have to evolve into efficient and effective mechanisms of value creation within a smart industry. The technological advancement and adoption of technological standards will be impacted by the coopetitive setting and the pursuit of coopetitive strategies.

2.12 Condition-Based (Predictive) Maintenance

Maintenance is vital in ensuring the availability, reliability and cost effectiveness of high-tech systems. Industry requires smart maintenance strategies to address the challenges posed by productivity, aging assets and servitization. Traditional maintenance concepts that are still commonly applied in industry rely on pre-determined fixed intervals for maintenance tasks. However, the degradation of systems is a dynamic process, governed by changes in both the system and its environment. The consequence is that many systems are either maintained too early, thereby spoiling a (significant) fraction of the system service life, or fail unexpectedly when the system is operated more intensively than anticipated. Condition-Based Maintenance (CBM) is therefore crucial to save on maintenance costs and increase system availability.

Production facilities (and public infrastructure) are subject to aging. Towards their original end of life, these assets need to be upgraded, built anew or scrapped. CBM offers the opportunity to extend remaining useful life or improve sustainability and ecological footprint. Servitization is the trend that capital goods, such as complex machines, installations, and vehicles, are not just sold as a product but also offered as a physical component of a service: the availability of the equipment is what is being sold, often in a performance-based contract. If such an arrangement is to work and to be profitable for the party offering this service, condition monitoring and maintenance (and operations) based on such monitoring is essential.

The challenge is to achieve just-in-time maintenance. Such a predictive maintenance concept can be realized by following a multidisciplinary approach, combining disciplines ranging from failure physics (failure modelling, life prediction) and structural health and condition monitoring to data analysis, maintenance process optimization and logistic challenges in resource planning.

The combination of data collection through smart sensor networks and advanced analysis of the collected data has great potential. Since many sensors are already available for process control, the specific challenge is to find out how that data can also be used for predictive maintenance. Data-mining techniques like machine learning may be useful for that purpose, but methods based on modelling system behavior and failure mechanisms are expected to perform better in this context. Moreover, additional sensors may be needed when critical parameters cannot be derived from the process-control systems. Intelligent health and condition monitoring systems, e.g., based on advanced vibration analysis, can then be added. Ultimately, the objective would be to completely monitor the (production) system health and performance from a remote control room. Moreover, the production and its degradation process should be fully captured by models and the operational and environmental conditions should be controlled so that the number of human interventions is minimized and their predictability is maximized. This will lead to a reduction of costs and an increase of system availability.

The most visible parts of Condition-Based Maintenance may not be the most crucial ones in ensuring a much higher acceptance of this new innovative way of maintaining assets. The most visible parts of the so-called data enrichment chain are data capture (through sensors) and data analysis (data handling and data analytics). A major challenge in data capture is the fact that data comes from different organizations and departments, and these may have conflicting goals and constraints towards sharing these data. The challenge in data analytics is to reconcile the perspective of the domain experts with their failure mode analyses with the perspective of the data analysts with their correlations between environmental and internal factors and degradation behavior. After that, the challenge becomes that of organizational collaboration in managerial decision-making, where financial, sales and other non-technical considerations have to be reconciled with the technical risks and opportunities. Next, the challenges come from planning and scheduling of the chosen course of action, and also from the organizational deployment of these decisions, partly through uniformly and adequately trained staff (e.g., with the aid of virtual reality and simulation) and smooth and robust IT-enabled workflows (e.g., with the aid of handhelds and augmented reality tools). Finally, the actual maintenance actions are performed in a standardized manner, with automatic logging of actions, and systematic evaluation afterwards of the effectiveness of the interventions so as to close the data enrichment cycle.

2.13 (Trusted) Data Sharing

More and more products (and services) will be designed, developed and produced (provided) by multiple parties, often industrial parties, but more and more also in combination with public parties and customers. Reasons for this sharing are (among others):

- **collaborative design** between producer and consumer, or within an ad hoc partnership between multiple, sometimes even public and private parties;
- collaboration in a **smart supply chain**, where OEM's work with subcontractors and these again with their subcontractors, material suppliers, etc.;
- **smart maintenance**, in which an OEM is sharing information about a product with a product user and an (independent) maintenance company;
- **extended product data lifecycle management** in which the whole history of the product, from design until usage and recycling in the field is being tracked and stored to enable better maintenance or better production;
- **servitization**, in which the actual use of a product is being sold, instead of the product itself.

To achieve a smooth and data-safe cooperation in all of the above cases, data and information about the product, the design, subsystems, use of the product, etc., have to be shared among all these parties. However, that what is being shared, here called 'data' for short, lies typically at the heart of the intellectual property and the competitive edge of the parties involved. Hence, the way the data is shared should make sure that the data can only be shared with the intended parties, and only for the intended purposes, hence, cannot be illegally handed to other parties, nor be used for other purposes than intended; this notion of sharing while keeping control is often referred to as '***data sovereignty'***. But before being able to discuss data sovereignty, questions about the actual data-sharing infrastructure need to be addressed. This includes (partly classical) themes such as data interoperability (future proof formatting guidelines, standardization), being compliant to (privacy) regulations and the secure and dependable storage itself (where, by whom, how long, until when, with which service-level agreements).

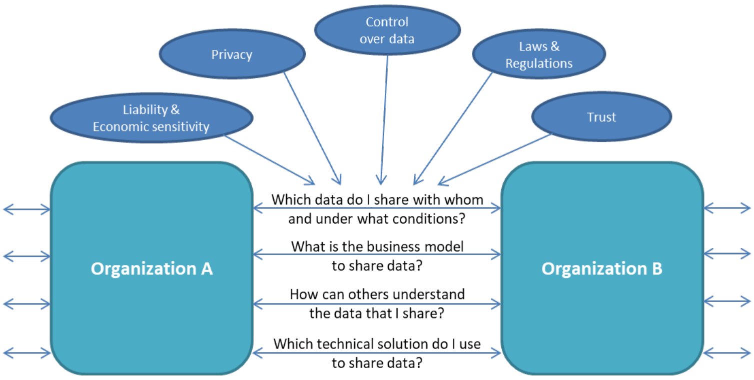


Figure 3 Trusted Data Sharing

The questions to be addressed in the above are not specific for smart industry, although they are present there quite strongly. Indeed, the broader topic of safe and secure data sharing is valid in general terms in the field of big data (in the Commit2Data program a call is planned on safe and secure data sharing, but not tailored specifically towards industrial applications). Also in the field of logistics there has been much progress on international (freight-) (EDI) data sharing, which can be of use in the smart industry context. In this case the Smart Industry community will follow contribute to an industrial Data Value Centre/Big Data Hub and contribute to international standard, in particular Industrial Data Space (IDS). Finally, the rising field of blockchain is of importance here; blockchain technology will become an important enabler for this field.

2.14 Cyber Security

Smart Industry transformation brings about many advantages in productivity, speed, efficiency, accuracy and customization. However, it raises new concerns about the overall system level qualities of the various network-centric production processes and products that are held together using a great many digital ties. The consequences that a breach of cyber security may have for physical safety, business continuity and critical infrastructures can be quite severe and costly. Where information systems or operational technologies exchange data, there is a growing vulnerability that needs to be kept in check. The autonomy, intelligence and adaptability of systems that allow them to reconfigure themselves and their products, further exacerbate the situation. The emerging risks and challenges call for real-time methods to ensure the cyber security of integrated and dynamic systems.

A key consideration is that security of singular component systems does not guarantee the security of overall combined cyber physical systems that are the result of ‘plug and play,' servitization, custom product configurations and automatically reconfigured supply chains. There is a significant challenge to develop methods to adequately deal with security in the context of smart industries as they are evolving, with particular attention to the security of services enabling trusted data sharing between partners. This should go beyond VPN (Virtual Private Network) connections, but include also (secure) digital identifiers for all actors involved (e.g. see the configuration used in the Industrial Data Space of upcoming digital identifiers as defined in a.o. the Dutch Blockchain Coalition).

Not all research and development in the cyber security field should be conducted within the framework of Smart Industry programs. The purpose is rather to identify specific challenging Smart Industry cases - in association with fieldlabs - that require a thorough approach to their overall system level cyber security, from shop-floor equipment (IoT devices, PLCs, SCADA systems, etc.) and smart products to servitization and value chain networks. On a Dutch national level, work can be done with the program Commit2Data. In Europe, an effort could be made to further develop a cyber-secure Industrial Data Space (IDS). It should be noted that no silver bullet for cyber security may be expected and that each of the transformation technologies addressed in this agenda may require specific solutions.

When addressing cyber security in actual Smart Industry practices, it is vital to consider the need for industries to secure their systems and value chain rapidly and comprehensively. The traditional in-company approach may have to make way for a more agile and collaborative approach to accommodate the pace of industrial change and also the multi-disciplinary nature of the challenges to be addressed. Companies may, for example, also make use of the proposed (regional) DTCs (Digital Trust Centers) and the ISAC (Information Sharing and Analysis Centre) and their specific industrial knowledge. In some cases work can be shared in the context of fieldlabs with research regarding critical infrastructures for secure data exchange.

2.15 Human Centered Technology

To design new personalized products, industrial systems and product service systems we should employ co-creation of value, system thinking, human technology interaction (HTI) and scenario-based design involving all stakeholders. Human technology interaction will change because products & systems get smarter and become connected through the Internet of Things. And as the use of sensors has become widespread, smart products and systems will increasingly present their users with actual information on their operation, giving usage, maintenance and repair instructions.

In industrial environments classical industrial robots are replaced by and existing manual work cells operators are enhanced with service and interaction robots. Such industrial systems work with significant more sensors in more unstructured, unknown environments, slower and in direct contact or next to humans. This requires co-evolution of flexible human and industrial systems in collaborative environments that integrate and support a seamless flow of information between human and the system with person-tailored user interfaces for human technology interaction. This requires the inclusive technology design of intuitive and logical interfaces and interactions between humans and robots, equipment and IT systems. Human centered technology is technology that provides optimal support during the performance of tasks to different specific groups of people, ranging from people with a low to a high education level and even people at a distance to the labor market.

Humans will interact with these increasingly smarter products and systems. All these devices and systems should recognize human requirements and behavioral patterns and compensate for age or inexperience related limitations. Smart systems, using sensors and more and more using Artificial Intelligence/Machine Learning/expert systems, are required to support fast and reliable reconfiguration and to minimize workload and learning time. Human behavior understanding, affective computing and social-signal processing are some of knowledge challenges. We need to understand what people are doing, how they are feeling and how they are interacting with each other and with technology.

Trust will play an important role in human technology interaction. Questions about responsibility, accountability, control and the user in the loop will become prominent. Jobs will change, some will disappear and new jobs will be created. Robots and smart ICT systems do not take over complete jobs, just some of the tasks in the job. Humans remain important to ensure flexibility. This is certainly true in 'low volume - high mix - high complexity' production processes in which Dutch industry is strong. Here the question is how new technology can optimally support humans in performing the tasks allocated to them, both cognitively and physically.

There exists many question that require further research. How do we distribute the tasks in the design phase? What are the options and how much freedom of choice (managerial choice) is there to secure both business performance and job quality aspects? How do we design dynamic task allocation, allowing for deviation from the allocated tasks in the operational phase (shifting work from humans to robots and the other way around) due to order changes, unexpected events, need to interrupt normal operation, etc. What are the effects of human-robot/device/control system collaboration on generic and more specific (e.g. trust) aspects of job quality? Which types of Inclusive Technologies for cognitive and physical support regarding allocated tasks are potentially successful? Which effects can be realized in terms of performance, job satisfaction and employability? And how do we design an intuitive, adaptive operator support system that adapts itself to the skills/experience level of the operator and to the quality measured in the primary process?

2.16 Employee Management

The content of work (e.g. 3D printers, virtual reality, cobots, AI platforms), the knowledge and skills demanded of employees (e.g. professional knowledge as well as some IT skills) or the social aspects (i.e. the interactions with colleagues, supervisors and people outside the organization) all evolve rapidly. People are and remain most important for any organization, but the nature of existing jobs and therefore also employee management (HRM) will change. Smart Industry requires more and more 'deep knowledge', but also more responsibility from employees and management for processes that are getting more and more critical. Workplace innovation is seen as a central practice to accomplish this stronger engagement of all actors in the company environment. Such a practice is a necessity if companies want to engage their personnel in supporting the continuous innovation process. What do employees need as competences, skills and attitudes to help generate this improved innovative performance?

Most people learn best and most by solving problems based in practice. Working, learning and innovation should be integrated once again to effectively handle the rapid development of technology. A smart connection of informal and formal learning arrangements is key for the future development of current and new employees. Skills intensive workplaces and a pervasive learning culture within firms (see OECD) poses an enormous challenge. Informal learning practices have to be effectively combined with formal practices to further develop new forms of '*Smart Industry*' craftsmanship. Education, experience, learning and innovating are the hallmark of craftsmanship, but now they are organized in disconnected silos.

The challenge is motivating people for change, but bigger issues touch upon the topics of (life-long) training, education and continuous innovation. Tackling this will require joint efforts (e.g. employees, organizations and external parties like social partners, universities and the government). The question remains what will be required of employees themselves and what demands will be placed

on both the employer in order to contribute to developing and maintaining value-adding employees. How to avoid losing your technical employees once there is a shortage on the labor market, how to keep elderly employees up to speeds with all the new digital technologies they never saw at school? Focusing on the HRM department in general, Smart Industry not only raises questions about their work context, or more specifically the changes to HR technologies, but also questions their activities and roles. Which type of social relationships are required to deal with employee management?
In addition, Smart Industry challenges the established positions of decision-making. The potential of possessing huge quantities of real-time data and the possibility of making this available to anyone you wish triggers the question of where to place responsibilities. To what extent are we able to, and do we want to, change the hierarchical structure of existing organizations**?** What does it mean to function with zero-management-layer organizations?

2.17 Smart Response

The challenge Smart Response, as described in chapter 1.3, deals with the response of economy and society to the changes caused by Smart Industry and the disruptive technologies (robotics, AI, embedded sensors and Internet of Things) connected to it. The question is not only how we respond to the acceleration of the digitization process but how we can anticipate these developments to realize the desired economic and social impact or avoid the negative effects for specific groups.

Economic and social impact of Smart Industry. How do the concepts opened up by Smart Industry affect society? On which points will they put pressure on the existing social order? How will economic ecosystems/networks, sectors, business models, organizations and jobs change?
How can we anticipate on Smart Industry developments to realize the desired economic and social impact and avoid the negative effects for specific groups? Which technological choices need to be made and how? How do we adapt businesses? What is possible and desirable from a societal point of view? Besides exploring the effects, attention needs to be paid to the question in which areas the Netherlands can develop *unique positions* (points on the horizon) and how these ambitions can be realized (Smart Industry, Smart Society). What is our 'smart response' or smart interaction by consumers, employees, politics, media, etc.? On which aspects will we focus our offensive and on which aspects do we have to be more defensive?

Scenario's. Today the societal challenges as sustainable energy and resources, healthy food, clean drinking water, societal cost of health and support for an elderly population, safe, sustainable and reliable mobility etc. impact industry in many ways. A proactive response to a still unknown future requires exploration of possible scenarios. Which social directions (smart society) and economic growth within ecological boundaries, type of jobs and employability, etc. do we want? As changes occur fast, where should we focus on?

International perspective and value chains. For years, outsourcing and offshoring were the ways in which companies strengthened their competitive positions and increased their profits. The first signs of a reversal of this trend are visible. Smart Industry allows production of small series, whereas offshoring to China is only profitable at very high volumes. Can we change offshoring manufacturing to new metropolitan/regional manufacturing? And if this it possible, value chains will change and how does this affect regional ecosystems and their smart specialization (from rustbelt to brainbelt). How will supply chains for regional rooted SME and super-national OEMs change?

Platform economy. Digitization of industry, all value chains, the whole economy and all of society has led to the emergence of the 'platform economy'. The rise if new monopolies whose size and power increases through positive network effects points to the advent of a new economic order. Companies like Google and the like are so rich that they can buy any new competitor and thus smother future competition in its early stages. How e.g. should we deal with the current trend to "winner-takes-all" platforms? What could be the role of the EU? Are there critical functions or assets we have to defend? Do we have to build up new technology positions?

Regional and special impact. But Smart Industry also has a regional and spatial impact. While towns and cities in the Netherlands and Europe grow and flourish, the countryside and peripheral regions face demographic and economic decline. Smart Industry offers new opportunities for new regional development and growth. What are the relations between investments in Smart Industry and the development of regional ecosystems, national economic development and export positions? What is the spatial impact of 'metropolitan manufacturing', that stands for small-scale, ecologically sound and flexible production close to consumers?

Sustainability. There are also major developments with regard to sustainability that require a smart response in the context of Smart Industry in the need for eco-efficient production. Additive manufacturing is the best-known example of a technology that allows production with less raw material. Less waste, closed cycles and automatic disassembly are the key words. How can Smart Industry technology contribute to the Sustainable Development Goals?

Technologies and skills. Smart Industry technologies are developing extremely fast. Instead of what we expected, applications of quantum technology arise already. Which key enabling technologies will become crucial for the Dutch Smart industry agenda? Technology can make people redundant, but it can also be used to support people in the labor process; human centered technology. The development of cobots and expert systems that support people in the performance of their tasks and make it possible for people to participate longer or at a higher level in the labor process. What are the effects on different kinds of jobs and on employment as a whole as technology and the Dutch working population change? How can we develop new learning environments that respond faster to new developments than traditional education is able to do? How can we set up organizations in a way that promotes learning and development? The challenge for education is also to set up tuition for the employed and the elderly. Continuous changes, creative skills, problem solving in complex environments are examples of challenges connected with Smart Industry to which education also needs to find answers.

Monitoring. Systematic monitoring of developments and specific interventions within the frame of the Smart Industry program is important to map opportunities systematically. Which companies are successful in Smart Industry and which are not and why? What are the effects of Smart Industry on business models, profitability, employment and environmental performance? What is the role of fieldlabs and how can they accelerate the adoption of Smart Industry? In connection with this, it is also necessary to investigate if and what kind of connections there are between investments in Smart Industry and regional and national economic development and export positions. What relations exist between R&D or ICT investments, the development of new business and growth of Gross (national/regional) Product?

3. Transformations

Research answers to the list of challenges of the previous section, lead to a better knowledge and technology base. However, these are in general not one-to-one immediately applicable in industry, and additional steps are required to integrate and develop them further into broad implementation of Smart Industry innovations that really make the difference (these are called transformations). New knowledge and new technologies can be implemented in company projects in their product design, service creation and execution, manufacturing and other operations. The transformations help to bridge the gap between industry needs and results of knowledge and technology development in public-private research projects.

In this chapter, we present the actual view on transformation industry is facing and link the knowledge challenges from the previous chapter to implementations, mainly by means of regional fieldlabs. These transformations describe a dynamic process, and hence will be reconsidered, updated, etc. on a regular basis.

Transforma-tions	Objective of transformation	Sub themes	Smart Industry 2018
1 Smart Manufacturing technologies	The latest production technology for smart industry	Advanced Manufacturing Robotizing	Advanced Manufacturing, High Precision Equipment Robotics & Mechatronics Smart Design & Engineering, Integrated Lifecycle Mgt
2 Flexible Manufacturing Systems	From large series to customized single-unit production	Single-unit production n=1 Additive manufacturing IoT/ cyber physical systems/ 5G	Additive Manufacturing Cyber Physical Systems Production Management
3 Smart Products	Products are smart and always digitally connected.	Ultra-personalized products and systems, Intelligent products, Internet of Things	Smart Design & Engineering Mass Customization Integrated Life-cycle mgt.
4 Servitization	From product supplier to service provider	Servitization, business models Maintenance-free production	New Business Models Trusted Data Sharing Condition-Based Mainten.
5 Connected factories	Companies are digitally connected and can share data in a cyber-secure way.	Digital connection/data sharing/ cyber security Semantic Interoperability	Trusted Data Sharing Cyber Physical Systems Cyber Security
6 Digital Factory	Digital simulation of whole factory	Digital Twin, zero defect/ first-time-right Digitization of product for design, simulation & production preparation	Digital Twin Cyber Physical Systems
7 Sustainable Factory	Minimal use of energy & resources	Reuse/refurbishing/recycling, Product/system use/leasing	Integrated Life-cycle Mgt New Business Models
8 Smart Working	Human centered technology not only an ethical obligation, but required for efficiency too	Human-mach. interaction/Inclusive Tech. Design of socio-technical systems at all aggregation levels	Human Technology Inter. Employee Mgt, Smart Response

The Smart Industry implementation agenda will use Smart Industry fieldlab and regional cooperation to bridge the TRL 4-7/8 technology readiness levels. The knowledge challenges are mainly focused on the initial research TRL levels 1-4/5. TRL 4-7/8 are applied technology and industrial development phases, whereas TRL is commercial business. As the knowledge challenges deals with research questions and (applied) universities and research institutes, the transformation deal company projects and public-private implementations.

3.1 Smart Manufacturing

A factory ultimately manufactures 100% defect-free products that at every process step 100% inspection takes place such that 100% of the time product/component stayed within the specifications. Output of one production step is 100% controlled such that the input of the next step is 100% within specs. Only then full automation and robotizing is possible. Also waste and subsequent repair and fault costs will be minimized. Zero defect implies equipment with high accuracy, extensive data logging. In the nearby future AI learning to adapt individual process steps to become self-learning will become available. The ambition of smart manufacturing is to make each process step, each individual equipment as smart as needed.

Zero defect is especially a topic, led by Philips Drachten, of the Region of Smart Factories fieldlabs. Also, the RoboHouse fieldlab and the optical sensor topics in the DOC fieldlab are active to enable transformation. And finally the High-Tech Software Cluster and the Flexible Manufacturing fieldlabs are focused on the topic of improving single machines/work cells to make zero defect possible.

The directly related knowledge challenges are robotics and mechatronics, high precision equipment, advanced manufacturing.

3.2 Flexible Manufacturing

Once a company reached a certain level in smart manufacturing (device level) full-fledged flexible manufacturing at factory level come within reach. The flexible factory of the future can download designs and manufacturing recipes from a product/OEM owner/designer and deliver the product on time to a customer around the corner. Flexible Manufacturing is about producing products in lot-size one for the price of mass produced product, produce them on order, not on stock any more for the most reliable and shortest delivery time. It are smaller, highly flexible factories located close to the customers, sometimes called metropolitan manufacturing in the sense of bringing industrial jobs back to town. In case of suppliers in a value chain, these factories are located in the regions where the main OEMs are located.

High complexity, low volume industries as the high-tech systems and maritime sector are important Dutch industry sectors whose OEM operate at world-class level. In these industries, flexible manufacturing capabilities are crucial and imply e.g. zero-programming of robots and equipment, large scale use of 3D printing, direct printing of electronics (flexible electronics). Robots, CNC machines, laser cutters, 3D printers can switch within cycle time to a program for the next, different product. This enables today the flexible production of series of one on the factory floor. One need teams of manufacturing people who can judge the manufacturability and reply on the quotations and have the capability to manufacture the products in the shortest time from quotation to shipment/payment. To minimize the administrative burden of a quotation-order-shipment-billing sequence for each individual project further automated EDI and blockchain based solution are foreseen for this transformation.

In the long run, these flexible factories must also be able to disassemble, refurbish and recycle the products based on their knowledge of how these products were once assembled. (Link to transformation smart products/servitization/sustainable factory).

Companies as KMWE, Frencken, NTS, SME suppliers, Smart Robotics in the high-tech manufacturing industry and maritime constructions (high-tech ships, platform and deep-sea equipment) with small series, complex products, frequent engineering changes with the need for shorter delivery times and fast deliveries without additional costs are of particular interest.
Fieldlabs are Smart Bending Factory, Smart Connected Supplier Networks, Added, 3DMM provide the prototype environments for this type of transition.

Knowledge challenges are additive manufacturing, mass customization, production management, but also cyber security and trusted data sharing.

3.3 Smart Products

Smart Products are as user friendly and attractive as possible, smart and always connected and designed from minimal total life-cycle costs (in energy, material and transport costs). Products will have embedded intelligence, probably using flexible electronics, to communicate with their environment/users. Capital goods will be customer specific, consumer goods even highly personalized. All product will make reuse of components and are a designed for flexible (n=1) production possible.

Companies involved are the design houses, but also OEM companies as Philips, etc. as well as supplies for (flexible) electronics suppliers as NXP, etc. Involved Smart Industry fieldlabs are the Ultra Personalized Products & Services (UPPS) fieldlabs, but also amongst others the Holst Center.

Knowledge challenges are smart design & engineering, mass customization, life cycle management, but also inclusive technologies.

3.4 Servitization

Large product suppliers become service providers that lease their equipment as part of a service to their customers. Instead of buying a printer or an X-ray system, etc., customers pay for a service package consisting of prints or X-ray images etc. This leads to new business models. This is the result of, amongst other technologies, the IoT (Internet of Things), 5G and immutable blockchain applications that enables remote monitoring of equipment. The service provider uses big data analyses, possible including AI technologies and intensive customer contact to constantly improve the quality of the services as provided. These players shift their R&D from manufacturing towards user behavior and subcontract the R&D for manufacturing to their suppliers.

A consequence of servitization is that products and systems get a longer life and/or refurbished because customers do not demand a new product but a service that works. At the end of a lease contract and at end of life, the owner will know better what the residual value of the product is to enable reuse, refurbishing or recycling.

Besides leasing products, we also see the emergence of servitization in maintenance in the Netherlands. The technical service provider monitors the equipment and installations at the customer for maintenance from a distance. Condition-based or predictive maintenance requires use of IoT and big data solutions. Especially for maritime applications, this may lead to ever better monitoring of a platform and, in the more distant future, to autonomous control. This aspect will also appear as part of digital twinning at digital factory. The servitization fieldlabs in the maintenance sector, all in close cooperation with World-Class Maintenance are not restricted to capital assets and equipment, but include also the Smart Dairy Farming fieldlab as an example of health monitoring of cows similar to conditioned-based asset maintenance monitoring that will result in a servitization business model. The ambition is that all high-tech systems, processes, agro, maritime installations and infrastructure can be safely monitored from a distance.

An important system component in servitization are digital platforms where multiple applications (apps) and multiple components work together e.g. where artificial intelligence modules are used for different domains or where shared/open (sensor) data is available for multiple use.

Examples of servitization companies are Philips, Canon-Océ, ships, planes and, in the future, car suppliers and lease companies. Companies in the maintenance servitization are Stork Asset Mgt, IJssel, Sitech, ABB, Siemens, Engie, Semiotic Labs, maintenance companies and all owners of expensive installations and suppliers of professional systems. The last companies are already active in all regions in the Smart Industry fieldlabs CAMpione, Camino, Smash, Smart Dairy Farming, the Garden (security), 5Groningen.

Technologies are interest for servitization are big data analysis, AI algorithms, cyber security, 5G communication, blockchain platforms, legal contracts. The knowledge challenges for this transformation are new business models, cyber physical systems, condition based maintenance and trusted data sharing.

3.5 Connected Factories

Smart Industry companies are digitally connected, cyber safe, exchange secure data using international standards and are able to optimized at the level of an integral value chain. Tenders, drawings, orders, transport details, invoices, measured (sensor) production/quality data are digital identified and can be, without vendor lock-in, exchanged using open standards. The ambition is to optimize, to lower costs, remove all errors and the speed delivery over a total value chain. It will result in significant delivery time reduction through automated delivery times between submission of design in tender up to delivery and payment, with constant progress monitoring.

Cyber security realized throughout the manufacturing industry, for administration, office and factory work floor. Safe and reliable data exchange and access to design according to mutually agreed access rules and contracts. International Industry 4.0 standards and blockchain including digital identities become a standard available technology.

Technologies as needed are cyber security, IoT coupling, glass fiber and 5G data communication and the proper legal contracts (copyrights, data-base regulation, privacy and software use rights). In the long run blockchain technologies will automatically select the best offer in terms of price and delivery for each tender in the value chain and control/log its progress.

Companies involved are the partners of Brainport Industries, SMEs, large OEMs (Philips, Océ, FEI, ASML, shipyards, Shell, etc.), but also software suppliers Siemens, SAP, Dassault, Exact, Isah, etc. and ICT support suppliers as KPN, IBM, Thales (as both user and security provider).

Involved fieldlabs in South and East Netherlands are the Smart Connected Suppliers Network, and the industrial security Smart Industry fieldlab the Garden. The knowledge challenges: Cyber Physical Systems, Cyber Security, Trusted Data sharing.

3.6 Digital Factory

The entire factory is internally digitally seamlessly and cyber-secure connected, from office, design, shop floor, logistics up to equipment maintenance and facility management. All products, processes and equipment have a digital version (digital twin) for design, (AR/VR) simulation, process modelling & control, maintenance (logging & repair instructions) and use registration. Next to the CAD data of all objects, the collection on its use with process and maintenance data can be used to train AI algorithms and continuously improve these algorithms. Using the real-time data received through IoT coupling, the historic data and the digital models it is possible to monitor, control and optimize a factory and its processes as well as to simulate them for planning and training purposes. In general sensor and equipment have more parameters, known by the sensor/equipment builder, that currently are used in today's operations. It is expected that more and more of the additional data is collected too.

The aim is to enable zero defect, first-time-right production. In zero defect production, essential data of each production step is collected and assessed. It is expected companies will take ownership and responsibility of all this data, the derived AI algorithms and keep them in-house. Self-sovereignty will imply discussions with suppliers and services providers as well as (new) legal constructs.

In the chemical process industry, such use of more extensive (white-box) models with more sensor information should allow automatic and remote process control, not only in steady-state mode, but also in (often non-linear) startup/stop/emergency transitions. Better models are also needed to ensure that waste is minimized. In the maintenances services the models should lead to zero-surprises. In the manufacturing industries, the digital twin models should lead to zero-programming.

Involved or interested companies: Philips (zero defect), Chemical industries (advanced process models) and fieldlabs are the High-Tech Software Cluster, but also RoSF. The knowledge challenges are digital twinning, cyber physical systems, (trusted data sharing) and human technology interaction.

3.7 Sustainable Factory

A sustainable factory uses as less energy and material as possible. It uses as much sustainable energy as possible. It also uses as much recycled/refurbished material and components as possible. Its products are suited for reuse/refurbishing/recycling and designed with most optimal total life cycle cost in mind and are suitable for servitization business models. A sustainable factory in the future will also be able to assemble and disassemble in lot-size one.

Multiple companies are interested, and the UPPS fieldlab have sustainability as integral design constraint. Knowledge challenges are therefore smart design and engineering, integrated life-cycle management but also new business models and for the disassembly also several of the robotics/manufacturing challenges.

3.8 Smart Working

Work in a factory should be exciting and motivating. People are fully supported by technologies and means they understand and, if needed, they are trained for and which makes them more productive and competitive on a world level. Operators become supervisors who have also learned to recognize problems and solve them in multidisciplinary teams. Human technology interaction should be so simple that people can effective use the technology (inclusive technology). But smart working also involves (social/legal) conditions as set by the desired economy & society.

Digitization, chain collaboration and new business models make other requirements regarding the arrangement of organization and work and the collaboration in business ecosystems. The discipline that researches these subjects in order to define solutions is called Socio-Technical Systems Design. The man-machine relation will have to be reinvented at all possible aggregation levels. This is strongly related to Inclusive Technology and Man-Machine Interaction. The challenge is not to see business, work and organization because of technological development but as the challenge to integrally design, introduce and manage socio-technical systems. This calls for early involvement of ergonomists and business management experts in technological innovation. It has been proven repeatedly that technology is only one of the factors determining the setup of organizations.

The opportunities offered by Smart Industry can only be taken if both industry and society make adaptations. What is the smart response of consumers, employees, politics, the media, etc.? How does Smart Industry fit into the urban landscape? How can Smart Industry contribute to maintaining industrial production and employment in the region? Which adaptations are required for the new value chains? Are new standards required? Is enough capital, venture capital or otherwise, available? Which new skills are required for the changing work population? How do we effectively strengthen the link between education and Smart Industry, not only for initial education (young students), but also today's workers of 35 year and older who will face the challenge of life-long learning for another 35 years with unpredictable (technological) developments.

The question how society needs to change to allow Smart Industry to succeed calls for a smart response including exploration of future scenarios. Explorations should include questions on desired societal directions (smart society) and economic growth within ecological limits. The ageing population raise questions regarding affordable care but also offers opportunities for new smart products and services.

These questions are relevant to all Smart Industry companies, labor unions, education institutes and society in general. All current Smart Industry fieldlabs will need to include skills labs for life-long-learning as a start, but also to start discussion on the social impacts of the technologies by the fieldlabs.

Knowledge challenges include human technology interaction/inclusive technology design, smart response and new employee mgt.

4. International developments

Smart Industry in the Netherlands has similar scope and ambitions as initiatives in other countries. To see Smart Industry in relation to these initiatives, an overview of international developments is given.

US:
In 2011, the US president issued a memorandum stating that it is of strategic importance to the USA that industry and industrial production accelerate the adaptation to new technological developments. The development is referred to as the development towards Advanced Manufacturing. Advanced Manufacturing is defined as developments that "depend on the use and coordination of information, automation, software, sensing, and networking and/or make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology (Executive office of the president, 2011). American industry embraced these developments and, in 2015, they set up a consortium called Industrial Internet of Things (*IIoT*)to further develop IIoT. This defines the Industrial Internet of Things as: "The Industrial Internet is an Internet of Things, machines, computers and people, enabling intelligent industrial operations using advanced data analytics for transformational business outcomes. It embodies the convergence of the global industrial ecosystem, advanced computing and manufacturing, pervasive sensing and ubiquitous network connectivity (Industrial Internet Reference Architecture p. 35). In 2016, the USA combined the development of IIoT with that of artificial intelligence and machine learning. In a report published end 2016, the White House stated that the developments in AI were very fast and noticeable and presented a major challenge for American industry. The fast developments in AI were already causing changes in the traditional American industrial workplace. It was predicted that AI developments would "change the types of jobs available and reshape the skills that workers need to thrive". (Artificial Intelligence, Automation, and the economy Executive office of the president, December 2016).

China:
China also plays a major part in digital developments in industry. In 2015, the Chinese government issued a memorandum entitled Made in China 2025. The message was that the Chinese government had to retain and expand China's position as important worldwide producer of goods. The memorandum is an ambitious program for the transformation of the Chinese industry. The Chinese government says it wants to "accelerate the transformation and industrialization of national defense and promote two-way transfer between military and civilian technologies. We will promote the full integration of next generation IT and Industrialization and take intelligent manufacturing as the main priority of integration" (Made in China 2025, July 2015, State Council). In 2017, the Chinese government extended this ambitious plan with a program aimed at strengthening China's position in artificial intelligence. The Chinese government describes this as follows: "At present, China's situation in national security and international competition is more complex, and must, looking at the world, take the development of AI to the strategic level with systemic layout, take the initiative planning, firmly seize the strategic initiative in the new stage of international competition in AI development, to create new competitive advantage opening up the development of new space, and effectively protecting national security" (A next generation AI development plan July 2017).

Europe:
In Europe, countries like Germany (Industrie 4.0), Italy (Intelligent Factories), and France (Industries of the Future) are working on comprehensive programs to make their industries tie in with this fast move towards digitization of industry and production processes. These national initiatives prompt the European Committee to work on a set of measures to support the digitization of European industry.

5. Contributions

The HTSM roadmap Mechatronics and Manufacturing was first formulated around 2010. In 2016, headed by Jan Post from the HTSM roadmap council, it was updated and rewritten by a writing team as the HTSM Smart Industry roadmap. It had a technological focus. In 2016 the NWA route Smart Industry was selected as one of the routes from 12.000 questions from the public. In three large group discussion in Eindhoven and The Hague in 2016, headed by Egbert-Jan Sol of the Smart Industry Program Office, the NWA route got a much broader scope then the HTSM roadmap, now including societal, legal and additional ICT topics.

The next step of the Dutch Smart Industry program will evolve from 2018 onward into an implementation program. In this context, the NWA route and HTSM roadmap are merge into this NWA/HTSM route/roadmap 2018 update to align the knowledge question with the selected implementation transformations.

The HTSM writing team and 25 people from the NWA Smart Industry mailing list sat two times together in 2017 in Utrecht to merge the documents.

Bart Ahsmann	ClickNL/TUDelft
Evert van den Akker	TNO
Gregor van Baars	TNO
Ruud Baartmans	TNO
John Blankendaal	Brainport Industries
Rolf Bossert	ClickNL/SIA
Paul Burghardt	Thales
Anton Duisterwinkel	Innovation Quater
Daan van Eijk	TUDelft
Wilbert van den Eijnde	Consumers Voice
Willem Endhoven	HightechNL
Govert Gijsbers	TNO
Milou Habraken	UTwente
Klaas ten Have	TNO
Boudewijn Haverkort	UTwente
Tom van der Horst	TNO
Bayu Jayawardhana	RU Groningen
Mikeal Jansson	Min EZK
Frank Karelse	SIA/ TKI HTSM
Fred van Keulen	TUDelft
Herma van Kranenburg	NWO-TTW
Harro van Lente	Uni Maastricht
Ben van Lier	Centric
Timo Meinders	Philips
Jan Post	Philips
Erik Puik	Hogeschool Utrecht
Wim Renders	Brainport Developm.
Pia Snijder	UTwente
Egbert-Jan Sol	TNO/Smart Industry
Bert Thuis	NLR

The group of contributors, writers and editors cannot guarantee that the text is complete. We realize that it still contains error. In case of errors or if you require corrections, you can forward your request to info@smartindustry.nl or directly to Egbert-Jan.Sol@TNO.nl and J.Post@Philips.com

6. Documents used (References)

The information shown in this roadmap is based on various contacts and meetings with stakeholders in the Smart Industry domain and on publications like roadmaps and other written information. A selection of these documents is given below:

- Nationale Wetenschapsagenda (NWA). Nov 2015 https://www.wetenschapsagenda.nl/
- COMMIT2DATA: https://www.dutchdigitaldelta.nl/big-data
- Actie agenda Smart Industry: Dutch Industry fit for the Future, TNO/'FME Agenda', November 2014
- *Smart Industry: Towards 21st century skills*; Science Agenda 2015-2025, April 2015, 'STW Agenda'. http://www.smartindustry.nl/wp-content/uploads/2015/06/Scientific-agenda-Smart-Industry-2015-2025.pdf
- The Global Information Technology Report 2014. World Economic forum 2014, http://www3.weforum.org/docs/WEF_GlobalInformationTechnology_Report_2014.pdf
- *Brainport Industries*: http://www.brainportindustries.com/
- *High Tech Systems Center:* http://www.tue.nl/en/research/research-institutes/top-research-groups/high-tech-systems-center/ E. Bruins, D. Koser, A. Stokking. Smart Industry: Towards 21st century skills – Science Agenda 2015 – 2025TNO-STW. April 2015: http://www.smartindustry.nl/wp-content/uploads/2015/06/Scientific-agenda-Smart-Industry-2015-2025.pdf
- EFFRA. *EFFRA Research Priorities*. **www.effra.eu**
- www.smartindustry.nl/english: Smart Industry - A vision for Dutch Industry fit for the future
- Holland High Tech: http://www.rijksoverheid.nl/bestanden/documenten-en-publicaties/-rapporten/2011/06/17/holland-high-tech/rapport-Top Sector-high-tech.pdf
- Robotics: Market Survey and Development for Brabant
- *Roboned:* http://www.roboned.nl/sites/default/files/RoboNED%20Roadmap.pdf
- Smartindustry: http://www.smartindustry.nl/
- Internationale verkenning beleid digitalisering van de industrie,: https://www.tno.nl/media/6272/internationale_verkenning_beleid_digitalisering_van_de_industrie.pdf
- Factories of the Future. Multi-annual roadmap for the contractual PPP under Horizon 2020. EFRA. 2013: http://ec.europe.eu/research/industrial_technologies
- Roadmap supporting position paper High Tech Mechatronics, G. van Baars et al. [http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/smart-industry/xxxx]
- *Agenda voor Nederland*, inspired by technology. Chapter: 'Dutch Industry, smart(-est) industry', https://www.tno.nl/nl/over-tno/meer-over-ons-werk/agenda-voor-nederland-10-inspirerende-essays/
- High Tech Systemen en Materialen: Kennis en Innovatie Agenda 2016-2019
- https://www.fraunhofer.de/en/research/lighthouse-projects-fraunhofer-initiatives/industrial-data-space.html
- Living in a networked World. Integrated research agenda Cyber Physical Systems - Geisberger E. and Broy M. eds. Acatech study March 2015)