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TNO-rapport

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Inhoudsopgave

1 Introduction

Dit rapport beschrijft de kennisontwikkeling binnen de Vraaggestuurde Programma's (VP) van TNO die bijdragen aan de doelstellingen van de Topsector HTSM voor de periode 2019-2022, met nadruk op de activiteiten in 2019.

De volgende VP's worden beschreven:
- VP Cyber Risk Management & System Resilience
- VP Radar & Sensorsystemen
- VP Human Health Risk Management Nano
- VP Automotive Mobility Systems
- VP Space & Scientific Instrumentation
- VP Semiconductor Equipment
- VP Flexible and Freeform Products
- VP Sociale Innovatie
- VP Environmental Technology
- VP HTSM-Bouw Innovatie
- VP Intensivering Smart Industry
- VP Embedded Systems Innovation

Dit rapport is onderdeel van de TNO Procedure Kennis, waarin de wettelijke verplichtingen beschreven staan rondom de inzet van overheidsfinanciering (genaamd Rijksbijdrage TNO).
Tot en met 2018 viel het VP Meerjarenplan qua timing samen met het TNO Strategisch Plan (in dit geval 2018-2021). Elk jaar verscheen er dan een update voor volgend jaar van betreffend Meerjarenplan.
Vanaf 2019 werkt TNO met 'rollende' VP Meerjarenplannen (voor onderhavig rapport 2019-2022), die elk jaar worden geactualiseerd voor volgend jaar èn met een jaar worden uitgebreid.

Doelgroep van dit rapport is het Ministerie van Economische Zaken en Klimaat en de Topsector HTSM. TNO zal dit rapport op haar website publiceren.

2 VP Cyber Risk Management & System Resilience

Contactpersoon TNO: Tjarda Krabbendam MSc

2.1 Samenvatting

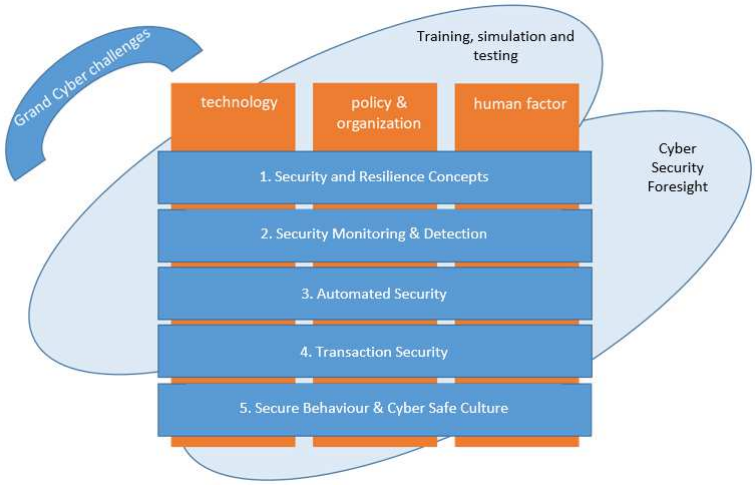
Digitale veiligheid is een essentiële voorwaarde voor een welvarende samenleving en een sterke economie. Door de snelle digitalisering van de samenleving en technologische ontwikkelingen zal Nederland voor een voortdurende uitdaging komen te staan om digitale veiligheid te behouden en te versterken. Het Vraaggestuurd Programma Cyber Risk Management & System Resilience draagt bij aan deze complexe uitdaging met innovatieprojecten op vijf cruciale thema's. Het thema '*Security and Resilience Concepts'* thema bouwt aan een robuuste en effectieve informatiedeling en samenwerking tussen partners in het digitale domein, zodat de Nederlandse samenleving als collectief in staat is om goed digitale risico's te identificeren, tijdig dreigingen kan detecteren en effectief kan handelen bij incidenten. Binnen de thema's '*Security Monitoring & Detection', 'Automated Security'*, en *'Transaction Security'* wordt essentieel technologisch onderzoek uitgevoerd naar het detecteren van digitale dreigingen, het automatisch afwenden van aanvallen en het veiliger maken van digitale informatie-uitwisseling. De producten uit deze thema's zijn belangrijke ingrediënten voor organisaties om hun digitale veiligheid te versterken. Het thema '*Secure Behavior & Cyber Safe Culture*' kijkt naar menselijke risico-perceptie en gedrag in het digitale domein, en hoe dat zich vertaalt naar organisatieculturen. Dit levert belangrijke inzichten op die organisaties kunnen gebruiken om digitaal veilig gedrag bij werknemers te stimuleren. Binnen deze thema's wordt er gekeken naar zowel de technologische uitdagingen, als ook bijbehorende beleids-, gedrags- en cultuurvraagstukken, met het doel om bij te dragen aan de capaciteitsopbouw van de Nederlandse overheid en bedrijfsleven – op strategisch, tactisch en operationeel niveau, in de vorm van visies, advies, analyses en technische prototypes. Hiervoor wordt er in dit programma nauw samengewerkt met de overheid, het bedrijfsleven en wetenschappelijke partners, internationale organisaties en netwerken. Met deze partners creëren we samenwerkingsverbanden waarbinnen we visies delen, experimenteren en innovaties een weg naar de praktijk laten vinden.

2.2 Korte omschrijving

Het doel van het onderzoeksprogramma VP Cyber Risk Management & System Resilience is: 'Nederland digitaal veiliger en weerbaarder te maken én tegelijkertijd de economische kansen van cybersecurity te verzilveren'.

Het Cybersecuritybeeld Nederland (CSBN) 2018 laat zien dat de omvang en ernst van de dreiging aanzienlijk is en er sprake is van continue digitale dreiging. De weerbaarheid staat onder druk door de complexiteit en connectiviteit van de digitale infrastructuur. Digitale sabotage of verstoring kan direct leiden tot aantasting van onder meer de nationale veiligheid. Nederland beschikt over de uitgangspositie om de economische en maatschappelijke kansen van digitalisering te verzilveren. Tegelijkertijd nemen de digitale dreigingen toe en worden ze steeds complexer van aard. Daarom is veiligheid in het digitale domein een topprioriteit voor het kabinet. Nederland werkt onder andere toe naar een landelijke dekkend stelsel van

cybersecurityverbanden ten behoeve van een digitaal weerbaar Nederland.[1] Het versterken van zowel fundamenteel als toegepast cybersecurity onderzoek is cruciaal.[2] TNO focust haar toegepast onderzoek op die cybersecurity problemen en onderliggende mechanismen waarvoor een Nederlandse kennisbasis en toepassing gewenst zijn voor bijvoorbeeld de veiligheidsorganisaties; en TNO draagt bij aan het oplossen van grote uitdagingen in cybersecurity, die niet vanzelf door marktpartijen worden opgepakt. Op basis van een externe en interne verkenning staan voor de periode 2019-2022 de volgende vijf programmalijnen en twee randvoorwaardelijke *capabilities* centraal:



1.Security and Resilience Concepts. Het cyberdreigingsbeeld is continu in verandering[3]. Dit betekent dat de Nederlandse cybersecurity capaciteiten moeten mee ontwikkelen met het dreigingsbeeld, zodat niet alleen de problemen van vandaag maar ook die van morgen kunnen worden aangepakt. Dit vergt diepgaande kennis van risico's, informatie infrastructuren en systemen, en het organiseren van cybersecurity capaciteiten. Alleen op basis van deze kennis kunnen bestaande capaciteiten worden doorontwikkeld en nieuwe concepten worden ontwikkeld en gelanceerd. Binnen dit thema onderzoekt TNO risicomanagement, informatiedeling en samenwerking in het digitale domein. TNO draagt hiermee bij de aan de ambitie '*Digitale slagkracht op orde*' van de Nederlandse Cybersecurity Agenda (NCSA) om o.a. te komen tot een landelijke dekkend stelsel van cybersecurity samenwerkingsverbanden ter bevordering van de slagkracht van publieke en private partijen. Aanvullend wordt in deze programmalijn kennis bij elkaar gebracht om het TNO cybersecurity onderzoek te sturen en te laten zien hoe cybersecurity innovaties helpen om maatschappelijke uitdagingen aan te gaan.

2. Security Monitoring & Detection. Het tijdig kunnen herkennen van cyberaanvallen is voor overheid en bedrijfsleven een kerncapaciteit. In de afgelopen jaren heeft TNO detectietechnologie ontwikkeld die o.a. door Defensie en financiële instellingen wordt toegepast. Daarbij richt TNO zich op niches die niet door bestaande detectieoplossingen worden ingevuld: we ontwikkelen nieuwe detectiemethoden, vaak ook voor specifieke typen IT-systemen die niet met reguliere detectieoplossingen kunnen worden beschermd. Onze technologie draagt direct bij aan de cyberveiligheid van Nederlandse organisaties. Door de technologie

[1] TK 2268582, 13 juni 2018
[2] Nederlandse Cybersecurity Agenda, p. 39-40, 21 April 2018
[3] 'Cybersecuritybeeld Nederland 2018: Digitale dreiging in Nederland neemt toe'

samen met de Nederlandse cybersecurity-industrie te ontwikkelen en op de markt te brengen worden bovendien economische kansen gecreëerd.

3. Automated Security. Het is voor security analisten een steeds grotere uitdaging om cyber dreigingen en aanvallen tijdig te pareren. Belangrijke reden hiervoor is dat cyber aanvallen in toenemende mate geautomatiseerd worden uitgevoerd. Menselijk handelen volstaat hierdoor niet meer om aanvallen snel en effectief te beheersen. Daar komt nog eens bij dat er een structureel tekort is aan gekwalificeerde cyber security specialisten. Om de snelheid van detectie en response te matchen met die van een cyber aanval is een “game changer” nodig. TNO ziet automatisering van security als een game changer en werkt aan technologieën voor geautomatiseerde analyse en mitigatie van digitale aanvallen op ICT infrastructuur.

4. Transaction Security. Transacties vormen de kern van economische activiteit: de uitwisseling van geld, goederen en diensten tussen verschillende partijen. De digitalisering en automatisering van transacties zal zich ook de komende decennia verder ontwikkelen van automatisering binnen silo’s naar automatisering over domein- en landsgrenzen heen. Zulke gedistribueerde transactie- en vertrouwensmodellen geven in combinatie met nieuwe (internationale) regelgeving (GDPR, PSD2/3) en technologische ontwikkelingen (blockchain technologie en de quantum computer) complexe uitdagingen op gebied van o.a. vertrouwelijkheid, privacy, identity management en robuustheid waar TNO innovatieve oplossingen voor ontwikkelt.

5. Secure Behavior & Cyber Safe Culture. Mensen zijn een onlosmakelijk onderdeel van het overkoepelende cybersysteem. Het systeem als geheel kan alleen veilig en weerbaar blijven wanneer alle onderdelen ervan – techniek, mens en organisatie – onder optimale condities kunnen functioneren. *Secure Behavior* in de werksfeer duidt op het kunnen uitvoeren van de primaire werktaken op een cyberveilige manier. Tot nu toe was de voornaamste manier om dit te bewerkstelligen het verhogen van cyber-awareness. Steeds meer organisaties realiseren zich echter dat het vergroten van awareness op zichzelf niet voldoende is om medewerkers veiliger gedrag te laten vertonen. Om een *cybersafe culture* te bereiken, moet de gehele organisatie, van hoog tot laag, gecommitteerd zijn aan cyberveilig gedrag en moet ook de sociale en fysieke omgeving van werknemers daarop in gesteld zijn. TNO onderzoekt de factoren die van belang zijn voor cyberveilig gedrag op de werkvloer, en hun onderlinge afhankelijkheid.
Naast deze programmalijnen investeert TNO in structurele *capabilities* die essentieel zijn om haar rol als innovatie-motor voor overheid en bedrijfsleven te kunnen spelen:

- **Capability: Cybersecurity Foresight.** Om te bepalen welke cybersecurity dreigingen, technologische ontwikkelingen en trends de komende jaren onze aandacht verdienen, wordt een periodieke cybersecurity horizonscan uitgevoerd.
- **Capability: training-, simulatie- en testfaciliteit.** Het cybersecurity-onderzoek van TNO maakt op diverse manieren gebruik van training-, simulatie- en testfaciliteiten zoals het Cybersecurity lab, Cyber Threat Intelligence lab en het Nationaal Cybersecurity Testbed om cybersecurity capabilities te ontwikkelen.

2.3 Resultaten 2019

Onderstaande resultaten zijn beoogde resultaten. In overleg met stakeholders wordt besloten welke onderwerpen in 2019 worden opgepakt en welke

doorschuiven naar 2020. Tevens kan het zo zijn dat een onderwerp in overleg met stakeholders in een gerelateerd programma wordt opgepakt, zoals VP Veilige Maatschappij, VP ICT of in de onderzoeksprogramma's met het bedrijfsleven, JenV, Defensie en Politie.

2.3.1 Security and Resilience Concepts

TNO onderzoekt risico-management, informatie-deling en samenwerking in het digitale domein. TNO draagt hiermee bij de aan de NCSA ambitie '*Digitale slagkracht op orde*' om o.a. te komen tot een landelijke dekkend stelsel van cybersecurity samenwerkingsverbanden ter bevordering van de slagkracht van publieke en private partijen.

1.a) Identificatie van Critical Information Infrastructure (CII)
'Critical Information Infrastructures' (CII) zijn ICT systemen en informatieprocessen die vitaal zijn voor het functioneren van de Nederlandse samenleving. Het is belangrijk om CII te onderscheiden van reguliere ICT, die bij uitval 'slechts' overlast veroorzaakt. CII moeten extra beschermd worden tegen uitval en aanval, en spelen een belangrijke rol bij een digitale risicobeoordeling. Het wordt steeds lastiger om vast te stellen welke ICT-systemen en -processen als CII gekwalificeerd moeten worden door de snelle ontwikkeling van het digitale domein en de vele onderlinge afhankelijkheden. Dit is een cruciale uitdaging voor organisaties met een verantwoordelijkheid voor de nationale veiligheid (zoals Defensie en de NCTV), en vitale infrastructuur (zoals Economische Zaken en Klimaat, Infrastructuur en Waterstaat of vitale aanbieders), alsook voor het Nederlandse bedrijfsleven.
Resultaten: Een overzicht van beschikbare methoden voor het identificeren van vitale informatie infrastructuur inclusief toegankelijke methoden voor MKB en kleine organisaties in de vitale infrastructuur.
(Beoogde) partners: Agentschap Telecom (programma Telekwetsbaarheid), NCTV/DCS, NCSC, EZK/DTC, JRC, geïnteresseerde vitale aanbieders en bedrijven.

1.b) Samenwerking en governance concepten voor cybersecurity
Zowel regionaal (o.a. FERM, CYSSEC, CWCB) als globaal (o.a. FIRST, Meridian, GFCE) ontstaan steeds meer initiatieven voor het uitwisselen van cyber security informatie en het afstemmen van maatregelen. Sommige van deze initiatieven zijn succesvoller dan anderen en onderzoek naar succesfactoren is schaars. Om tot een gewenst beschermingsniveau van de vitale infrastructuur en ondernemend Nederland te komen, moeten bedrijven en publieke organisaties op de juiste wijze met elkaar in contact staan en samenwerken. Deze kennis draagt bij aan de NCSA ambitie ' *Digitale slagkracht op orde*' om o.a. te komen tot een landelijk dekkend stelstel van informatieknooppunten.
Resultaten: Nieuwe concepten voor samenwerking en governance, voortbouwend op eerder TNO onderzoek naar cybersecurity informatiedeling, publiek-private samenwerking en ketenweerbaarheid. Voorbeelden: governance-structuren voor informatieknooppunten en sectorale CERTs of rol- en taakomschrijvingen voor publieke toezichthouders en raden van toezicht in het beheersen van cyber risico's.
(Beoogde) partners: NCTV/DCS, NCSC, EZK/DTC, FERM, CYSSEC, CWCB, DNB, Erasmus School of Law (ELS), Meridian.

1.c) Incentives voor cybersecurity
De ontwikkeling van het digitale domein gaat snel, terwijl de ontwikkeling van cybersecurity capaciteiten bij organisaties achterblijft. De eerste ambitie van de NCSA, '*Digitale slagkracht op orde*', stelt dat organisaties moeten beschikken over adequate capaciteiten en middelen om hun taken vorm te geven. Organisaties zien in veel gevallen echter onvoldoende toegevoegde waarde van extra cybersecurity capaciteiten in verhouding tot de kosten, voelen geen noodzaak of willen enkel tot

actie overgaan wanneer anderen dat ook (moeten) doen. Onderzoek naar 'incentives' voor cybersecurity draait om de prikkels die organisaties ervaren om wel of niet in cybersecurity te investeren.[4] Dit kunnen bedrijfseconomische prikkels zijn, maar ook prikkels uit regelgeving, sociale normen of publieke informatievoorziening. Onderzoek naar incentives voor cybersecurity is van groot belang voor TNO om de innovaties waar wij aan werken ook daadwerkelijk gebruikt te zien worden. Innovaties zonder de juiste prikkels voor adoptie zijn gedoemd te mislukken.
Resultaten: Een state-of-the-art overzicht van kennis over incentives voor cybersecurity bij organisaties, en methodes voor beleidsmakers om mogelijke incentives in kaart te brengen bij de cybersecurity vraagstukken en te evalueren. Deze kennis worden praktisch vormgegeven in de vorm van een instrument voor beleidsmakers, welke toegepast zal in een aantal use-cases.
(Beoogde) partners: NCTV/DCS, NCSC, EZK, TU Delft, Cyber Security Raad.

2.3.2 *Security Monitoring & Detection*

Binnen de programmalijn *Security Monitoring & Detection* focust het onderzoek zich op drie onderwerpen: het voorkomen van cyberaanvallen (*spear phishing*), effectievere detectie in real-time (*data- en sensorcorrelatie*), en het kunnen herkennen van ongedetecteerde aanvallen die al actief zijn (*threat hunting*). Dit onderzoek geeft invulling aan de "Defence" pilaar in de NCSRA, en specifiek aan de thema's '*intrusion detection and prevention, anomaly detection'* en '*monitoring and improving situational awareness and context-aware event correlation*'.

2.a) Spear phishing

Veel gerichte, geavanceerde en succesvolle cyberaanvallen blijken achteraf te zijn begonnen met een '(spear)phishing e-mail' waarmee een 'initial intrusion' is bewerkstelligd. In de markt zijn goedwerkende e-mail spamfilters, maar geen adequate oplossingen voor detectie van (spear)phishing. TNO heeft de state-of-the-art in de internationale research-literatuur in kaart gebracht op het gebied van detectie van spam en phishing en daarnaast zelf ook eerste experimenten gedaan op het gebied van (spear)phishing detectie.
Resultaten: TNO bouwt haar onderzoek op dit gebied verder uit en zal de resultaten beproeven in een (operationele) Proof of Concept. Het doel van dit onderzoek is om technische middelen te ontwikkelen (algoritmes en software) om deze opkomende bedreiging in de kiem te smoren als aanvulling op de awareness campagnes die veel organisaties organiseren voor hun medewerkers. De resultaten zijn met name van belang voor organisaties waarvoor cyberspionage en fraude grote bedreigingen zijn en voor marktpartijen die detectietools ontwikkelen.
(Beoogde) partners: ABN AMRO, de beleidsdepartementen (EZ, JenV, DEF), bedrijven in vitale sectoren en topsectoren, cybersecurity industrie (zowel productleveranciers als service providers), en nationale en internationale kennisinstellingen.

2.b) Data en sensor correlatie voor detectie van geavanceerde cyberaanvallen

Geavanceerde cyberaanvallen zijn vaak lange tijd actief. Binnen een aanval kunnen verschillende aanvalsstappen worden onderscheiden. Detectieproducten richten zich vaak op specifieke databronnen en aanvalsstappen. Correlatie vindt veelal plaats in de *Security information and event management* (SIEM). TNO combineert kennis van cyber- en wiskundige technieken om anomaliedetectie op basis van netwerkverkeer significant te verbeteren door data- en sensor-correlatie dichter bij de bron te laten plaatsvinden dan in de SIEM.
Resultaten: In 2018 heeft TNO reeds geëxperimenteerd met het combineren van verschillende databronnen (specifiek: NetFlow en DNS data). In 2019 wil TNO

[4] Zie ook pilaar 'Governance' van de NCSRA III

nieuwe correlatiealgoritmes ontwikkelen zowel voor verschillende features uit één enkele bron als features uit meerdere of gecombineerde databronnen. Het doel is om hiervan een Proof of Concept te ontwikkelen en te beproeven op basis van operationele netwerkdata.
(Beoogde) partners: NetDialog, de beleidsdepartementen EZK, JenV en Defensie, bedrijven in vitale sectoren en topsectoren, cybersecurity industrie (zowel productleveranciers als service providers), en nationale en internationale kennisinstellingen.

2.c) Threat hunting support
`*Threat hunting'* is het proactief speuren naar cyberaanvallen die erin geslaagd zijn om de bestaande detectiesystemen te omzeilen en actief zijn in het eigen netwerk. Veel grote organisaties richten hunting-teams in, maar moeten nog kennis en ervaring opdoen over hoe verdachte signalen kunnen worden opgepikt in grote hoeveelheden netwerkdata. TNO onderzoekt hoe threat-hunters kunnen worden ondersteund met analytische- en visualisatie-tooling.
Resultaten: In 2018 is door samenwerking met threat-hunting teams in de financiële markt kennis opgebouwd over de huidige inrichting en processen. Daarnaast is geïnvesteerd in het verkrijgen van goede datasets die nodig zijn om tools te kunnen ontwikkelen en valideren. In 2019 zal de kennis worden verdiept en zal een Proof of Concept hunting tool worden ontwikkeld en getoetst met data uit een operationele omgeving. Het doel is om het threat hunting proces efficiënter te maken.
(Beoogde) partners: Achmea, DutchSec, de beleidsdepartementen EZK, JenV en Defensie, bedrijven in vitale sectoren en topsectoren, cybersecurity industrie (zowel productleveranciers als service providers), en nationale en internationale kennisinstellingen.

2.3.3 Automated Security

Binnen de programmalijn *Automated Security* richt het onderzoek zich op analytische tools en modellen ter ondersteuning van security analisten en aan technieken voor volledig geautomatiseerde mitigatie van cyber aanvallen. Dit geeft invulling aan de 'Defence' pilaar van de NCSRA, en specifiek aan de thema's 'automated defence', 'dynamic risk management' en 'security operations and incident response'.

3.a) Security Decision Support
In 2018 is een eerste Proof of Concept ontwikkeld van een 'Security Decision Support Tool' voor security analisten. Deze decision support omgeving ondersteunt de security analist door om Cyber Threat Intelligence (CTI) en security events geautomatiseerd te analyseren en te bepalen wat mogelijke (of zelfs de beste) vervolgacties zijn om een dreiging of aanval te pareren. De tool genereert onder meer zogeheten *Attack-Defence Graphs* (ADG's) als representatie van mogelijke aanvalspaden in de ICT infrastructuur van een organisatie.
Resultaat: In 2019 zullen het decision support-concept en de Proof of Concept implementatie worden doorontwikkeld door deze te plaatsen in een praktische context en aan te passen aan de behoefte van beoogde eindgebruikers.

3.b) Automated Response
Er is een toenemende aandacht voor het vergaand automatiseren van het incident response proces. Dit project brengt in beeld welke response mechanismen volledig geautomatiseerd kunnen worden om cyber incidenten '*at machine speed'* af te handelen. Een snelle geautomatiseerde afhandeling helpt om de impact van incidenten te minimaliseren. Geautomatiseerde afhandeling is echter vaak een lastige opgave doordat systemen steeds vaker opgebouwd zijn uit ketens van (sub-)systemen die door verschillende partijen worden beheerd. Dit introduceert extra

technische en organisatorisch uitdagingen voor geautomatiseerd ingrijpen bij een incident.
Resultaten: In 2019 zal in de TNO Research Cloud geëxperimenteerd worden met dergelijke technieken en zal een Proof of Concept ontwikkeld worden. Daarbij zal speciale aandacht gegeven worden aan de technische en organisatorisch uitdagingen voor toepassing in ICT infrastructuur met meerdere administratieve domeinen.
(Beoogde) partners: SOC en security architecten van grote organisaties, Managed Security Service Providers (MSSPs), leveranciers van security oplossingen, nationale en internationale kennisinstellingen.

2.3.4 Transaction Security

Transacties zijn de kern van economische activiteiten: de uitwisseling van geld, goederen en diensten tussen verschillende partijen. TNO ontwikkelt innovatieve oplossingen om digitale transacties veiliger en robuuster te maken.

4.a) Blockchain Security
Blockchain technologie en specifiek het '*smart contracts*' concept heeft de potentie om de rol van de 'vertrouwde derde partij' over te nemen in handel, transacties en informatie-uitwisseling. Het wegnemen van een potentieel beïnvloedbare centrale partij vergroot het vertrouwen dat wat afgesproken is ook daadwerkelijk uitgevoerd wordt. Het smart contracts concept wekt grote verwachtingen, maar brengt ook fundamentele en praktische vragen over toepassing met zich mee. In Als er verschil blijkt te zijn tussen de intentie en verwachting achter een smart contract en de uiteindelijke code, dan kan dit grote gevolgen kan hebben voor betrokken partijen. Samen met partners bouwt TNO belangrijke kennis op over hoe te komen tot veilige en robuuste toepassing van smart contracts.
Resultaten: In 2018 heeft TNO hiervoor een zestal oplossingsrichtingen benoemd. Eén daarvan zal in 2019 verder worden uitgewerkt, namelijk het toepassen van statische analysetechnieken en -tools om kwetsbaarheden in smart contracts te identificeren. Dit onderzoek geeft invulling aan de 'Design' pilaar van de NCSRA, specifiek het thema 'safer programming languages and platforms'.

4.b) Trusted Execution Environments
In onze snel digitaliserende wereld gelden steeds strengere privacy-regels (AVG) maar ook steeds vaker *bring-your-own-device* (BYOD) beleid. Dit leidt tot een grotere behoefte aan technologie waarmee op de end-points (PCs, tablets, telefoons) integere en afgeschermde uitvoering van programma's kan worden afgedwongen. Daarmee kan dan een trust-basis gebouwd worden voor verschillende toepassingen (o.a. sleutelbeheer, maar ook informatiedeling (MPC) en identity management). Deze technologie (Trusted Execution Environments) wordt steeds meer praktisch toepasbaar. Een van de bekendste toepassingen op dit moment is SGX van Intel.
Resultaten: TNO wil in 2019 kennis over en (praktische) ervaring met deze technologie verdiepen. Dit onderzoek richt zich op de 'design' pilaar van de NCSRA, en specifiek op de thema's '*resilient design for security in insecure environments'* en '*compartmentalisation solutions'*.
(Beoogde) partners: Partijen uit de financiële wereld (Rabobank, Volksbank, ING, APG, PPGM), verzekeraars, de Nationale Blockchain Coalitie, ministerie van JenV, de Nationale Politie en Cyber Security Agency (Singapore).

2.3.5 Secure Behavior & Cyber Safe Culture

TNO onderzoekt de factoren die van belang zijn voor cyberveilig gedrag binnen organisaties en hun onderlinge afhankelijkheid.

5.a) Gedifferentieerde toepassing

Hoe verhouden de behoeften van verschillende domeinen en organisatie(s)(culturen) zich tot verschillende aanpakken om cyber-secure gedrag te verbeteren? Het resultaat is een gedifferentieerde aanpak om cybersecurity te verbeteren als functie van het domein (bijv. financieel, de zorg, vitaal infrastructuur) of de organisatiecultuur (bijv. oriëntatie op veiligheid, hiërarchische structuur, focus op stabiliteit en regels versus flexibiliteit). Dit sluit aan bij de NCSA-ambitie 'cybersecurity kennisontwikkeling' waarin de oproep wordt gedaan rekening te houden met de meest gedragswetenschappelijke inzichten om digitale vaardigheden van burgers en werknemers verder te ontwikkelen.
(Beoogde) partners: O.a. beleidsdepartementen EZK, JenV, IenM, Defensie, BZK, BZ), financiële instellingen (bijv. asr, ING), kennisinstellingen (Universiteit Twente, NSCR/UvA, Haagse Hogeschool), IT en IT security bedrijven (bijv. Sparki, BeOne, Capptions).

2.3.6 *Randvoorwaardelijke capabilities*

6.a) Capability: Cybersecurity Foresight: Horizon scanning & forecasting
Horizon scanning en *forecasting* zijn essentiële capaciteiten voor cybersecurity research en capaciteit ontwikkeling. Bij horizon scanning wordt er in informatiebronnen (media, publicaties, expert opinions) gezocht naar signalen van verandering waarmee er eerder geanticipeerd kan worden op toekomstige dreigingen. Bij forecasting wordt er een onderbouwde schets van de toekomst neergezet die onderzoekers en beleidsmakers kunnen gebruiken in hun programmering en beleidsvorming.
Resultaten**:** Om te bepalen welke cybersecurity dreigingen, technologische ontwikkelingen en trends de komende jaren onze aandacht verdienen, wordt een periodieke cybersecurity horizon scan uitgevoerd. Zoals vermeld in aanbiedingsbrief van CSBN 2018 aan de Tweede Kamer[5] is het van belang de technologische en maatschappelijke ontwikkelingen nauwgezet te volgen. Zo kan tijdig worden gesignaleerd waar zich mogelijk nieuwe digitale kwetsbaarheden en dreigingen en kunnen deze worden geadresseerd.
Om de analyse- en forecasting capaciteiten van cybersecurity professionals op individueel en groepsniveau structureel te verbeteren, wordt een *cyber forecasting training en tournament* georganiseerd.

6.b) Capability: training-, simulatie- en testfaciliteit
Voor het ontwikkeling en toepassing van nieuwe cybersecurity concepten zijn training-, simulatie- en testfaciliteiten onontbeerlijk. Dit soort faciliteiten maken het mogelijk om bijvoorbeeld aanvalsscenario's in representatieve IT-netwerken te simuleren, nieuwe detectietechnologieën en securityoplossingen experimenteel te testen, en trainingen te kunnen opzetten en uitvoeren. Omdat digitale dreigingen en technologieën zich voortdurend ontwikkelen, is het van belang om dit soort faciliteiten duurzaam op te zetten zodat ze aangepast kunnen worden aan de actuele en toekomstige situatie. Binnen dit VP wordt gekeken naar de opbouw van training-, simulatie- en testfaciliteiten, en hoe deze optimaal ingericht en ingezet kunnen worden.

2.3.7 *Externe aansluiting*

Het TNO Meerjarenprogramma 'VP Cyber Risk Management & System Resilience' (CRM&SR) bouwt voort op bestaande beleids- en visie documenten, cyberstrategieën en cyber innovatie agenda's in de Nederlandse, Europese en internationale context. Denk bijvoorbeeld aan de in 2018 uitgebrachte de Nederlandse Digitaliseringsstrategie (Nederland Digitaal), de Nederlandse Cyber Security Agenda (NCSA), de Nationale Cyber Security Research Agenda (NCSRA)

[5] TK 2268582, 13 juni 2018

III, de Internationale Cyberstrategie (2017) en de maatschappelijke uitdaging 'Veilige Samenleving'.
TNO neemt samen met de Ministeries van Defensie (DEF), Veiligheid en Justitie (JenV), Onderwijs Cultuur en Wetenschap (OCW), Economische Zaken en Klimaat (EZK), Binnenlandse Zaken (BZK) en de Nederlandse Organisatie voor Wetenschap Onderzoek (NWO) deel aan de werkgroep 'Veilige Samenleving', die gestart is met het opstellen van de Publiek Private Kennis- en Innovatieagenda 'Veilige Samenleving'. Het TNO Meerjarenprogramma VP CRM&SR is in de geest van de inhoudelijke ambitie van deze maatschappelijke uitdaging opgesteld.
Het opstellen en de uitvoering van het onderzoeksprogramma VP CRM&SR vindt plaats in nauwe afstemming met VP Veilige Maatschappij, programmalijn Cyber Security & Societal Resilience (CSSR), VP ICT, programmalijn Cyber Security, en de TNO onderzoeksprogramma's met het bedrijfsleven, JenV, Defensie en Politie. De onderzoeksprogramma's versterken elkaar. Innovaties in het VP CRM&SR richten zich op de cyberveiligheid van organisaties/sectoren, en op het versterken van de nationale IT- en cybersecurity-industrie. De focus van het VP Veilige Maatschappij ligt op de maatschappelijke veiligheid en weerbaarheid van de samenleving als geheel. VP ICT richt zich ter aanvulling op de andere onderzoeksprogramma's op de ontwikkeling van AI- en netwerkdata-gebaseerde aanvalsdetectie algoritmes, en de integratie van dergelijke algoritmes in een geautomatiseerd ICT platform voor mitigatie van cyber aanvallen en ondersteuning van security analisten.

2.4 Dynamiek

Het belang van cybersecurity kennisontwikkeling wordt onderstreept in de Nederlandse Cyber Security Agenda. In een brief aan de Tweede Kamer op 26 juni 2018[6] is dit nogmaals bevestigd:

> *'Het versterken van voldoende en hoogwaardige ontwikkeling van zowel fundamenteel als toegepast cybersecurity onderzoek is cruciaal. Gericht multidisciplinair onderzoek over de gehele kennisketen heen dat zowel naar oplossingen voor de langere of kortere termijn kijkt, is van het grootste belang, zo vindt het kabinet. […] Vanwege het huidige versnipperde landschap van organisaties die zich bezighouden met cybersecurity kennisontwikkeling, wordt vanuit het kabinet een verkenning gestart naar de mogelijkheden voor versterking van de kennis en innovatieketen voor cybersecurity, de opzet van een Kennis- en Innovatie Agenda daartoe en hoe een langjarige samenwerking, tussen publieke en private partijen, over de hele kennis- en innovatieketen heen kan worden georganiseerd. […] De verkenner wordt gevraagd om ten behoeve van zijn advies alle relevante actoren te consulteren, bestaande financieringsstructuren in kaart te brengen en de mogelijkheden voor verbetering van technologie overdracht te signaleren.'*

TNO is een sleutelspeler in de Nederlandse cybersecurity kennisontwikkeling door haar positie in de valorisatieketen tussen (universitair) fundamenteel onderzoek en de toepassing in de samenleving. TNO is een aanjager voor publiek-private samenwerking om de digitale weerbaarheid van Nederland te versterken en economische kansen in cybersecurity te verzilveren. Voor kennisopbouw en innovatie richt TNO zich op cybersecurity vraagstukken waarvoor een Nederlandse kennisbasis en producten gewenst zijn, zoals die van de Nederlandse veiligheidsorganisaties. Deze organisaties hebben vaak te maken met *wicked problems* in cybersecurity waar geen simpele oorzaak aan te wijzen is, en waar geen eenvoudige oplossingen voor bestaan. Bij dit soort grote uitdagingen spelen veel factoren een rol, en is een diep begrip van de positie, capaciteiten en

[6] TK 26 643 nr 544, 26 juni 2018

beschikbare middelen van betrokken partijen essentieel. Marktpartijen pakken dit soort uitdagingen niet vanzelf op. TNO kan vanuit deze rol een aanzienlijke bijdrage leveren aan de op te stellen Kennis en Innovatieagenda.
De units Defensie en Veiligheid en ICT van TNO werken intensief samen op cybersecurity, zowel vanuit het perspectief van Nationale Veiligheid, als het perspectief van bedrijfscontinuïteit en het verdienvermogen.

3 VP Radar & Sensorsystemen

Contact person TNO: Frank van den Bogaart
Contact person Topsector:
- HTSM Roadmap Security: J. Troost – Thales Nederland B.V
- HTSM Roadmap Electronics: L. Warmerdam – NXP

Contac person Government:
- Venema – Ministry of Defence HDB
- J.C. Dicke – Ministry of Economic Affairs and Climate Policy, Commissariaat Militaire Productie
- KTZ J. de Jong – Ministry of Defence DMO/AM
- KLTZ ir. T. van Heusden – Ministry of Defence DMO/AMS/ Bureau Technologie Integratie

3.1 Summary

The TNO applied research carried out in this VP is reported in the HTSM Roadmap Security and in the HTSM Roadmap Components and Circuits and contributes to the Societal Theme 'Security'. The VP now consists of 3 program lines:
- Roadmap Radar en Geïntegreerde Sensorsuites 2030 (~ 69% of VP in 2019);
- Mission Critical Systems (~ 18% of the VP in 2019); and
- Passive Sensors for Defence and Security (~13% of the VP in 2019).

In the course of 2018, a start was made with the subject of Quantum Sensing, which could possibly develop into a 4th program line.
The impact of the VP is aimed at strengthening the global leadership and competitiveness of our national defence and security industry, associated technology suppliers, SMEs and universities. Activities are in general carried out in a triple helix construction due to the nature of the defence/security domain.

The *Roadmap Radar en Geïntegreerde Sensorsuites 2030* focusses until 2022 (and in fact until 2030) in particular on the sensor suite for the next generation of frigates of the Royal Netherlands Navy (RNLN). A major goal for 2022 is the Evolution Design Model (EDM): a PPP to demonstrate a functional prototype. Another great goal towards 2022 is the implementation and realization of low-TRL research in 4 innovation areas to lay the technological basis of the 2030 Roadmap. Related activities are focused on the design and realization of various monolithic microwave integrated circuits (MMICs) on GaAs, GaN and SiGe semiconductor technologies. A concrete result in 2019 is the completion of the DAISY2 MMIC-chipset. DAISY2 will prove a cost reduction of a factor of 10 compared to the current state-of-the-art in radar technology. Additionally, DAISY technology allows to reduce the volume of a radar sensor by a factor of 25, resulting in a thickness of only 2 cm. A step that can be compared with the transition from the bulky 'classical' television set to a flat panel LCD TV screen.

The overarching goal of the program line *Mission Critical Systems* is to design software-intensive management and highly complex systems that are crucial for carrying out successful defence missions and security operations together with national stakeholders and industries. For 2019-2022 the focus is on naval integrated mission management, command & control in maritime support centers. In 2019, the H2020 project MARISA will deliver a toolkit with a suite of methods,

techniques and modules, to adaptively fuse data from various heterogeneous sources. In the PADR project OCEAN2020, the effects of UXV integration in the CMS of the Dutch Navy are studied against objective of optimized manning.

The program line *Passive Sensors for Defence and Security* focusses the next years in particular on using optical sensors for security and defence and associated image processing. A major goal is to establish a solid ecosystem of relevant Dutch SMEs that are active in this domain. In 2019 projects will be started to include turbulence mitigation in sensors. In addition, deep learning as well as other machine learning techniques will be applied to provide a smart region-of-interest capability. This enables full exploitation of 25 Mpixels+ high resolution camera sensors.

3.2 Short description

In general, for all program lines, the basic objective is to support Dutch defence and security industry, generate impact on export opportunities and employment, based on industrially relevant R&D and excelling particularly in our speed of innovation. To that end programs and ideas are developed to serve the national OEMs, SMEs and their supply chain partners in the field of sensor technology and in the field of command and control systems. Dutch industry as well as research institutes have a top position in the world and are strong, highly innovative players. The Netherlands is world market leader in radar and command and control systems for navies. The Netherlands hosts also one of the major semiconductor industries worldwide; access to such semiconductor technology is a key enabler.

The specific goals of this VP are:

- to develop high-tech components and subsystems within a triple helix together with our national defence/security industry and governmental parties to fulfil their joint requirements as launching customer; and
- to design and develop complex sensor and associated C2 systems that are crucial for carrying out successful defence missions and security operations.

To achieve these, it is necessary to create technological breakthroughs and to build in-depth knowledge in several carefully selected innovation areas in which we aim to be a worldwide key player; the selection of these areas is primarily based on what we consider as critical and crucial to develop the IP locally in the Netherlands.

The *Roadmap Radar en Geïntegreerde Sensorsuites* considers 3 technology innovation areas relevant for this VP: 1) Radar and Suite Concepts to develop flexible, reconfigurable and multi-functional sensor suites whose performance is better and more robust than 'the sum' of the performances of the individual sensors. This requires new architectural concepts that allow new processing and interfacing technologies, not only in the back-end but also in the front-end; 2) RF Front-ends including large scale packaging and infra technologies to enable the critical hardware realisation of above-mentioned concepts; and 3) Advanced AESA algorithms and processing techniques for among others reconfigurable processing and to enable new functionalities.

The overall objective of *Mission Critical Systems* (MCS) is to design and develop adaptive autonomous systems for combat management, platform management, bridge management and mission management in the military naval and land

domains and in the civil maritime domain. By combining the scientific areas of general artificial intelligence and complex adaptive systems design, MCS can make decisions that are critical to maintain the mission goal under varying circumstances and for varying availability of resources. Key to the success of MCS is to model the complex relations between sensors, weapons, propulsion, and energy systems, as well as their interaction with the human operator.

A key enabler for future optical sensors is to improve image enhancement techniques to enable optical sensor systems in defense and security applications to perform optimally. While traditional image enhancement techniques show now fundamental limitations, machine learning techniques in particular deep learning will allow a next generation of image enhancement.

3.3 Results 2019

Typical results that are reported below are obtained through various contracts with many different sponsors and funding agencies. In general we target:

- Sponsored contracts with Dutch industry and SMEs in defence & security.
- Contracts of the European Defence Agency (EDA) carried out together with national and with EU defence industries and research institutes.
- Contracts within the scope of national funded programs and regional funded programs (EFRO) carried out with national industry, national universities and SMEs.
- Contracts within the scope of the Security calls of Horizon2020 that we carry out with national defence related companies, other national companies and universities and international industry and universities.
- Contracts within the Joint Technology Initiatives ECSEL and the EUREKA cluster PENTA of the European Commission carried out with national defence related companies, other national companies and universities and international industry and universities.

In particular we should emphasize the extensive cooperation with the EDA. Within the EDA framework all program lines partner together with almost all major European defence sensor manufacturers (Thales, Leonardo, Henshold, Rheinmetal, Airbus, SAAB), with partners that provide critical EU defence technology (UMS, NXP, OMMIC) and with all relevant defence research institutes (Fraunhofer FHR, Fraunhofer IOSB, FOI, ONERA, III-V Labs). Our activities are fully aligned with the Strategic Research agendas of EDA which are even partly initiated and set up from our program lines.

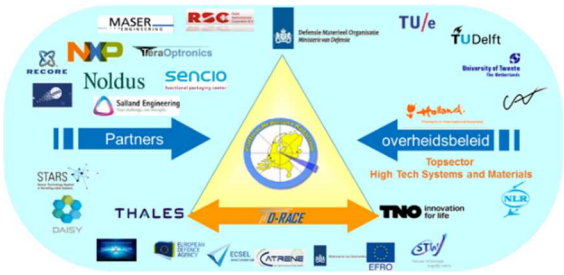
We explicitly prepare ourselves to be active in the Research and Development programs as part of the European Defence Fund of the EC starting in 2021.

The VP has a strong link with the Societal Theme Security and with four Routes of the Nationale Wetenschapsagenda: “Quantum- en nanorevolutie”, “Smart Industry”, “Tussen conflict en coöperatie” and “Waardecreatie door verantwoorde toegang tot en gebruik van big data”.

The technologies developed in the military/security domain are aimed to have a wide social relevance for both military and non-military applications. Demonstrable spillover effects, related to a great diversity of activities with related companies and SMEs, to other economic sectors are generated.

3.3.1 *Roadmap Radar en Geïntegreerde Sensorsuites*

Dominant is our national Roadmap Radar and Integrated Sensor Suites, governed by the Platform Nederland Radarland. Activities within this context are carried out within the Triple Helix and with several partners in the ecosystem of which the 2019 snapshot is given in the figure.

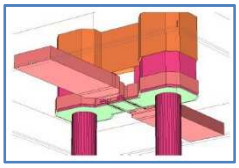


It is expected that the Roadmap 2030 will need a similar partner structure as the Roadmap 2010-2020. This implies a bundling of public and private investments and a very intense cooperation with end users. For example in the period 2010-2016 we worked together with 8 Dutch knowledge centres, 8 national industries, 28 national SMEs, 15 European knowledge institutes and 40 international companies. A similar number is expected and at least required to realize the Roadmap 2030!

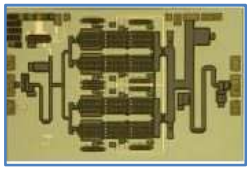
The end goal of the Roadmap 2030 is a new integrated sensor suite for the next generation frigates of the Royal Netherland Navy. All intermediate annual results contribute to this final goal. On the other hand, these interim results have been formulated in such a way that the results can also be exploited in other (economic) domains.

The Roadmap relies on scientific breakthroughs; cooperation with the 3 Technical Universities is essential, in particular with the Centre of Array Technology of the University Twente (CAT). The relevant chairs are seen as critical providers of long-term scientific knowledge addressing promising developments at a very early stage.

The EDM (Evolution Design Model) completes the Roadmap 2010-2020 and focuses the next years on the demonstration of a TRL5 so called “X/S band one-radar functionally integrated with an ESM system” for the benefit of the next generation of functionally integrated sensor suites for the Royal Netherlands Navy and is carried out with Thales and the Royal Navy with in-kind support of others. The EDM contains and demonstrates the integrated results of all previous detailed R&D studies.



The focus of the innovation area front-end technology is on the design and realization of high-frequency electronic circuits on GaAs, GaN, SiGe and passive technologies, in particular 1) on the efficient generation of very high levels of microwave power, based on GaN semiconductor technology and on revolutionary design techniques. We expect RF power levels exceeding 100W which is not yet demonstrated in Europe; 2) on the very dense integration of (multi-channel) transmit and receive chains, based on SiGe BiCMOS semiconductor technology which makes new radar and communication architectures feasible and 3) on the integration of so-far un-integrable components such as very selective filters and protection components. The main (national) industrial players include Thales Nederland, NXP and Philips. The field of HTSM, of which 50% of the industrial R&D is in the key technology *micro- and nanoelektronica,* is fully international. This is reflected in our customer and partner base, which includes almost all major European defence companies and RF semiconductor manufacturers. New activities that have been initiated recently, after careful alignment with our stakeholders in the Roadmap Components and Circuits, are focused on realizing an ‘Arbitrary Beam and Waveform

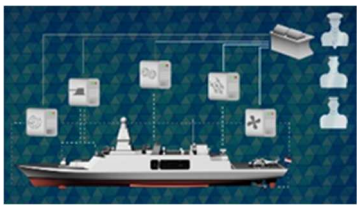


Antenna' (ABWA), foreseen in D-ART. The feasibility of ultra-miniaturized short distance range sensors integrated in small caliber military ammunition will be demonstrated in 2019. Both new activities are seen as the key to future sensor systems for defence and security applications.

The innovation area Advanced AESA algorithms and Processing Techniques focuses on the design and development of new disruptive waveforms, advanced signal processing and machine learning techniques for both the detection, tracking and classification of extremely difficult threats as well as for the detection and identification of small UAV's that are used for drug transport. Within H2020 scope with the RNLN, police forces, research institutes and European defence industry the detection, classification and prediction of the landing spot of small drones used for drug transport will be demonstrated.

3.3.2 Mission Critical Systems

In the past, Mission Critical Systems has focused on the modeling of operational effectiveness of military missions and security operations and the performances of resources for surveillance and planning of resources. Once the effectiveness and performance measures have been integrated in a goal function, this function can be used to plan the optimal assignment of resources and setting of the resource parameters over time. In 2019-2022 this approach will be validated in a number of use cases, i.e. fusion of heterogeneous information for risk management in a maritime support center (MARISA use case Den Helder), and integration of UXVs in a naval combat system for the Dutch Navy (OCEAN2020 use case M-Frigate).



For the EU project MARISA, a fusion toolkit will be demonstrated in 2019 together with coastguard centers from e.g. the Netherlands, Spain and Italy. The toolkit, which will be developed with other partners, serves as a technology demonstrator which is interesting from a technology as well as a business perspective. From the viewpoint of technology, TNO will develop the goal function in terms of metrics and meta-metrics for an absolute comparison of various observation systems and information resources. In this way, an autonomous selection of observation resources can be made as to adapt to changes in the environmental state while maintaining the coastguard center's operational objective. From the business viewpoint, the Navy's Operational Head Quarter and the Coastguard's Maritime Information Center will fuse into the Maritime Support Center in the near future. Additional functionalities are required for maritime command and control compared to current nautical operations. TNO aims to play an important role in this transition process.

Similarly, for PADR's OCEAN2020 (PADR are the Preparatory Actions for Defence Research from 2021 and beyond), additional functionalities for the Combat Management System of the new M-Frigates will be defined together with the Netherlands Navy. In OCEAN2020, a multitude of partners participate, research institutes as well as industry. This provides an ideal multiplier of TNO experience in this field, yet in broad terms that are non-specific for the Navy's CMS designed by JIVC/SATS. Specific details are defined in separate national studies that have been initiated because of OCEAN2020. Moreover, PADR's OCEAN2020 is extended in H2020 which provides Mission Critical Systems with a long-term multiplier for this subject preparing for the European Defence Fund with strategic partners such as Thales, RH Marine and Damen.

3.3.3 Passive Sensors for Defence and Security

The ongoing activities regarding advanced image processing, camera signal conditioning and techniques for behavior recognition together with Dutch SMEs like Photonis, Adimec and Nedinsco are continued from 2019 onwards.
In addition, deep learning as well as other machine learning techniques will be applied to provide a smart region-of-interest capability. This enables full exploitation of 25 Mpixels+ high resolution camera sensors by integrating into the camera a pre-selection and subsequent visualization, providing a standard HD output with high-resolution insets of regions of interest. This allows also direct generation of metadata to effectively use the optical sensors by MCS-like systems.
An foreseen project within EDA demonstrates the compensation of the effects of turbulence in optical surveillance systems. Partners are ADIMEC and Fraunhofer-IOSB. An envisaged PENTA project strives towards a further improvement of the performance in imaging systems for (amongst others) security applications by using higher spatial, temporal and spectral solutions.
In addition, initiatives have been started to demonstrate 3D scanning techniques for real-time detection of risk full behavior in prisons to increase security.

3.3.4 D-ART (D-RACE – Advanced Radar Technology)

From 2019 until 2025 the program D-ART (D-RACE - Advanced Radar Technology) is scheduled. D-ART consists of low-TRL research and within this program new system concepts, front-end technologies, algorithms and signal processing techniques will be investigated and, when feasible, demonstrated which are expected to be of primary importance for the development of future sensor suites as defined in the Roadmap Radar and Integrated Sensor Suites 2030 of the *Platform Nederland Radarland*.

The research to be carried out in D-ART will cover two main themes from the Roadmap, namely:

- Arbitrary Beam & Waveform Antenna (ABWA) and related radar concepts.
- Enabling technologies for Incremental Capability Enhancements (ICE).

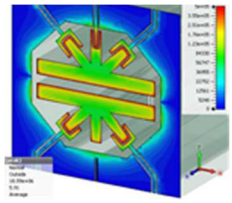
The ABWA and ICE technologies are enablers for real time reconfigurable radar systems, that are adaptively configured depending on the tasks at hand, the contextual information, and the available hardware. Based on the mission goals and the information that is already available, an optimal configuration of the sensor suites can be achieved in near real-time. This flexibility is a fundamental building block for future fully adaptive, closed-loop (cognitive) radars.

3.3.5 Quantum Sensing

Quantum technology based sensors may well in the future disrupt and transform the military battle field or even the balance of power. This very-low-TRL program line aims to co-develop our understanding of the added value in actual military use cases in parallel to the process of improving our technical understanding.

Future warfare at sea, in the air, at land or in space requires sensors that are an order of magnitude better than the current state-of-the-art. The required accuracy to measure many physical constants, such as particles, time, temperature, gravity and electric-magnetic fields is not possible with existing type of sensors. Quantum superposition states are extremely sensitive to its environment. For sensing applications this sensitivity of quantum systems to its environment may enable sensing tools with enhanced and new capabilities. Quantum radar may have the capability to detect targets unseen by current systems, and quantum navigation technology may lead to precise form of positioning systems.

In the year 2019, the project will focus on the understanding the fundamental working principles along with their limits and usefulness with respect to existing systems. This work will be conducted together with the “natural” partners QuTech and TU Delft, in addition an industrial national base will be pursued.



Different types of NV-based sensors and superconducting quantum sensors are studied. The two main quantum radar concepts are reviewed (single photon quantum radar and entangled photon-pair quantum radar). The goal is a preliminary quantum sensor demo. In short, in the year 2019 we aim to establish a founding work for a continuous high quality hands-on expert assessment of the potential added value of quantum sensing technologies for military power.

3.4 Dynamics

Program lines are updated with respect to the program lines as reported in the plan 2018-2021. In addition, additional budget is allocated in 2018 to the VP resulting in a potential new program lines from 2019. The changes are indicated in the table below with an explanation of the changes in the footnotes below the table:

Program lines in VP P104 Radar and Sensor Systems	
Reported in plan 2018-2021	**Meerjarenplan 2019-2022**
Radar and Integrated Sensor Suites, stakeholder Platform Nederland Radarland	*Radar and Integrated Sensor Suites*, stakeholder Platform Nederland Radarland Including: *D-RACE / D-ART* with stakeholders Platform Nederland Radarland and D-RACE, Dutch MKB, ODMs and technical universities
Mission Critical Systems with stakeholders Dutch Maritime Defence industries and Royal Dutch Navy	*Mission Critical Systems* with stakeholders Dutch Maritime Defence industries and Royal Dutch Navy
Sensors and Systems for Security with stakeholders Dutch Industry, Dutch Airports, Dutch National Police forces and Royal Dutch Marechaussee	
Technology for Passive Sensors with stakeholders Dutch SMEs in the field of Electro-optical systems	*Passive Sensors for Defence and Security* with stakeholders Dutch SMEs in the field of Electro-optical systems
	Quantum Sensing

The program line *Sensors and Systems for Security* is completed in 2017. A book entitled “Toekomst van Sensing” will be published in 2018 and contains a.o. the results of this program line. No significant future contribution is expected from industry which makes further investments on this topic in this VP not effective.

D-ART: In 2018 a preliminary investigation of possible research topics, and discussions with the future D-ART partners will allow to identify the most relevant and promising techniques that should be further investigated in the upcoming D-ART program at an early stage, thus leading to a significant risk reduction for the D-ART program itself.

Quantum Sensing: The budget allocated for 2018 identifies and explores the topics in the area of quantum sensing relevant for military applications. The goal is to

coordinate action towards military quantum technology. The potentials and the challenges of quantum sensing technologies for defence applications from a very wide field will be explored and assessed leading to a first version of a quantum sensing roadmap as basis for a program line from 2019 onwards.

Mission critical Systems: For Mission Critical Systems, a recent development that will prove of strategic relevance for military as well as civil operations is the integration of UXVs in combat systems and maritime support centres. Because operating multiple UXVs is labour intensive for the crew and costly for the customer, autonomous UXV operations in a scalable architecture provides optimization of manning and systems and at the same time reduces operating cost.

4 VP Human Health RM Nano

Contact person TNO: Wouter Fransman
Contact Topsector HTSM: Frank de Jong

4.1 Summary

As one of the Key Enabling Technologies, nanotechnology has emerged in a broad area of industries and applications. By the time regulators became aware of potential omissions in guidance and guidelines addressing the nanospecific nature of chemical substances and products, products were already on the market. Scientific evidence obtained from research still had to be developed. This lack of timely alignment has formed a crucial hurdle to appropriately govern the risks of nanotechnology. The public currently also remains unsure about nanomaterials/nanotechnology and potential human health risks, while they would benefit greatly from the use of nanomaterials in innovative materials, products and applications. This VP Human Health Risks Nano therefore aims to develop reliable tools, guidance and training for proper risk assessment, risk management and communication of these risks during and after product innovation to assist industry in their decision making during product innovation.

TNO develops knowledge to assist industries in taking into account the safety of their (nano)product during the innovation of new materials and products. TNO invests in this VP Human Health Nano in the development of innovative tools, guidance and training to support safe innovation and risk governance for innovative SME, sector organizations and industry in the absence of clear guidance and regulations. The activities of VP Human Health Nano in 2019 consist of collaborative work in various H2020 EU projects (NanoREG2, NanoFase, CaLIBRAte, EC4SafeNano, Gov4Nano) and will result the development of various innovative risk assessment models into a toolbox containing: LICARA nanoSCAN, Guidenano Tool, SUN Decision Support System, caLIBRAte system-of-systems, NanoSafer, Stoffenmanager Nano, and the Future nano Needs Bayesian belief network. Further results in 2019 are the development of safe-by-Design (SbD) and Safe Innovation principles and linkage to the regulatory process. Through the participation of TNO, also the Dutch Nanocentre (www.nanocentre.nl) will be connected in 2019 to the European EC4SafeNano initiative, as an international nanosafety platform. For future and emerging technologies such as nanotechnology, clear communication about the state-of-the-art, knowledge, concepts about risk perception, transparency about dealing with uncertainties is of utmost importance and help to influence the risk perception of the public regarding nanomaterials, increase their market value and help companies in anticipating potentially conservative regulations. TNO's work in 2019 will result in clear conclusions and communication on nanomaterial health risks for the commercial success of nanomaterial innovative research and implementation in Europe.

4.2 Short description

Large expectations surround the potential for manufactured nanomaterials to be key elements in the development of innovative materials, products and applications. Manufactured nanomaterials are already produced in large amounts and it is expected that in the next decades numerous new nanoproducts will enter the

market every year. For companies it is important to produce sustainable products and comply with regulations. In order to overcome regulatory difficulties and negative market perception on nanomaterial human health risks, clear conclusions and communication on nanomaterial health risks are now urgent. This will support the commercial success of nanomaterial research and innovation in Europe.
VP Human Health RM Nano builds new knowledge and networks on human health risk management of manufactured nanomaterials and supports safe innovation of nanomaterials. In order to assist stakeholders (industry, investors, insurers) to overcome safety, regulatory and market perception barriers for the investment in pilot plants, and scale up / product launch facilities various milestones are defined:

1. Safe innovation and risk assessment for industry
   (driver: lack of good quality risk assessment and management tools that fit with industry needs. Make generic risk assessment tools specific to specific industries and industrial sectors).
2. Risk governance and implementation of 'soft law' and good practices in industry
   (driver: absence of legal requirement on nanomaterials and therefore unwillingness to invest in beneficial technology by industry, investors and insurers. Need for regulatory supported guidance on how to manage the risks of nanomaterials by industry and consumers).
3. Setting up a network and trusted environment for industry to share successes and problems
   (driver: lack of confidence in nanotechnology as an enabling technology due to regulatory and HSE uncertainties. Strong urge to use nanotechnology due to economical, societal and environmental benefits).

4.3 Results 2019

4.3.1 The results of VP Human Health RM Nano in 2019 in various EU projects.

The **NanoReg 2** project, builds around the challenge of coupling Safe-by-Design (SbD) to the regulatory process, demonstrates and establishes new principles and ideas based on data from value chain implementation studies to establish SbD as a fundamental pillar in the validation of a novel manufactured nanomaterial. Activities of TNO result in translation of a stage-gate innovation model into a workable safe innovation approach (SIA) and the link between the SIA toolbox and the NanoReg2 database and ontology. TNO demonstrates the integration of the SbD approaches to the innovation process of the industrial partners. This result in the identification and addressing of barriers to the application of SbD concepts. Provision of industrial SbD Tools and SOPs should establish commercially viable grouping and SbD concepts. The NanoReg2 fits well with Milestone 1.
Within the **caLIBRAte** project, many of the key "nano-specific" model developers, data hosts, and case-study builders in Europe have gathered to collaborate with the result to establish, test, refine and calibrate relevant models for implementation in a common risk governance framework. The framework focusses on risk governance of nanomaterial by different stakeholders (regulators, large industries, SMEs, insurance companies) during and after product innovation. TNO leads the work package on human risk assessment (HRA) models in strong collaboration with RIVM (The Netherlands), GAIKER (Spain), FIOH (Finland), NCRWE (Denmark) and TUT (Finland). In 2019, this will result in the further improvement of risk assessment models by implementation of new approach methodologies (NAM) and subsequent linking into a system-of-systems toolbox of various tools to support safe innovation. The caLIBRAte project fits well with Milestone 1.
In the **NanoFase** project, TNO produces a country-specific inventory and a high

resolution spatially distributed emission map for nanoparticles in the environment. Within the **EC4SafeNano** project, 15 well known European institutes build a virtual institute resulting in assistance to governments and industries with their nanosafety issues. TNO leads WP1, in which the needs related to nanosafety experienced by governments, industries and other stakeholders are mapped. TNO is responsible for coordinating the inventory of tools and methods, training, standards, SOPs and guidance/best practice documents. This results through the participation of TNO, in the Dutch Nanocentre (www.nanocentre.nl) the connection to this European initiative. In addition, TNO leads the technological innovation (related to nanomaterials) network with the result to 1) set up the legal mechanisms to operate the centre after the end of the project, addressing the contractual relations, IPR issues, governance; and to 2) build a business model and to design a business plan for a sustainable centre. The EC4SafeNano project fits well with Milestone 3. Given the interests at stake, the European Commission has set out a European Strategy for Nanotechnologies, based on a safe, integrated and responsible approach. Within this, Mandate M/461 is a mandate for standardization activities regarding nanotechnologies and nanomaterials addressed to CEN, CENELEC and ETSI by the European Commission. TNO invests in the elaboration of a program of standards with the result to take into account the specific properties of nanotechnology and nanomaterials in the standardization process.

4.3.2 The result of VP Human Health RM Nano in 2019 in various knowledge investment projects

4.3.2.1 Sector specific Safe-by-Design and risk assessment tooling

There is a need for sector specific risk assessment tools addressing specific exposure scenario's and the hazards of sector specific nanomaterial and nano-enabled products. In various EU funded projects development has focused on the generation of generic Safe-by-Design and risk assessment frameworks. Examples of these are caLIBRAte, NanoReg, NanoReg2, LICARA, Future Nano Needs. One of the difficulties arising from these generic frameworks is that they are seldomly directly applicable to specific cases in practice since these require more specific tooling and frameworks. This is also shown in the NanoStreem project with the result the matching of many available nano risk assessment tools against the needs of the semi-conductor industry. In 2019 we aim to develop sector specific frameworks for safe by design and/ or risk assessment of nano-enabled product and processes. We aim to find relevant partners to co-develop such frameworks and tools, with specific focus on: 1) Green ICT, 2) Nanomaterials for battery development, 3) Semi-conductor industry.

4.3.2.2 Risk Management

Risk management of nanomaterials has received considerable attention in recent years, especially in the United States (NIOSH, 2013) and as part of various European Union (EU) research projects – amongst others LIFE NanoRISK, SUN, NANoREG, Scaffold and GUIDEnano. It is apparent from these initiatives that there is limited information available regarding the efficiency of risk management measures (RMM) for nanomaterials, with a handful of open source or published reviews on the effectiveness of workplace RMM (Frijns, 2016; Oksel et al., 2016; NIOSH, 2013; OECD, 2009; Goede et al., 2018). TNO's work in 2019 will result in a new risk management approach to control exposures to nanomaterials by obtaining information on the quantitative RMM efficiency from a number of sources, e.g. the CEFIC RMM Library (CEFIC, 2016), the OECD emission scenario documents (OECD, 2016), the Exposure Control Efficacy Library (ECEL) (Fransman et al., 2008). These sources are focused on chemical substances that represent

substantial variation in efficiency of RMMs and do not specifically account for nanomaterials yet. In 2019, the list of effective control measures for the workplace is linked to frequently occurring exposure scenario's as indicated by industry. Resulting in a set of "best practices". In the 'soft law' initiative in 2019 TNO assesses the efficacy of a set of methods currently applied in practice which results in the future requirements for companies to report their risk management measures with regards to nanomaterials. In 2019 collaboration with the Ministry of Social Affairs and Employment is sought resulting in a combined roadmap. This work package fits well with Milestones 1 and 2.

4.3.2.3 Quantitative risk assessment tool knowledge base

Various qualitative risk assessment models have been developed for nanomaterials, of which Stoffenmanager® Nano was developed by TNO and introduced in 2011 as a separate module to Stoffenmanager® (Van Duuren-Stuurman 2011). The risk bands will be developed into a semi-quantitative risk assessment approach. In 2019 a start will be made towards quantification of the risk bands for specific exposure scenario's and collaborations for co-financing with various partners will be sought to start this work and update the knowledge base in the public domain. In future years work will focus on: 1) identification of nanomaterials in practice; 2) Quantifying the exposure bands for all source domains; 3) Link to NECID and ECEL and other databases; 4) exposure scenario libraries; 5) Hazard assessment and NRV's; and 6) Effectiveness of risk management measures. Dustiness modelling has been highlighted as one of the major improvements in exposure assessment of powders. Measured dustiness data was found to be a good potential predictor for estimating the emission potential of powdered MNM, which forms the basis as a sensitive input parameter in most of the HRA tools. In 2019, TNO's work will result in a dustiness library together with the Danish National Research Center for the Work Environment (NRCWE), which will be accessible from the caLIBRAte nano-risk governance portal and is considered to become open for further expansion by certified data contributors. TNO will work in 2019 on the sharing and collation of measured dustiness data resulting in a harmonized data library to enable better meta-analysis of these data to study the most predictive parameters of emission potential of nano-powders for improved exposure modelling purposes. This work package fits well with Milestone 1.

4.3.2.4 Nano Particle sampler and automatic filter analysis

De availability of nanomaterial exposure data for the development of quantitative exposure model development and sensor validation is limited. The collection and the interpretation of the large number of data needed to do this is complex, because: 1) sensors are not specific for chemical composition; 2) determination of the chemical composition is only possible after air sampling on filter over a longer period of time for SEM-EDX analysis (typically 4-8 hours); and 3) (semi-)quantitative SEM-EDX analysis is a labor intensive and difficult process. Recent technological developments enable the loading of SEM-EDX filter in a much shorter time span. There are developments that enable the replacement of manual SEM-EDX analysis by a more objective and quantitative automatic filter analysis. Combining both techniques would reduce the time and costs of collecting exposure data. In 2019, TNO will investigate the technical possibilities and feasibility of combining both techniques resulting in a validated fast and automatic quantitative analytical method for particle size, composition and morphology of particles in the air. This work package fits well with Milestone 1.

4.3.2.5 Value chain analysis and communication

In many cases the value chain plays an important role in how chemical substances are applied and what the associated health risks are. Nanomaterial producers are

dependent on the demands of their down-stream business clients, who are dependent on the information supplied by the producer. In may products, it is unclear whether nanomaterials are incorporated in the product, mainly due to the absence of clear regulation on labelling of nano product content. Current activities with regards to the value chain analysis are ongoing in collaboration with the inspectorate of the Ministry of Social Affairs and Employment. In 2019, a nanomaterial case study will be performed on which information is relevant with the result to assess and manage the risks along the value chain and to investigate what incentives there are to share this information up- and downstream. This Work package fits well with Milestone 1 and 2.

4.4 Dynamics

Since 2007, the European Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) regulation is in force. Already in 2008 it was concluded that REACH focuses on substances in any size, shape or physical state. Nanomaterials are already included in the REACH regulations as no distinction is made according to size. At ECHA there is a growing attention for the registration of nanomaterials under REACH. Based on these governmental developments, there is an increasing awareness to perform a proper risk assessment for nanomaterials and to comply with the regulations. VP Human Health Nano is building new knowledge and networks on human health risk management of manufactured nanomaterials and supporting safe innovation of nanomaterials. TNO has a strong position in currently running Horizon 2020 calls in the field of nanosafety and has a leading position in the field of exposure assessment, risk assessment and modeling, tool development and risk management. Scientifically there are still many challenges to assess the risks of nanomaterials. According to the Nanosafety in Europe 2015-2025 it is concluded that the various costs related to safety to the industry can be substantially reduced by enabling the manufacturing companies to focus their investment on safe materials by encouraging safe innovation. The main achievement will be the development of integrated risk assessment and decision frameworks to enable forecasting the potential impacts of nanomaterials on human health and the environment, and adequate risk management. Undertaking this may require the development of novel risk assessment strategies, sensors and standardized measurement methods together with companies that will replace the current ones, being equally reliable, affordable but faster. Environment, health and safety solutions mapped to the specific requirements of market driven value chains will provide industry at all stages in the innovation chain with the confidence that the materials that they are using will not present future business risks (reputation, litigation) resulting from unforeseen safety problems with their materials. This will maximize and support the uptake of these materials in the development of new processes and products.

5 VP Automotive Mobility Systems

Contactpersoon TNO: Marike Hoedemaker

5.1 Summary

The VP program ‘Automotive Mobility Systems’ (VP AMS) is aligned with the Topsector HTSM, Roadmap Automotive and aims to strengthen the competitive position of the Dutch automotive and mobility industry. The TKI HTSM Roadmap Automotive is directional for the content of the TNO VP AMS program, which contributes to the scope of the Smart Mobility and Green Mobility agenda of the HTSM Automotive Roadmap. The demand control becomes most specific with the TKI Roadmap Automotive and the interaction with regard to TKI proposals and projects.

The VP AMS falls within TNO in the unit Traffic and Transport, in the Roadmap ‘Automotive”, focusing on the realization of efficient, safe and sustainable mobility. The program 2018-2021 is focused on a number of important societal challenges in the areas of air pollution, climate change, traffic safety and efficient and reliable mobility. We do this by focusing on lowering the Green House Gas emissions like CO_2 and NOx and the acceleration of deployment of automated and cooperative driving. There are two subprograms Smart Vehicles and Sustainable Vehicles:

1. Smart Vehicles
The main goal of the Smart Vehicles subprogram is to increase traffic safety and througput, by development of *advanced solutions*, *tooling* and *innovative methodologies* that support governments and companies with implementation, deployment and scaling-up of connected vehicle automation to maximize operational & functional safety of vehicles, while guaranteeing robustness & reliability in real-world conditions.
It is important to show the added value of (semi-) automated driving in which aspects like the behavior of users and other traffic participants, society, business and legal aspects are taken in to account.
In 2019 we will continue to increase the operation domain of automated vehicles resulting in better performance including more complex maneuvers on highways and towards full automation at lower speeds in confined areas. More insight into behavior and interaction with traffic will be obtained via further developing the scenario based assessment methodology Streetwise.

2. Sustainable Vehicles
The main goal of the Sustainable Vehicles subprogram is to optimize towards the efficient use of energy for propulsion of vehicles while changing from fossil fuels to sustainable fuels and/or from a combustion based propulsion to a hybrid- or fully electric propulsion (including the use of hydrogen) by development of advanced or disruptive technologies, methodologies and solutions that support the governments and companies with implementation and deployment of these solutions into the

market. This will contribute to a significant reduction of emission of Green House Gasses (CO2 and NOx) as driven by the Paris Agreement 2050 and the US EPA23. In 2019 we will demonstrate on a Diesel-Natural Gas engine the improvements on emission with a new generation high pressure gas fuel system. In this way we verify our control models for an EPA23 + Low NOx fuel efficient thermal management strategy. In addition, our Aftertreatment toolchain will extended with a validated CH4 emission model on the basis of which the previously mentioned control models are provided with input.

The VP program AMS also cooperates with the subprograms “Cooperative Mobility” and “Smart data for logistics” which are part of the VP program Smart Logistics and Mobility.

- Cooperative Mobility focuses on designing, monitoring and evaluating smart mobility solutions to show how cooperative systems contribute to improving traffic flow, traffic safety and decreasing emissions.
- Smart Data for logistics focuses on logistic concepts to improve efficiency in transport of people and goods to create new economic value.

5.2 Short Description

Smart Vehicles

The main goal of Smart Vehicles is to increase traffic safety and throughput, by development of *advanced solutions*, *tooling* and *innovative methodologies* that support governments and companies with implementation, deployment and scaling-up of connected vehicle automation to maximize operational & functional safety of vehicles, while guaranteeing robustness & reliability in real-world conditions. Focus is on connected vehicle automation on public roads, taking both vehicles and road-side systems into account, in complex environments and achieving safe and efficient interaction with other road users, including vulnerable road users such as cyclists.Developments focus on four specific areas: *Vehicle Automation Technologies (Autopilot), Connected & Cooperative Multi-vehicle Control (Platooning), Scenario-based Safety Assessment (Streetwise), Real-world Safety Performance Validation (Streetproof).* Developments take place in different vehicle domains ranging from trucks, cars, delivery vehicles and automated guided vehicles.

To realize our goals we foresee the following activities and cooperations:

- Experimenting and piloting of highly automated vehicles on public roads for transport of people and goods.
- Development of technologies and functionalities for realizing multi-brand platooning as an important part of realizing interoperable connected and automated driving.
- Development of technologies and functionalities for realizing pilots of platooning passenger cars and automated parking of vehicles in urban areas.
- Single vehicle automation (e.g. highway pilot) towards SAE level 4 based on a common architecture and software framework allowing multiple automation functions to operate safe and comfortable.
- Development and application of Hardware in the Loop (HiL) test environments for independent development of platooning systems.
- Development of a scenario based validation methodology, suitable for development, testing and validation of automated driving functions to accelerate safe introduction of highly automated vehicles on public roads.

Sustainable Vehicles

The subprogram Sustainable Vehicles focuses on lowering the emissions of Green House Gasses. These gases contribute to the undesirable further warming of the earth whereby global goals (Paris agreement) and regional requirements (Euro VI in Europe and EPA23+ in the United States) force society and industry to take measures.

TNO is committed to the development of validated models, methodologies and tool suites that result in optimal use of engine/propulsion technology for vehicles (long-haul, city-bus),vessels and stationary applications. Optimal means in this case both the lowering of GHG emissions and the improvement of the quality of the living environment, as well as the reduction of the operational costs for the user.

This subprogram is divided into four focus areas:

Flex-Fuels & Combustion Technologies
Controlled combustion of mixed diesel, natural gas and other future sustainable fuels using our RCCI methodology, enabling >50% brake thermal efficiency, low greenhouse gas emissions and engine-out NOx and PM emissions. This is interesting for long-distance transport but also for static applications such as generators. The RCCI combustion methodology is an important research area on our multi-year technology roadmap. One of the targeted results is a multi-cylinder HD engine demonstration with a BMEP range of 25 bar, with NOx and PM emissions under the current Euro VI limit.

Electrified Powertrain Solutions
Battery Management (State, Charge, Thermal) and Predictive Energy Management, optimization of WTW and TTW emissions, minimize the total cost of ownership (TCO) by efficient use of energy stored used for advice and assess future clean and sustainable vehicle technologies powered in combinations of battery electric and hybrid / fuel cell.

Powertrain Performance Validation Center
Cost-efficient real-world performance assessment and validation methodologies for sustainable energy technologies and/or deployment of hybrid technologies for light- and heavy duty vehicles, to maximize the sustainable performance of vehicles.
For measuring this under unique extreme conditions (pressure and temperature) to test the robustness of the system.

Hydrogen for Fuel Cell Solutions
The long-term fuel transition and the current trends show that hydrogen will play an increasingly important role as an energy carrier for electric transport. To achieve a CO2 neutral transport system, TNO supports the use of the fuel cell by developing algorithms for state-of-health and state-of-function estimation of the H2 Fuel Cell, model-based calibration and validation of the best possible Fuel-Cell – Battery combination for a specific use case, providing a robust, efficient and reliable powertrain with the lowest possible TCO.

To realize this vision, we plan the following activities and collaborations:
1. The development of validated combustion and exhaust gas aftertreatment models which lead to an reduction of the CO_2 and NOx emissions in order to achieve the EURO VI and EPA23 requirements for a conventional dual fuel diesel - CNG engine for long haul transport.
2. The development of validated models for powertrain solutions based on use batteries for electric propulsion in combination with a fuel cell as range extender with which we can determine the best configuration for Zero Emission vehicles,

based on the desired deployment and scope with an optimized technical and economic life of the battery.

Within this VP the collaborations within the automotive sector in the Netherlands are also actively linked to demands that are developed within the Ministries I&W and EZK as well as the RDW.

5.3 Results 2019

Smart Vehicles

In 2019 we will continue to increase the operation domain of automated vehicles resulting in better performance including more complex maneuvers on highways such as lane changes and overtaking and higher levels of automation, and towards full automation at lower speeds in confined areas such as parking lots and distribution centers. Using information of road-side and IoT systems will be an important enabler to increase the operational design domain. Safe and efficient interaction between automated and non-automated traffic will be a key topic, as well as interoperability between automated vehicles.

We will work together with international vehicle OEMs and suppliers in multi-year development programs, but also via TKI (NL Smart Mobility) and EU projects (EU L3pilot, EU Autopilot, EU ENSEMBLE, EU Prystine, EU ARCADE). We have a strong cooperation with academia via a number of TNO employees with part-time professorships and employees working on their PhD (Eindhoven Technical University, Delft Technical University, Nijmegen University).

More insight into behavior and interaction with traffic will be obtained via further developing the scenario based assessment methodology Streetwise. More data will be obtained from vehicle fleets and the detection and analysis algorithms will be further developed and integrated into a cloud-based processing pipeline. Data will be obtained via running projects (EU L3pilot, EU Autopilot, EU MeBeSafe, EU Headstart, EU ENSEMBLE, TKI (NL Smart Mobility), PUMAS (B2B consortium). Cooperation on Streetwise with Nangyang Technical University in Singapore will continue and cooperation with B2B partners will be further increased (Itility, TASS/Siemens, AVL).

Sustainable Vehicles

In 2019 we will demonstrate on a Diesel-Natural Gas engine the improvements on emission with a new generation high pressure gas fuel system. In this way we verify our control models for an EPA23 + Low NOx fuel efficient thermal management strategy. In addition, our Aftertreatment toolchain will extended with a validated CH4 emission model on the basis of which the previously mentioned control models are provided with input.

The following activities with partners and knowledge institutes are started now or prepared to start later in 2018/2019 and contribute to the Roadmap 2018-2021:

- TKI consortium with DAF, focus efficiency and emissions for RCCI Diesel-Gas.
- TKI consortium for zero emission bus transport where the issues related to battery (state of charge, state of health, comfort energy and route optimization energy use) are captured in a methodology to asses large amount of vehicle data to derive the best possible optimization of the use of energy.
- FVV consortium (KIT, TNO, RWTH, SHELL, WESTPORT), focus on fundamental research on HPDI RCCI to minimize CH4 emissions (Q3/2018).

- ZE-Lab Joint Research Collaboration (TU Eindhoven, TNO, DAF, Shell), focus on basic fuel and combustion issues to achieve a higher efficiency of the internal combustion engine when using sustainable and renewable fuel (Q4/2018).
- STW Towards a HiEff engine: Open Innovation collaboration with Eindhoven University of Technology, DAF, TNO, Delphi, Sensate to focus on new pre-mixed combustion concepts, Reactivity Controlled Compression Ignition (RCCI) and Partially Premixed Combustion (PPC), are studied in CI engines as they are ultra-clean, have very high indicated thermal efficiencies (57-59% reported in literature), and enable the usage of a wide range of (bio-) fuels (fuel flexibility).(Q1/2018)
- Eindhoven University of Technology - TNO - BMW: PhD Research on BMW Scalable Active Balancing System (SCALES)(Q4/2018).

5.4 Dynamics

The VP program AMS connects with Maatschappelijke Uitdaging VI: Mobiliteit en Transport. According to this MU a transition is needed to a fully clean and safe transport sector in order to keep and increase in the future the positive contribution of Transport and Mobility in our society.

The MU Transport en Mobiliteit is focused on decreasing the side effects that now devaluate our prosperity (like CO_2 emission, fine dust, noise, traffic casualties and land take).
A direct link with the developments in the VP AMS is shown in the description of the technological developments in the area of ITS, automated mobility and electric mobility:

"*Technologische ontwikkeling in de wereld van transport en mobiliteit gaat snel, door grote aanbieders van technologie, zowel op het vlak van automatische en elektrische voertuigen, material handling apparatuur, als intelligente verkeersregel-technologie, coöperatieve ITS, sensoriek, connectiviteit, aandrijftechnologie en materialen. Een belangrijk toepassing hiervan is de ontwikkeling van autonoom vervoer voor personen en goederen. De verwachting is dat in een aantal jaren, commerciële oplossingen voor autonoom vervoer binnen bereik zullen zijn van consumenten en bedrijven. Nederlandse organisaties en bedrijven dragen in PPS verband bij aan de ontwikkeling van autonome voertuigen, vliegtuigen en vaartuigen. De Topsectoren HTSM en Water leveren hierin belangrijke bijdrages met de ontwikkeling van technologieën voor veiligheidssystemen, navigatie en coöperatieve ITS en de toepassing daarvan in smart automated mobility diensten en intelligente transportmiddelen. Een andere belangrijke toepassing van ITS zijn de veiligheidssystemen waardoor zowel het aantal doden als het aantal zwaar gewonden verder gereduceerd kan worden. Hierbij is samenspel tussen technologie, mens en infrastructuur van essentieel belang. De maatschappelijke kosten hiervan in Nederland bedragen 12 Miljard Euro per jaar en is als zodanig groter dan de maatschappelijke kosten van congestie in het verkeer*".

On the European level TNO stays active in partnerships like EARPA, ERTRAC, ERTICO, etc., but also in direct cooperation with the EC, like in STRIA and GEAR2030.

TNO cooperates with her partners in different kinds of projects:

<u>Cooperation project within the Dutch or European research programs</u>

In these projects with mixed funding, TNO cooperates with Dutch companies, knowledge institutes and other stakeholders. TNO secures that the developed knowledge is relevant for the Dutch partners within these projects and that the knowledge is innovative for the TNO programs (and with that the HTSM Automotive Roadmap).

New knowledge development within contract research
Assignments for contract research at TNO sometimes focus on application or further development of existing knowledge, but more often they focus on the development of new knowledge. TNO secures that new knowledge development within contract research always fits within her Roadmap.

TKI projects
Making use of the TKI allowance that is generated in the above mentioned projects, TNO can perform the so-called TKI projects. These projects fit by definition in the HTSM Automotive Roadmap and are always aligned with the HTSM Automotive Roadmap team, with the goal to improve the competitive strength of the Dutch industry and the well-being of society.

New knowledge development financed by the Government
Part of the VP program is focused on research to develop new background knowledge. It concerns mostly new knowledge areas or deepening of knowledge that does not directly fit within other projects.

6 VP Space & Scientific Instrumentation

Contact person TNO: Kees Buijsrogge, Hans Klaufus
Contact Government: Arnaud de Jong (ADS NI) Space, Marco Beijersbergen (Cosine) Advanced Instrumentation

6.1 Summary

Our multi-annual R&D program 2019 – 2022 supports our ambition to:

- Contribute to **preventing climate change.**
- Allow for **secure broadband connectivity.**
- Help **understand the Universe.**
- Support **economic growth in the Netherlands and the European Union.**

Therefore, we organize the VP along the following program lines:

- Instruments for **Earth Observation** and related **Space Data Utilization** and **Climate Modelling.**
- Technologies for **Satellite Communication.**
- **Scientific Instrumentation**, including instruments for **Big Science**, **Ground-based Astronomy**, **Space-based Astronomy** and **Diagnostics for Fusion Energy.**
- **Igniters and Propulsion Systems.**

For 2019, the following (main) results (per PMC Cluster) are planned, whereby we aim to involve Dutch suppliers in the chain:

- Development of the opto-mechatronic heart of the CO_2 instrument and basic specifications of the NO_2 and Aerosol instruments for Sentinel 7 and its precursor satellite in the framework of the ESA Copernicus program.
- Improved free form optics design and analysis to further reduce instrument volumes, whilst also establishing manufacturing techniques, for application in small satellites.
- Development of prototypes and flight models of several systems for laser satellite communication (e.g. prototype Optical Head for satellite communication at low altitude – LEO).
- Silicon mirror development and metrology systems for application in the Einstein Telescope Pathfinder (measurement of gravitation waves).
- For the LISA (Laser Interferometer Space Antenna) mission we will create a very precise pointing mechanisms for the alignment of three satellites.
- Developing space data based advisory tools with a focus on air quality issues – an area where TNO has considerable heritage due to its satellite instrument development as well as atmospheric modelling tool Lotus Euros.
- Development of a new promising novel concept for plasma-based small satellite propulsion.

6.2 Short description

Our VP programs are all aligned with the goals of HTSM Space and Advanced Instrumentation Roadmaps.

6.2.1 Instruments for Earth Observation, Space Data Utilization and Climate Modelling

Our main objective in this area is to maintain and strengthen the Dutch position with regard to monitoring the composition of the Earth's atmosphere. Our flagship goal is to develop – in collaboration with the Dutch ecosystem (Airbus NI, SRON, KNMI, …) – a new Dutch instrument, which will succeed the very successful TROPOMI instrument, and will monitor CO_2, NO_2 and aerosols. This instrument will help monitor the Paris agreement and provide insight into climate dynamics.

In this commercial EO market the emphasis is on information products, rather than on instruments. We will work on the development of data processing methods that can enable global information services that provide actionable information to decision makers in governments to help address these climate issues.

6.2.2 Technologies for Satellite Communication

Our aim is to develop state-of-the-art optical terminals for ground, air and space usage for the value chain of global satcom providers. We will work on our four main drivers:

- Fast: ultra-high data throughput with a long-term target of a 10 Tbit/s feeder link to a GEO-satellite.
- Secure: communication links with ultimate protection, suitable for the post-quantum era with a long-term target of a Quantum Key Distribution service with satellite nodes, which is resilient to hacking attacks.
- Far: data links over very long distances with a long-term target of a link to a deep space science mission, such as a planetary or asteroid mission.
- Multi-point: simultaneous communication with multiple senders and receivers with a long-term target of a multi-beam optical space terminal in GEO-orbit, receiving data from various nodes (space, aerial, naval) and transmitting towards multiple users.

This emerging market is a very promising opportunity for Dutch industry to extend its space-related activities into a commercial market. In this development we will position Dutch high-tech companies as a potential supplier for the terminals and their subsystems.

6.2.3 Scientific Instrumentation

We intend to strengthen our position with regard to developing high-grade instruments to perform world-class science, both in space and on ground.

In 2018 VDL has won the ESO contract for the ELT M1 support structures developed by TNO (with help from NOVA and VDL). We will continue with this technology by making it applicable (deformable mirrors, laser guide stars, support structures) for the other big telescopes in the world, and by involving Dutch industries again for the series.

In the space-based astronomy domain we use ESA's long-term planning for space science missions, 'Cosmic Vision 2015–2025', as a guideline. In the years to come, we will work on pointing mechanisms for the LISA mission (detection of gravitational waves). We intend to position ourselves for the metrology system for the PLATO mission (detection of terrestrial exoplanets).

In big science we want to prepare for the future by making sure that the Einstein Telescope (detection of gravitational waves) will be built here, and we will aim for a technical role in developing mirrors and metrology systems.

6.2.4 Igniters and Propulsion Systems

We have two main goals in this field: the development of *Green Fuel* for space propulsion, and micro-propulsion technology that will enable propulsion for small satellites for accurate positioning within a constellation, for orbit corrections to improve lifetime and for deorbiting at the end of life.

6.3 Results 2019

6.3.1 Instruments for Earth Observation

6.3.1.1 Institutional Instruments and Subsystems (optical/radar) and Optical Calibration

In the Sentinel 5 project the development of the sophisticated ground support equipment for the UV1 and TSBOA subsystems will be finalized and demonstrated in flight hardware prior to delivery to the customer (Airbus).
For future missions:

- For the proposed new Dutch instrument Sentinel 7 precursor we will work on the development of the opto-mechatronical heart of the CO2 instrument. The drivers for the aerosol and NO2 instrument have higher spatial and spectral resolution, reduction of straylight and lower weight and costs, therefore reduction of size, mass and straylight are crucial.
- For the Sentinel 7 (CO_2) mission TNO will work with industry and research Institutes (SRON) on instrument bread boarding of key elements of the NO_2 and Aerosol instruments for Sentinel 7 in order to raise the TRL level to at least TRL5. This relates well to the proposed Dutch instrument.
- For Sentinel X – SAR land monitoring (L-band radar technology) TNO will work on predevelopment activities for the Transmit/Receive modules of an L-band radar instrument.
- For Sentinel 10 (Hyperspectral land imaging) TNO will work with industry to study the calibration requirements for instrument concepts to establish the process and equipment needed to successfully characterize and calibrate the instrument to meet the challenging observation requirements of the mission.

6.3.1.2 Small Satellite Concepts

TNO will continue to develop new concepts for optical instrument technologies based on user needs in both the institutional and commercial markets. The aim will be to continue with atmospheric trace gas measurements with a higher spatial resolution and lower weight and costs.
Key to achieving this are:

- Support for improved free form optics design and analysis to further reduce instrument volumes, whilst also establishing manufacturing techniques (e.g. using grinding and MRF), to be demonstrated through bread board designs.
- Support for additive manufacturing, both design techniques and manufacturing to achieve highly complex objects (e.g. mirrors) requiring minimal finishing for use in the Space environment. Bread boarding and testing of selected components and/or structures will be an objective.
- Support for bread boarding of specific optical sub-systems (e.g. polarization scramblers) to ensure adequate TRL maturity levels for future mission applications.

These activities will be closely tied to cooperation with industry on possible future upstream missions for small satellite instrumentation.

6.3.2 Technologies for Satellite Communication

6.3.2.1 Laser SatCom

The following activities are targeted for 2019:

- Prototype CPA (coarse pointing assembly).
- Prototype LEO-LEO Optical Head.
- Flight model of a CubeSAT laser communication terminal integrated and ready for flight.
- Prototype Gigabit/s class ground station with for instance Gigabit/s class compatible Bulk Multiplexer.
- Kick-off the development of a ground station for QKD (AO in the downlink).
- Numerous activities related to Ground-Ground, Ship-Shore communications testing to increase TNO's knowledge position.
- Key technologies for multi-user Optical Heads for Space Terminal.

6.3.2.2 RF SatCom

For the RF domain we target developments in higher bandwidths (i.e. Q-/V-bands) with ESA and Dutch industry, as well as an Artes 5.2 project initiated by ViaSat for the development of an airborne satellite phased-array antenna di-electric lens.

6.3.3 Scientific Instrumentation

6.3.3.1 Big Science

For 2019 we are targeting participation in the development of the *Einstein Telescope Pathfinder*, a scaled-down engineering model for the Einstein Telescope: a third-generation gravitational wave telescope. Technological developments will be in silicon mirror development and metrology systems.

6.3.3.2 Ground-based Astronomy

Activities in 2019 will consist of targeting:

- A conceptual design for the TMT M2 whiffle tree support structure, leading to potential work with Dutch industry partners, such as VDL, NOVA and S&T.
- A completed working prototype (to the testing phase) of the 60cm DM for UH2.2, in a team approach with Dutch industry (VDL, Hyperion, S&T) and a mirror supplier/partner. This may include DM component lifetime and other testing reports.
- A joint design study of the ELT LGS, leading to potential contract award with Dutch industry (VDL, S&T, Demcon).
- A scaled Proof of Concept sensor breadboard, demonstrating key technology development to compete for the ELT co-phasing sensor contract. Potential Dutch industry partners include Demcon and S&T.
- Conference papers and posters regarding the above technology developments, demonstrating the strength of Dutch contributions to Astronomy.

6.3.3.3 Instruments for Space-based Astronomy

In 2019 TNO will demonstrate the feasibility of its technology for the LISA and PLATO missions. Those activities fit very well with our priorities as described in the National Space Roadmap (Optical Instrumentation Roadmap). In addition, they support the NWO Strategy 2015-2018 to strengthen the science system in the Netherlands and increase the science contribution to society. For LISA we will continue our work on very precise pointing mechanisms for the alignment of the three satellites. For PLATO we will prepare ourselves with the first concepts on a metrology system for the telescopes.

6.3.4 Space Data Utilization and Climate Modelling

In 2019 TNO will focus on developing space data based advisory tools with a focus on air quality issues – an area where TNO has considerable heritage due to its satellite instrument development as well as atmospheric modelling tool Lotus Euros. We can only improve this once we are able to monitor the transport of aerosol pollution and its origins. Today's breakthroughs in space technology allow us to measure atmospheric pollution concentrations using satellites (e.g. TROPOMI). The advantage of satellite measurements is that they are objective and repeatable.

I. Policy & Decision Support for air quality issues e.g.
   - Source apportionment
   - Satellite validation air quality models using to be developed data assimilation methods
   - Optimized emission reduction method using health and economic constraints using Lotus -Euros and EVEReST tool developed by TNO Energy

II. Specific Lotus Euros data processing for certain air pollution species e.g.
   - Using TNO's innovative airborne Spectrolite NO_2 sensor to create input data to improve air quality prediction over urban areas
   - Space data-based emission tracker of SO_2 for refiners and ships in protected SECA zones
   - Developing improved methods to predict deposition of ammonia, one of the EU's largest air quality polluters
   - Space based real-time dust prediction systems

III. Expansion
   TNO expects to start diversifying its knowledge position towards Greenhouse gases and water issues where we have less of a position in space data to date but have specific growth targets, e.g. in relation to
   - Methane hot spot finding
   - Measuring national stock take of greenhouse gases for the Paris agreement from space
   - Water pollution, aqua farming, bio diversity

6.3.5 Igniters and Propulsion Systems

Activities in 2019 will be targeting the development of a new promising novel concept for plasma-based small satellite propulsion, based on existing TNO technology of the *Exploding Foil Initiator*.

Additionally, we will continue our research for the development of a new green rocket and/or satellite propellant as a replacement for hydrazine.

6.4 Dynamics

6.4.1 Instruments for Earth Observation

The emphasis of our VP program for 2019 and further will be on knowledge development for state-of-the-art CO_2, NO_2 and aerosol instruments in the coming years. This to prepare us for -hopefully- a next Dutch instrument. The NO_2 and aerosol instrument should have a very good performance (spatial and spectral) and be cost-effective and light-weight. The measurement of these trace gases and corresponding knowledge development is relevant for not only the institutional but also for the commercial market, not only for the ESA chain but also for NASA and China.

6.4.2 Satellite Communication

2018 was the year that we had our technological and commercial breakthrough in laser satcom. In 2019 and onwards we will work on technologies that will position us and the Netherlands globally in this emerging market. We have a very clear focus: with our continuous improving technological building blocks and our systems and domain knowledge, we will work on the development of state-of-the-art optical terminals.

6.4.3 Scientific Instrumentation

In Ground-Based Astronomy we will build further on the position we got from our M1 ELT success. This gives us the opportunity to prepare for the future technological demands from telescopes all over the world.

With our technology development for Space-Bases Astronomy in the past years for the LISA instrument we have positioned ourselves very well. Now that the mission has been selected by ESA, it is time to continue with that and also prepare for the PLATO mission.

In Big Science we can harvest from our investments in KM3NET, we have a running NWA-project. The aim now is to position ourselves and the Netherlands politically and technologically for the Einstein Telescope.

6.4.4 Space Data Utilization and Climate Modelling

In the past year we have built a very good position in the institutional ecosystem of climate modelling. We can now develop the modelling needed for the upcoming commercial needs in this market and align it better with our (small) instrument development.

7 VP Semiconductor Equipment

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- Joep Pijnenburg (trekker HTSM Roadmap Semicondurctor Equipment & ASML)
- Ton Flaman (trekker HTSM Roadmap Healthcare & Philips Healthcare)
- Frank de Jong (trekker HTSM Roadmap Nanotechnology (incl. quantumtechnologie) & Thermo Fisher Scientific)

7.1 Summary

The primary goals of TNO's Roadmap on Semiconductor Equipment is to support the Dutch semiconductor equipment industry to create new economic opportunities and more sustainable jobs, while providing key enabling technologies to the information driven society; to develop minimal invasive and low cost medical diagnostics instruments; and to create building blocks and an evolving strategic Dutch ecosystem for unprecedented compute power and inherently save communication by quantum technologies.

Semiconductor Equipment
The Dutch semiconductor industry holds a world leading position in equipment for immersion lithography and the maturing EUV lithography, plus dominating positions in equipment & modules for electron beam microscopy and lithography, wafer processing equipment and others. We aim to add new scanning probe based metrology equipment to this Dutch portfolio by 2022.
Goals for 2019 include a design for an EUV reflectometer to be used for more accurate measurements on material modifications due to EUV illumination. The particle detection platforms will be improved to be able to measure particles smaller than 30 nm, and to detect micron sized particles on a mask backside within minutes. And the scanning probe microscopy technology will be improved to allow for quantitative measurements on buried finFETs.

In 2018 the Dutch companies and institutes active in Integrated NanoPhotonics (INP) have joint forces in the Photon Delta Public Private Partnership (PPS) and aim for a dedicated industrial ecosystem by 2026. In 2019 TNO will initiate a new research roadmap for multi-physics INP design, combining optical-, thermomechanical-, and high-frequency electronics design, and executes a feasibility study on wafer level packaging in collaboration with the to-be-launched Chip Integration Technology Center in Nijmegen.

Optical instrumentation for the (bio) medical market
TNO's Medical Photonics program aims to accelerate innovations and their implementation in optical diagnostics instrumentation for health care. We develop bio-photonics technologies to enable better and faster diagnosis and monitoring of diseases in (a)symptomatic stages; better and/or personalized treatment for patients, and thus reduced healthcare costs and a sustainable health care system.

Quantum technology – part of the QuTech initiative
Today, our ability to use previously untapped quantum effects in customized systems and materials is paving the way for a second quantum revolution. TNO aims to exploit these effects in new systems and new concepts using our core quantum technology expertise. In 2019 TNO together with TUDelft aims to have realized the first quantum computing (2 qubits) and quantum internet (2-city link) demonstrators.

7.2 Short Description

Semiconductor Equipment
By 2022 EUV lithography tools will be operated in a EUV intensity domain where plasma effects, e.g., material-plasma interactions, are dominant over the conventional photon-based contamination growth. TNO has developed a new EUV exposure and analysis facility called EBL2 to study these effects. Also RF- and microwave induced plasma techniques are used to mimic these conditions. Moreover, the application field of this contamination control knowhow will be extended to EUVL 'infrastructure', such as reticles and pellicles (i.e. membranes to protect reticles).
The second major development for system lifetime and productivity improvements will be prevention, diagnostics and remediation of (nano) particle contamination, which will be critical for the ramp-up of EUVL, and/or the introduction of the 10nm node and beyond. TNO's key activities will be on detection techniques for sub 30 nm particles on surfaces, and prevent strategies for (nano)particles landing at critical surfaces and creating possible defects on devices.

In the coming period TNO will focus on the development of advanced measurement modes of Scanning Probe Microscopy. Primary goals are based on sub-surface modes for applications related to overlay and alignment metrology and defect inspection, as well as full 3D metrology (nano-tomography).

The goals of the program on integrated photonics are aligned with the ambitions of PhotonDelta. TNO aims to have convincingly demonstrated one or more applications of, e.g., a packaging technology that will lead to low-cost pluggable optical modules, which can easily connect to other such modules, to fibers, or to an underlying substrate with waveguides, (b) an on-chip spectrometer 10x smaller compared to existing solutions, (c) a wearable sensor capable of detecting molecules having a spectral fingerprint in the 2 – 15 µm wavelength range. (This program is funded from the 'additionele middelen 2018' and on.)

Optical instrumentation for the (bio) medical market
This program, aligned with the HTSM Healthcare Roadmap, aims to accelerate medical and technological innovations and their implementation in health care. Within the program we develop bio-photonics technologies to enable better and faster diagnosis and monitoring of diseases in (a)symptomatic stages, better and/or personalized treatment for patients, less invasive surgical procedures leading to improved health outcomes, and reduced healthcare costs and a sustainable health care system.
By 2022 several demonstrators, clinical trials, or products are foreseen based on one of the three different technology platforms:
- Ophthalmic imaging platform
- Fluid characterization platform
- Nano-photonic biosensing platform

Quantum technology
Where the first phase of QuTech (2014 – 2017; Proof of Principle) focused on accelerating research and making the transition towards a mission-based way of working, the second phase (2018 – 2022; Proof of Concept) will be used to demonstrate progress on key technologies (critical milestones) resulting to the following deliverables in 2022:

- Pre-prototypes of a fault-tolerant quantum computer based on three different qubit technologies (superconducting qubits, electron spin qubits silicium, and spin qubits in NV centers), accessible online.
- Pre-prototype quantum internet, with a 2022 milestone of a four-node internet between Amsterdam, The Hague, Leiden and Delft, accessible through an online portal allowing quantum communication between nodes.
- The topological quantum computing program works towards a first stable qubit of this specific type.

7.3 Results 2019

Semiconductor Equipment
In 2019 the EUV beam line (EBL2) is expected to be fully operational. Besides customers driven projects, specific knowledge development will be done on a/o EUV induced plasma effects. TNO will collaborate with partners in the ECSEL project Tapes3, where we plan to start with the realization of an in-situ reflectometer. Also samples of partners (e.g. reticles) will be exposed and analyzed to learn about the effect of EUV on reticles.
The RapidNano and FastMicro platforms will be improved to be able to measure particles smaller than 30 nanometers, or 1 micro sized particles within minutes. A method to generate in a controlled way, and to monitor these tiny particles in vacuum will be developed as part of a TKI project.

Within TAKEMI5 TNO develops ‘through layer’ scanning probe microscopy concepts. Samples delivered by the project partners, such as FinFET structures, are helping this development. Also metamaterials are investigated to be used for metrology applications.

TNO continues the multi-annual collaborations a.o. with UT on EUV optics, in the H2020 project Viruscan (mechanical measurements on viruses), ECSEL project 3DAM (metrology), a TKI project on plasma-material interaction, and TTW (STW) projects on reconfigurable meta-instruments (AMOLF, ESA, Bruker, VSL), and on Lensless Imaging of 3D Nanostructures with Soft X-Rays (ASML, VSL, Focal, Coherent, AFS, PANalytical, TUD, TU/e, UT, UU, VU).

Integrated Photonics relates to the Topsector High-Tech Materials and Systems and the Photon Delta Public Private Partnership. In the first half of 2018, the ‘Nationale Agenda Fotonica’ and the ‘Strategisch Plan PPS PhotonDelta’ were offered to the House of Representatives (2e Kamer), outlining future directions for photonics and integrated photonics. The deliverables for 2019 are:
- Concepts for wafer level photonic packaging, supported by the academic and industrial partners; in collaboration with the to-be-launced Chip Integration Technology Center in Nijmegen.
- TNO will bring together experts from optics, integrated optics, thermomechanics, material sciences, and high-frequency electronics design to draft a first version of a scientific roadmap on multi-physics research.
- TNO will draft together with PhotonDelta partners new application development roadmaps for integrated photonics in medical technologies (together with partners in the new research center in Amsterdam), laser satellite communication and quantum communication.
- Partners include PhotonDelta and Tyndall Institute (Ireland). For quantum photonics, Andrea Fiore. For manufacturing, cooperation with companies such as Ficontech, PI, and K&S is logical.

Two technologies of which the feasibility will be investigated, as part of the Roadmap to be developed for integrated photonics in medical applications:
The on-chip spectrometer is a generic component that will serve multiple purposes. Devices that match a single mode fiber are well known in the optical communications industry, however, implementations that efficiently can detect diffuse ambient light are non-existent. Such devices will find their applications in astrophotonics and metrology, as well as in medical, with again the corresponding top sectors as application contexts. For example, in smart bandages, fibers may collect spectral information from the underlying tissue to monitor the healing process of a wound. Also, the on-chip spectrometer may become a key component in long-wavelength gas sensors. The deliverables for 2019 are:

- Identification of different use cases and specifications, considering in particular gas detection, medical analysis and astrophotonics/space applications.
- On-chip spectrometer designs and demonstrator chip.
- Designs for optical interfacing and packaging, suitable for fabrication by HT-STED.
- Partners: LioniX, VU Amsterdam (Imran Avci, Johannes de Boer).
- Links to other TNO activities: High Throughput STED Lithography, ExpoSense.

Integrated Optical Sensors will enable detection of various gasses and liquids in industrial applications (Topsector High-Tech Materials and Systems). Key applications are expected in a medical context (Topsector Life Sciences and Health). For example, in order to protect people's health the maximum exposure to benzene has been reduced to a level that current sensors cannot detect. Spectral identification of glucose in interstitial fluid will potentially lead to a minimally invasive glucose test for diabetes patients. This activity aligns well with the NWA routes 'meten & detecteren' and 'Gezondheidszorgonderzoek, preventie en behandeling' which explicitly mentions the need for further measurement techniques for medical research, prevention and treatment.
Deliverables 2019:

- Partners: nanoPHAB (TU/e spin-off), LioniX, VU Amsterdam.
- Links to other TNO activities: ERP ExpoSense.
- Demonstrator long-wavelength sensor for selected use case. Report on sensor architectures suitable for low-cost and miniature applications.

Medical photonics
Ophthalmic imaging platform
Together with a Dutch industrial partner TNO has developed a prototype low-cost hand-held fundus camera for use in primary care. After some technological improvements by TNO this prototype should be industrialized by the industrial partner and reaching the market in 2019. An additional invention (a novel method for "trans-palpebral illumination") that allows even further reduction of the cost of retinal photography has been explored; IP will be filed and in 2019 a demonstrator retinal imaging system using trans-palpebral illumination will be built. Furthermore TNO continues, within a EU funded project ("MOON"), with the clinical validation of a fluorescent fundus camera for curcumin imaging, which binds to protein (senile) plaques in the retina and can be visualized using fluorescence imaging. This is an important development aiming at earlier detection of Alzheimer's disease using an eye-scan. Meanwhile, a novel (low TRL) ophthalmic imaging platform is under development that involves looking into the eye with a camera and quantifying light scattering, absorption and fluorescence from the retinal images thus made. The scattering and absorption properties of the retina are related to retinal tissue structure and organization as well as to retinal physiology. Multi-spectral measurements of these properties enable earlier detection of eye diseases such as

diabetic retinopathy, age-related macular degeneration and glaucoma, as well as of systemic diseases such as cardiovascular and neurodegenerative diseases. In 2019, this novel technology will be validated and tested on human volunteers. In parallel, an industrial partner will be sought for further development, validation and commercialization of the technology. Finally, together with academic partner VU, a confocal laser scanning ophthalmoscope has been designed for retinal oximetry. IP regarding oximetry and haemoglobin concentration estimation through the eye has been filed, and business opportunities regarding these inventions will be explored in 2019.

Fluid characterization platform
In 2019 a TKI project with Neokidney and VUmc will be performed to further develop and validate the LIBS technology in a clinical setting. Also, a demonstrator LIBS system will be developed. In parallel, we will apply for EU funding to increasing the TRL of this platform, and preparing a path towards industrialization and commercialization of the technology.

Nano-photonic biosensing platform
A spin-off company of TNO, Delta Diagnostics, will bring ring resonator biosensors to the market in 2019. TNO will continue to explore the use of photonic integrated circuits (PICs) and waveguides for medical applications. Development of a spectrometer-on-a-chip as well as applications of mid-infrared evanescent field sensing will be explored in 2019, together with academic partner VU.

Quantum Technology
Fault Tolerant Quantum Computing
In 2019 the Quantum Inspire platform (www.quantuminspire.com) will be fully launched, making not only a quantum emulator available to society, but also QuTech developed quantum computing hardware. Its envisioned that this platform will host different kinds of quantum computing qubits that have been developed at QuTech and will grow into a first proto-type of a Quantum Computing Cloud service. Qubit quality has to be improved and in 2019 new nanofabrication processes as well as new chip designs will be tested.
Due the participation of Intel and Microsoft, new partners have to fit to the consortium. Some of the most likely and interesting partners for technology transfer are Zurich Instruments, KeySight and QuBlox. In 2019 projects will be started up to facilitate room temperature electronics technology transfer from QuTech to industry.

Topological Quantum Computing
The cooperation between StationQ and QuTech requires a re-focus of the long term goals and the efforts needed to reach these goals, the details of which still need to be worked out. In the meantime, TNO has set-up a bilateral relationship with Microsoft, providing quantum device development expertise. Most of the activities in the topological roadmap are cross-fertilization activities, where know-how from other QuTech Roadmaps are used, such as: nanofabrication, data analyses, simulator developments, etc.

Quantum internet & secure communication
In 2019, the first 2-city Quantum Link will be established. Furthermore, the blueprint for the quantum internet will be developed in the Quantum Internet Alliance project. The development of this blueprint will be based on QuTech’s NetSquid quantum internet simulator. In 2019 NetSquid will be extended to be able to do so.
Finally, first breadboard prototypes of key components of the quantum internet will be developed and tested in QuTech laser labs.

Partnerships will be started based on ‘open innovation’ and pre-competitive research. In principle, every party could participate. KPN is foreseen to become a strategic partner of QuTech in 2019.

7.4 Dynamics

Semiconductor Equipment
In multiple TNO projects in 2018, the need for miniaturized photonic devices intensified. (For example, in the Laser Satcom program which gained a lot of interest. In metrology challenges, where miniaturized interferometers are needed to track autonomous units. For miniaturized gas sensors as part of the ERP ExpoSense. And even in quantum technologies (QuTech) where e.g. frequency conversion is based on LiNbO3 waveguides and miniaturization is needed to obtain increased stability.) The miniature spectrometer was identified as a generic building block. Efficiency calls for a solid infrastructure and expertise team in integrated photonics that could serve many applications. Strengthening that expertise team is a goal for 2019 as well.
Recent advances in NIR waveguide technology (i.e. Mirphab) and work by our contacts at the VU Amsterdam now open the possibility to explore single-mode waveguide-based sensing at long wavelengths.

In the ERP Structural Integrity 2018, a range of different sensor technologies for the detection of surface acoustic waves were compared. Integrated photonic ring resonators showed promising results, which is the motivation to investigate in 2019 where the technologies of photo acoustics and integrated photonics can benefit from each other.

Optical instrumentation for the (bio) medical market
As also stated in the “Nationale Agenda Fotonica” of 2018, a Photonics Technology for Health Center will be established in Amsterdam. Since TNO is a strategic partner of the VU, the initiator of the PTHC, we will closely collaborate regarding this development in 2019.
A new topic that was identified in 2018 and will be explored in 2019 is the use of photonic health patches (technology by Holst) for measurement of tissue optical properties. Monte Carlo simulations of light transport in tissue will be used to guide the optical design of such patches.

Quantum Technology
In 2019 the Business Development activities of QuTech will take off with the new Business Development Director in place, hired by TNO. The goal is to find new (European) partners, and to start Quantum Technology transfer projects with industry as well as facilitating QuTech start-ups. The mid-term evaluation of QuTech is rescheduled to early 2019. It is likely that there will be modifications to the mission and vision statements and the post-2025 strategy of QuTech.

One of the main obstacles currently encountered in the development of a fault tolerant quantum computer prototypes is the quality of the quantum processors. The expected progress in quality was not met in 2018, this could be having an effect on achieving milestones in 2019.

The cooperation between StationQ and QuTech requires a re-focus of the long term goals and the efforts needed to reach these goals. The details of which still need to be worked out, especially in the context of the bilateral relationship between TNO and Microsoft which is evolving next to the QuTech – Microsoft collaboration.

8 VP Flexible and Freeform Products

Contact person TNO: Jaap Lombaers

8.1 Summary

In VP ‘Flexible and Freeform Products’ we develop technology for next generations of smart products, made by digital manufacturing processes. Applications are in multiple domains such as healthcare devices, automotive and home products. The program consists of the following program lines:

Digital Manufacturing Systems
We develop new technologies for digital manufacturing processes such as 3D printing. With digital manufacturing, the shape of the product is not defined physically (e.g. by a mould or mask) but by the software that controls the manufacturing system, allowing for customization of products and cost-effective small series manufacturing. In 2019 multi-material powderbed and FDM will be developed in order to create personalized nutritional food. Within pharma printing the powderbed printing technology will be developed to control the porosity of printed pills, leading to controlled drug release. For both food and pharma printing a multi-nozzle (N>10) system will be developed as a first step to upscaling.
For the manufacturing industry we develop technologies to increase throughput and lower the cost of digital manufacturing by parallelization and line-integration.

Materials for Additive Manufacturing
One obstacle to Additive Manufacturing becoming a mature manufacturing technology is the limited performance of available materials. We therefore aim to enlarge the application possibilities for polymer materials in Additive Manufacturing. In 2019 our focus is on (1) combining different materials in a single product (‘multi-material AM’), demonstrated by a.o. printed antenna’s and on (2) developing processes to 3D-print parts with continuous fibers in it, improving the mechanical performance of these parts but also allowing for integration of new functions.

Hybrid Printed Electronics
For the next generation of ‘Internet of Things’ products, a hybrid combination of flexible, printed electronics and ‘conventional’ silicon-based electronics is the way to go, such that every object can be made smart by integrating a thin foil which contains all functionalities. In 2019, a pilot line will be established that combines printing technology of interconnects together with a novel ultrafast curing technology and assembly. In addition, a new printing technology using lasers, LIFT, will be shown to be able to print 10 micron wide features. In 2022, the full pilot line should be opertational and used for creating first product prototypes in medical and/or automotive applcications.

Large Area Technologies
Organic Light Emitting Diodes (OLEDs) for lighting purposes have been one of our key topics for many years. We are now establishing a pilot line allowing companies to get acquainted with this technology in advance to committing to mass manufacturing. Furthermore, in 2019 we continue to develop applications for our core capabilities in ‘Spatial Atomic Layer Deposition’ (S-ALD), a unique process to cost-effectively make very thin layers of high quality. Our prime focus will be on the use of it in displays, teaming up with our spin-off SALDtech to realize a prototype machine. We accelerate our activities on next generations of batteries for electric

driving, making use of our core capabilities in deposition technologies. In 2019 we proceed with an advanced concept (3D Li-ion batteries) making a full-functioning demonstrator which should lead to a full pilot line for 3D-SS batteries in 2022.

Thin Film Transistors
Our metal-oxide transistor circuits are directly deposited on large-area substrates. Whereas 'conventional' chips provide much more computing power on a very small area, we enable cost-effective distribution of simple circuits over large area's such as with displays and imagers. In 2019, the technology will be re-used to create various other applications:

- An ultrasound array that is shown to be feasible for medical imaging.
- A fingerprint array integrated in a (phone)display.

In 2022, the first working ultrasound array for medical imaging is shown for the heart, and first applications with optical imagers on body for measuring blood flow parameters is operational.

8.2 Short description

Digital Manufacturing Systems
In AMSYSTEMS Center, TU/e and TNO are teaming up on this topic. Digitally controlled manufacturing processes such as 3D printing / additive manufacturing provide opportunities for personalization and customization of products and for integration of additional functions in products. These processes however still have limitations in materials, productivity and quality. Goal for 2022 is to enable broader application of digital manufacturing in industry, including commercial application in the food industry (digital food processing) and pharma industry (pharma printing).

Materials for Additive Manufacturing
This program line is executed in Brightlands Materials Center (BMC), a joint initiative of TNO and the Province of Limburg with TU/e and UM as academic partners. One of the key obstacles to Additive Manufacturing becoming a mature manufacturing technology concerns the limited performance of available materials. BMC focuses on polymer materials. The 2022 goal is to introduce new material-process combinations in industry, enabling wider usage of Additive manufacturing.

Hybrid Printed Electronics
This program line of Holst Centre (joint initiative of TNO and imec) combines printing with silicon-based components to realize electronics devices that, unlike standard Printed Circuit Boards, are flexible, stretchable and 3D-formable. Main application domains are in wearable/medical devices, automotive and human machine interfaces (HMI). The main goals for 2022 are:

- Flexible/stretchable electronics: deploy in commercial products; establish manufacturing pilot-line (both sheet-to-sheet and roll-to-roll).
- Structural electronics (3D electronics made by in-mould and 3D printing technologies): establish a mature technology portfolio for in-mould electronics (IME); identify possibilities of 3D Printed Structural Electronics.
- Sensoric surfaces: develop applications of printed sensor arrays, e.g. for temperature and pressure; develop energy harvesting technologies for integration in autonomous sensor arrays.
- Printing process innovations: bring Laser-Induced Forward Transfer (LIFT) deposition to high resolutions; develop photonic soldering into a mature technology.

Large Area Technologies
This Holst Centre program line develops processes and applications for low-cost, large area thin-layer deposition.

- In partnership with RTOs in EU, establish a pilot production line for flexible OLEDs for lighting and signage products, making application of OLEDs in products accessible to a large group of companies preceding mass manufacturing.
- Contribute to future generations of batteries for electric vehicles and stationary storage. Demonstrate 3D Li-ion solid-state battery, apply Spatial Atomic Layer Deposition (S-ALD) to enable Li-metal anodes, enhance battery performance by developing monitoring systems with printed sensors.
- Create and improve applications of S-ALD, with first focus on equipment for the flat panel display (FPD) industry teaming up with our SALDtech spin-off and with additional outlets in batteries, optical coatings, thin-film photovoltaics, membranes.

Thin Film Transistors
This Holst Centre program line targets applications of thin film transistor technology such as displays and imagers (image sensor arrays).

- Establish a pilot-line for TFT manufacturing as a foundry for external parties, fabricating prototypes of next-generation displays, photodetectors and other large area electronics applications.
- Develop of (im)printing techniques to scale down the transistor dimension to less than the value of 1.5 micrometer that is currently the limit for (flat panel display) lithography tools, addresses the need for high pixel resolution, in-pixel intelligence and faster switching speed.
- Develop alternative materials and deposition methods that do not require high vacuum deposition leading to cost reduction.
- Develop novel OLED pixel scaling technologies leading to 800-ppi displays with sufficient lifetime; transfer technology to display industry.
- Realize semitransparent microLED displays.
- Develop our organic photodetector technology full display-area fingerprint scanner and touch sensor in mobile phones.
- Develop our organic photodetector technology towards near-infrared sensitivity and deploy in CMOS cameras and novel biomedical applications.

8.3 Result 2019

Digital Manufacturing Systems

- Food printing: most food items consist of multi-materials and therefore the goal for 2019 is to develop multi-material powderbed printing. For FDM already initial steps have been made on multi-material printing via coaxial and multi-nozzle printing. The next step in FDM printing is towards personalization and for that purpose inline mixing and dosing is the goal.
- Pharma printing: challenges for the pharma industry are 1) reduction of cost and duration of medicine development; 2) increased effectivity of medicine; and 3) improved therapy compliance and patient comfort. Goal is to demonstrate the ability to vary dosage and release profile by designed porosity and shape of printed pills.

- Industrial AM: a redefinition of this program is ongoing and will be completed by the end of 2018, leading to new priorities within the overall trend towards high-throughput, line-integrated digital manufacturing systems for Smart Industry.

Materials for Additive Manufacturing

- One line of research concerns combining different materials in Additive manufacturing: multi-material AM. As a lead application domain, in 2019 the applicability of the technology to produce 3D all-dielectric lens antenna's will be demonstrated, in collaboration with TNO's radar technology team in The Haque.
- The second line concerns 'continuous fiber additive manufacturing'. By integrating continuous fibers in AM-made parts, not only mechanical properties can be improved but also new functions can be integrated, for instance by use of electrically or optically conducting fibers. First demonstrations will be realized in 2019.

Hybrid Printed Electronics

Flexible/stretchable electronics

- The capability of our devices to be highly body conformable (stretchable, thin) will be further increased. New materials will be evaluated with partner companies like Henkel and DuPont. Besides this first commercial products will be enabled based on our technology platform. For example by Bambi Medical (Eindhoven start-up), Philips (Health patch) and Hugo Boss (smart clothing).
- In the framework of EU funded projects InScope, a pan-European pilot line for hybrid printed electronics is being established. Holst Centre is coordinating this project. In 2019, first cases will be manufactured on this pilot line.

Structural electronics

- We will continue with technology for manufacturing of printed electronics on a thermoformable base film (e.g. PC, ABS) that subsequently can be used as an insert in an injection moulding process, with industrial partners like DuPont and Faurecia. The 2019 focus will be on improving the compatibility with the injection moulding process.
- With regard to 3D Printed Structural Electronics, equipment for this has been developed at AMSYSTEMS Center in previous years. In 2019, a first round of process development and demonstrator realization will take place on this equipment.

Sensoric array surfaces

- Printed electronics technologies allow for a relatively easy realization of distributed electronic functionalities on large surfaces. In particular, there has been already for a number of years strong industrial interest to print arrays of sensors on such large surfaces. For example, pressure sensors (shoe inlays, smart bedding) and also temperature sensors (thermal mapping). The development of unique and innovative sensor array concepts is an important focus area at Holst Centre already for a number of years. For 2019, this topic will continue with an important focus on printed piezo sensors (energy harvesting, deformation sensing) and on temperature sensors (for e.g. battery packs).

Printing process innovations

- Holst Centre has been working for a number of years on various innovative manufacturing technologies for printed electronics. These concern printing technologies like LIFT (laser induced forward transfer) and PhaTT (photonic ablation transfer technology) but also curing technologies like photonic sintering and photonic soldering. These technologies are seeing recently an increased

industrial interest from companies like Murata, Panasonic and Orbotech. For LIFT technology, the goal is to develop the technology so it allows for much higher printing resolutions, with the ultimate goal be 5 um line/spacing (currently 50 um line/spacing). For 2019, a first step will be set into this direction. For photonic soldering, the goal is to further mature the technology. For 2019, research will start with a R2R photonic soldering tool to be installed by Novacentrix on the Holst Centre R2R assembly line.

Large Area Technologies

OLED pilot line and barriers

- The pilot line for flexible OLEDs, which is developed through the EU funded project PI-SCALE, is fully up & running by end of 2018. In 2019, it will be used to complete the demonstrator cases with four launching customers who are part of PI-SCALE, and for new customers that are contracted through targeted business development and sales activities. Key partners in this will be Fraunhofer FEP as technology co-provider and Audi, REHAU and Pilkington as launching customers.
- Expand and finetune our key PECVD, S-ALD and solution coating technologies for water barrier substrate and direct encapsulation, with ultra-low Water Vapor Transmission Rate (WVTR), for design-in and application in OLED, PV and displays, together with various industrial partners in the relevant market segments.

Batteries

- Demonstrate the first complete 3D solid-state battery comprising all key technology building blocks: 3D bottom electrode, S-ALD functional layers, in-situ Li metal deposition, and top current collector. Prepare detailed business case for value extraction, with spin-off seen currently as most likely path forward.
- Demonstrate capability and value of S-ALD for engineering various interfaces in Li-ion batteries. This can include modification of cathode sheets or separator foils, passivation of Li metal anodes, and deposition of solid-state electrolytes. Partners will be in the battery value chain: materials providers, cell manufacturers, OEMs.
- Demonstrate the applicability of printed temperature sensors for integration in battery packs and battery management systems, together with TNO Automotive in Helmond.

Spatial Atomic Layer Deposition

- With partner SALDtech, construct the first S-ALD equipment dedicated to display manufacturing, scalable to larger Gen sizes. Demonstrate the applicability and performance of S-ALD layers (TFT channel, dielectric) in displays.
- Expand materials and application scope of S-ALD by demonstration of indirect plasma S-ALD, ‘ABC’ S-ALD (with ‘C’-cycle to do in-situ anneal) and area-selective S-ALD.
- With partner Solliance, demonstrate performance of S-ALD functional layers in various types of thin-film PV (CIGS, PSC).
- Explore potential S-ALD benefits and propositions in adjacent technology domains such as optical coatings, membranes, and LEDs.

Thin Film Transistors

- In partnership with BMC, imec, TU/e, KU Leuven and imec, establish a pilot production line for flexible TFTs and a one-stop shop that (local) industry as well

as knowledge institutes can approach for support (supported by Dutch-Flemish Interreg office, project ‘Flexlines’).
- Continue our focus on increase of reproducibility and repeatability of the TFT production process as well as its description in a design-rule-manual, so that third parties can design electronics that can then be manufactured in our pilot line.
- Building upon our TFT background, continue to engage with display innovators to develop technologies and prototypes of next-generation displays. This involves companies such as LG Display, CPT, Barco and Osram. Key need is for smaller pixels and transistors that can deliver more electrical current.
- The underlying technologies are addressed and re-used in other application fields as well. In the past few years we have developed a large-area photodetector technology, that combined with a high-energy scintillator, was used to demonstrate, for instance, curved CT-like detectors (with Philips Research and Philips Medical) and high-resolution detectors (with Siemens). With their main supplier, dpiX (USA) we started a technology transfer, to be finalized in 2019, after which dpiX can supply to Siemens and Philips detector plates with Holst Centre technology inside.
- Integrate high-resolution fingerprint scannng inside the area of a mobile phone display.
- Working with both academic groups (TU/e) and renowned material suppliers screen new photosensitive materials for the near-infrared sensitivity. Here, the idea is to extend the color range from CMOS detectors from blue, green and red to the infrared. This improves night vision and is useful for 3D face recognition. We also believe that low-cost and flexible near-infrared photodetectors are useful in biomedical applications, for instance to measure blood oxygen saturation and -indirectly – blood pressure. This seems do-able in 2019 but when we can reach wavelengths approaching 1500nm we can think of non-invasive glucose monitoring, a dream for decades.
- We continue to keep an eye on integrate our TFT backplanes with other types of sensors. Here, a new focal point is the use of polymer transducers to make large-area ultrasound imagers. In 2019 we will make the first prototypes, and in parallel develop use-cases. This will be done together with our TNO colleagues in Den Haag, and the TU Delft.

8.4 Dynamics

Compared to our 2018 plans, main changes are summarized as follows:
- **Photovoltaics:** the major change in this VP is the transfer of the photovoltaics research in this VP (Solliance) to a new VP managed by TNO’s new unit ‘ECN part of TNO’. Meanwhile we will ensure that synergies between PV and the topics in VP ‘Flexible and Free-form Products’.
- **Digital Manufacturing Systems**: we now position Additive Manufacturing as one of the options towards manufacturing systems under full digital control and are pursuing synergies with other TNO activities in the frame of ‘Smart Industry’. Process research will be increased and engineering efforts towards large prototype setups will be reduced.
- **Materials for Additive Manufacturing:** the program line has further focused as described under goals 2019.

- **Hybrid Printed Electronics:** no changes are foreseen as compared to the 2018 plan.
- **Large Area Technologies:** we scale back our ambition level in the OLED pilot line in view of technological challenges and low market growth. We intensify our plans in the field of batteries, based on discussions with industry and EU policy makers. We widen the exploration of potential S-ALD applications beyond displays and in thin-film PV.
- **Thin Film Transistors:** no changes are foreseen as compared to the 2018 plan.

9 VP Sociale Innovatie

Contact person TNO: Sandra Eikhout (Dir. Markt GL), Steven Dhondt
Contact person Government: Herm van der Beek (EZK), Henk Gritter (EZK)

9.1 Summary

Smart Working, as a part of the Smart Industry initiative, focuses on what the optimal work setting is for operators. Smart working looks at which technological and organizational solutions help improve and develop skills and performance of Smart Industry operators. Smart Industry can only be as smart as its' operators are. Two major context developments are central for Smart Working: robotization and digitization. Together with companies, the program tries to develop solutions for operators to deal with rising skill and performance demands. Managers and collaborators, internal and external, are more and more dependent on each other. Work changes constantly, on the short and on the long term. Our solutions help the operator to maneuver faster within a factory setting with robots, collaborative robots (cobots), exoskeletons, operator support systems and other digital support systems. Operators get tools to learn on the long term.
The Smart Working projects are focused on robotics, cobotics, cognitive support systems, use of digital information and communication in work settings. Operators need to have a maximum of autonomy to adopt these tools in the work settings. Having this responsibility and ability will help the operator to generate the required knowledge and skills to deal with the necessary changes. The projects therefore create solutions that take account of physical, cognitive and psycho-social demands on operators, but also on the organizational conditions to allow working in multi-disciplinary and autonomous working environments. This means solutions at the workplace level (exoskeletons, collaborative robots, augmented reality training and guidance for operators) and at the organizational level, cooperation between operators, colleagues and robots (Workplace Innovation, lean systems, blockchain driven organizations). Smart working also involves (social/legal) conditions as required by society.
The solutions are always science and practice based. For the success of the program, the disciplines human factors, organizational sciences and technical sciences need to work in concert on solutions and designs. Collaboration with technical experts and information system specialists is also crucial. Next to a new set of projects, the program invested into Fieldlab/Living Lab environments and a small lab environment for testing operator support systems, exoskeletons and cobotic workplaces.

Goals 2022
The P207 Social Innovation (Smart Working) program has two objectives: (1) First of all, the development of a concept of Operator 4.0 in Smart Industry and Logistics, a model in which new and flexible ways of cooperation between operators and technology are realized in production and logistics processes. Core ideas are performance, safety, health and sustainable employability; (2) Secondly, the development of a concept to create Smart Organizations in Smart Industry and Logistics, more flexible, inclusive and productive organizational concepts. Skill development is connected to the organizational objectives. Core ideas are digitization (including blockchain technology), platformization of company structures and Big Data. The outcome of the program is instructive, productive and innovative

work in Smart Industry and Smart Logistics. For companies, the program delivers flawless and more efficient production systems.

What has been achieved by the end of 2019?
The Operator 4.0 project line leads to new concepts about matching human tasks and robot tasks. New in 2019 are: a new user interface for a bolt mounting robot on the shop floor and a model to better fit the design of an exoskeleton to human requirements; a concept of robot support linked to the flexible deployment of employees and employees with a distance to the labor market; a second version of a concept for cognitive operator support has been developed. The project line Smart Organizations will provide new organizational concepts for a learning environments for industrial settings and logistics in 2019. In 2019, from the roadmap on how organizations are better connected to blockchain and other digital technologies, a concept is formulated for managing learning behavior on the basis of blockchain.

9.2 Short description

The Smart Working 2019-2022 program focuses on the development of new concepts of human-technology (Operator 4.0) and organization-technology integration (Smart Organizations) with the purpose that modern work can be connected to new forms of robotization and digitization.

Goals 2022
The outcome of the program is flawless, productive, healthier, safer, and more knowledge-intensive work in Smart Industry and Smart Logistics. We strive for a new concept *Operator 4.0* because the Smart Industry processes have changed drastically. Robots and operators used to work independently from each other and the productivity of robot-human systems depended mainly on the correct programming of the robots. Further integration, flexibilization and acceleration of production processes force people to produce directly and together with robots. Robots will have to be able to 'communicate' with their environment differently. In this development, new cognitive operator support technology (e.g. augmented reality) is increasingly becoming an important link in flexible and error-free production. The productivity and flexibility of these people-oriented technologies depend on optimal conditions (and interaction) for the Operator 4.0 and the application of Workplace Innovation concepts. It should be clear what knowledge, skills and attitude the operator 4.0 should have and how this concept fits into the Smart Organization. The goal with this first line of research is to achieve the following objectives by 2022: (1) have adapted the general concept to specific robot technologies (cobots, exoskeletons) or sectors; (2) adapted the concept of robot support so that employees with a distance to the labor market can be deployed in industrial production environments. With this concept, new target groups such as younger, inexperienced employees, flex workers and older employees in high mix, low volume, high complexity production processes can produce flexible and error-free; and (3) an adaptive concept for cognitive operator support has been developed/tested.
In the further integration of production and service provision processes in the digital environment, platformization of companies is another important trend. The internet ensures the integration of tasks and processes. New possibilities on the internet such as blockchain technology offer new perspectives on the organization of the work. To be able to respond to both developments, new concepts in Smart Working 2019-2022 are developed about the optimal conditions for *Smart Organizations*, based on the principles of Workplace Innovation. The goal is to deliver a concept of

new organizational forms (Smart Organization) in Smart Industry that help industrial companies become more productive. In companies, concepts for digitization (including blockchain technology) and platformization have been developed and applied. For this type of technology we want to develop a development path aimed at better use of data and organizational principles.

Which knowledge/technology is needed to get there?
First, we collect new concepts about 'operator 4.0' and 'smart organizations' through literature research, conferences, monitor data and discussions with companies. Second, (ecosystem) partnerships in the sectors will be continued. Third, testing in practice is necessary for testing and evaluating the various concepts: we already have an Operator Cognitive Support System test setting in Leiden and a robot environment in both Delft and Leiden. Together with our partners, we create other learning environments at customers or at partners (including educational institutions). A test environment is planned with STC Rotterdam for analysis of alternative devices in warehousing; a joint venture with the TU Dortmund and Fraunhofer IML is considered to develop lab-setting for Workplace Innovation. Fieldlabs help to come up with solutions with a broad set of stakeholders. To safeguard our knowledge, we focus on ecosystems in which research institutions, education and companies work together on new solutions. Examples: Fieldlabs FlexMan (BIC), RoboHouse (SMITZH), Fieldlab Social Innovation, the Skillslabs in HTSM. Lab environments and Fieldlabs will be finalized. In the following years the concepts are further developed.

9.3 Results 2019

What are the intended results in 2019?
The Smart Working program provides the following deliverables:

- New concepts for human-robot interaction in manufacturing and logistics. More in particular, we deliver models based on performance, health and employability perspectives:
  - to appropriately use exoskeletons in production and logistics environments;
  - to deploy cobot solutions (human-robot collaboration) which function optimally.
- Concepts to make Operator Support Systems adaptive based on the measured quality, operator capacity and the current skill level so that operators in high-mix low volume high complexity production environments learn faster, work faster, are more flexible, are less annoyed and produce faultlessly.
- New organizational concepts and skills of operators to work with robotization and digitization:
  - New digitization solutions (including Blockchain, Artificial Intelligence) require that employees deal with software and systems in a new way: we provide a first Proof of Concept on how blockchain can guide behavior aimed at learning at work.
  - Far-reaching robotization (exoskeletons, cobots and operator support) requires new (technical, cognitive and social) skills from employees: we deliver new concepts to function optimally in those environments. The principle of adaptive support is also central to these concepts. Exoskeletons can be made more adaptable by measuring human intention and operator support systems can adapt to the skill level and the current need for cognitive and physical support.
- Models for optimal conditions for Smart Organizations.

- Blockchain is being explored as a new tool to organize work differently: with this new technology it becomes possible to change from centralized control and support of production processes, towards decentralized control and support. The program provides a Proof of Concept on how blockchain driven organizations make the best use of knowledge and insights from employees and groups of employees.

What are the intended deliverables for 2019?
Operator 4.0 project line:
Continuation of current projects:

- H2020 HORSE: a concept about matching human and robot tasks, with optimal integration of the operator in robot environments; setting up competence center in Fieldlab Robohouse (Delft) with industrial use cases.
- RAAK (G)een moer aan: develop a job allocation model and new user interface for a bolt assembly cobot on the shop floor.
- TKI LSH Exoskeletons (Hero 2.0): developing a model to better align the design of exoskeletons with human requirements.
- Fieldlab Flexible Manufacturing: developing and demonstrating collaborative robot concepts and operator support concepts in low-volume, high-mix and high-complexity environments.
- JIC I-Botics: further deepened knowledge about Human-Controlled Robotics.
- Interreg FOKUS: extensive testing of how new cognitive operator support systems work and can be adapted to the needs of individual employees and constantly changing products and processes; setting up cross-border knowledge clusters in close cooperation with Flemish partners.
- TKI Dinalog project on man and robot in the warehouse: integrating Automated Guided Vehicles and operator functions in warehouses in close collaboration with Erasmus University.
- TKI HTSM Adaptive Manufacturing: Development of adaptive operator support using projection technology in assembly environments.
- H2020 DT-FoF-02-2018 Rossini: Design, develop and demonstrate an inherently safe, modular and scalable platform for the integration in industrial production environments or human-centered robotic technologies. Project will start on 1-10-2018.

Planned project proposals 2019:

- RAAK Assembly 4.0: Design or Augmented Reality supported assembly in close cooperation with HAN university or applied sciences, RUG and about 10 SMEs.
- H2020 DT-ICT-07-2018-2019 - The human factor: human competences in synergy with technological progress.

Project line Smart Organizations
Continue projects:

- Fieldlab Social Innovation: setting up the Fieldlab and developing it into the Skills Labs in Smart Industry.
- EU-E-lean project: insight into best practices of new organizational concepts.
- SBO Paradigms 4.0: in collaboration with KU Leuven and Antwerp Management School, look for solutions that help us understand what happens to skills in the new organizations and workplaces.
- GAK project on Modelling Labor Market Impacts: a model for estimating in time what new forms of robotization and digitization will entail.

- H2020 Shift2Rail - CCA Human Capital: skill situation in the railways sector of the future.
- H2020-Transformation01: build on this developed knowledge and develop a European knowledge position. Project will start on 1-11-2018.

Planned project proposals 2019:
- H2020 – Innosup: Workplace Innovation.
- EASME Connected Assisted Driving and Demand Requirements: for the European Commission to investigate the consequences of CAD for future skills in logistics sectors.
- Blockchain in learning environments.
- NWO-TKI Living Logistics Labs: Setting-up a living lab investigating impact of robotization, mechanization and digitization of warehouses on skills, organizations, and delivering a model for increasing innovative strength within logistics companies.
- SMO project in industrial settings, connected to Skills Labs in HTSM.

Which research is needed?
In 2019 we will mainly work on the development and underpinning of the new concepts on 'Operator 4.0' and on 'Smart Organizations'. We conduct experimental lab research, research in practice, literature research, conferences and discussions with the companies. We continue to build on the partnerships that we have built up over the past years in P207. We develop tests and test environments for the evaluation of these concepts. This implies cooperation with national and international partners. We are working on the development of the Fieldlabs Social Innovation, Skills Labs Smart Industry, Flexible Manufacturing at the Brainport Industries Campus (BIC) and Fieldlab RoboHouse (part of ecosystem Smart Manufacturing: Industriële toepassing in Zuid-Holland). For the blockchain research we are working on a Proof of Concept with DIVOSA.

Which parties are or will be involved?
On the company and funding side:
- FME, FNV, AWVN, Agoria (BE): in the framework of the Fieldlab Social Innovation and Interreg FOKUS; linked to these social partners there are broad networks of HTSM companies.
- Human Capital Table Logistics and TKI Dinalog: for various skills projects in logistics. In this sector we have broad connections with companies.
- Brainport Industries: together with end users (OEMs and Tier One suppliers), robotics suppliers, system integrators, Technical University Eindhoven and the Fontys and Avans Universities of Applied Sciences in the ecosystem of Fieldlab Flexible Manufacturing.
- Werkspot: a knowledge center is being developed for the topic 'platform economy'.
- Start collaboration within the Horse project (TNO Competence Center) in RoboHouse with partners (Robovalley, Festo, Exact, Hogeschool Den Haag, Delft University of Technology, Innovation Quarter) in Delft, South Holland.
- Flanders Make, Sirris, KU Leuven and the Open Manufacturing Campus : Flemish research partners in the Interreg project FOKUS.

The program also links up with (TNO) Early Research Programs, ERP i-Botics and ERP Blockchain. The program ensures a substantive alignment with these research programs. Different elements can be better selected in those ERPs. The application of these ideas follows in the program P207.

In the Netherlands we work together with the universities of VU Amsterdam, University of Twente, TU Eindhoven, Erasmus University and Utrecht University and several Universities of Applied Sciences:

- VU Amsterdam: collaboration in several exoskeleton projects. Knowledge development in the field of wearable robots (among others 3 PhD students, of which 1 appointed from ERP i-Botics).
- Erasmus University: partner in TKI Dinalog and NWO-TKI project.
- With the University of Twente, we are building the knowledge center i-Botics.
- With the University of Utrecht, we will have one PhD student, linked to the Future-of-Work program. The University of Utrecht is collaborating in the context of the NWA Smart Industry route.
- Start-up collaboration on robotics with university of Applied Sciences The Hague and Den Haag, TU Delft in RoboHouse Delft.
- With the TU Eindhoven we collaborate in the Fieldlab Flexible Manufacturing and the H2020 project Horse.
- Collaboration with the Avans, Fontys, Windesheim and Hogeschool Utrecht colleges. Avans and Fontys are working in the Fieldlab Flex Manufacturing and RAAK (G). Windesheim and Fontys work together in logistics (Living Lab Logistics).

We have several partnerships in Europe. The most important foreign cooperation:

- With KU Leuven (Belgium) with whom we have acquired the Paradigms 4.0 project on Industry 4.0 applications.
- With Sirris, Flanders Make and KU Leuven in which we collaborate intensively within the framework of FOKUS.
- With the TU Dortmund and Fraunhofer IML, a collaboration is set up in Logistics 4.0.

What is the external connection with government or top sector KIAs or with NWA routes?

The results of the program, error-free and productive work - more skills-intensive work - healthier work, is relevant for different target groups. Firstly, the program closes with flawless, productive work and organizes in the first instance the interests of operational, logistical and HR managers in (industrial) companies. Secondly, the insight and overview of the applications in the companies provide information for policy makers in the sectors (social partners) and in policy. The concepts Operator 4.0 and Smart Organizations are useful for all stakeholders. The insights for skills are specifically relevant to the further development of the Roadmap Smart Industry (NWA agenda) (among others 5.8 Human Technology Interaction). Human-machine interaction is central to the HTSM program. The program is further aligned with the 'Future of Work' plan that was programmed in the SZW Multi-Annual Program. The SZW program mainly focuses on the labor market consequences (polarization, higher skill requirements, inclusiveness) of new workplace and organizational concepts. The Smart Working program allows for skills-intensive workplaces to arise. This makes the program relevant for the Technology Pact, for the partnership between the Human Capital Tables of the top sectors (Life Long Development Initiative). TNO can acquire a directing role with the whole in the national (SER) and international (OECD) skills agenda.
The P207 program is mainly in line with the themes of the Top Sector Smart Industry (NWA route 20. Smart Industry) and to a certain extent of the Topsectors Logistics and LSH. For the Smart Industry top sector, it is important that we contribute to the Challenge "Strengthening Key Technologies - More advanced manufacturing systems and processes". We already have data on which parts of

the Smart Industry Roadmap are important (e.g. 5.8 Human Technology Interaction). The program provides knowledge for the themes Robotics and Big Data.
In addition to this core focus, the program also matches other societal challenges:

- Challenge III - Health and care: KIA "Longer, Healthier life"; Theme VWS "Prevention". This concerns the NWA routes 6. Health research, prevention and treatment, and 25. Big data.
- Challenge VI - Mobility and transport (Smart mobility): KIA Topsectors Logistics and HTSM; NWA routes 11. Logistics and transport (Logistics as an enabler). NWO-themed blockchain.
- Challenge VIII - Inclusive and innovative society. NWA route "16. On the way to resilient societies ".
- Challenge "Strengthening Key Technologies - ICT": KIA Top Sectors Logistics and HTSM. NWA routes 20. Smart Industry and 25. Value creation through responsible access and use of big data, themes Robotics and Big Data.

9.4 Dynamics

Developments in relation to plan 2018.
In the following table, the planned and realized project initiatives are stated. The actions for 2019 show which new project need to be finalized.

Project line Operator 4.0	***Project line Smart Organizations***
Realization 2018	
• Interreg project FOKUS • TKI Dinalog project • TKI HTSM Adaptive Manufacturing • H2020 DT-FoF-02-2018 Rossini • TKI LSH Hero 2/ LSH Skelex	• SBO Paradigms 4.0: in collaboration with KU Leuven and Antwerp Management School, look for solutions that help us understand what happens to skills in the new organizations and workplaces • H2020-Transformation01: build on this developed knowledge and develop a European knowledge position
To be realized 2019	
• RAAK Assembly 4.0: Design for Augmented Reality supported assembly • H2020 DT-ICT-07-2018-2019 - The human factor: human competences in synergy with technological progress	• SBIR Blockchain: in collaboration with University of Groningen to see what blockchain can bring to the skills issue (feasibility study). At TNO we have developed a roadmap for blockchain and organizational functions • NWO-TKI Living Logistics Lab: impact of far-reaching robotization, mechanization and digitization of warehouses and processes on skills, organizations, education, size and quality of employment • EASME Connected Automated Driving and Skills: for European

	Commission to determine which skills are needed for autonomous driving

What is the impact?
In the 2019 program, the course had already been chosen to focus more on the new project lines in 2018 (digitization and robotization). These options continue to form the core of the new long-term plan. In the new long-term plan we will continue to work in the Topsectors HTSM, Logistics, LSH. We remain committed to strengthening our European leading position in new European projects and initiatives to set up joint lab environments (Germany, Belgium).

10 VP Environmental Technology

Contact person TNO: Marinke Wijngaard
Contact person Government: Wim van der Meer, Bert van Haastrecht (HTSM. M2i)

10.1 Summary

The world population is growing, consumption and production are increasing. This results in climate change, deterioration of environmental quality (health, industrial safety and ecosystems), depletion of material resources.

The worldwide Paris agreement poses a greenhouse gas emission reduction target of 80% between 1990 and 2050. That requires an energy transition towards a CO_2 neutral society, which will affect all industrial and societal sectors. Notwithstanding the improved air quality in Europe, every year about 400.000 premature deaths are related to air pollution and more than 5% of the medical costs in The Netherlands is due to a bad quality of the environment; which results in a societal cost of 5-7 billion Euro each year. Environmental risks and chemical safety management are at the eve of a transition from decontamination and containment to prevention of risks and dangerous situations.

In addition, The Netherlands has the ambition to realize a circular economy in the year 2050 by means of sustainable circular chains in which materials are being reused completely and all the used energy is produced in a sustainable way. The intermediate goal for 2030 is to reuse 50% primary materials (mineral, fossil and metals). Given this goal The Netherlands is following the ambition level of comparable countries. Earlier TNO research concluded that encouraging circular product chains can lead to an extra added value of 7 billion Euro in 2025 and an additional 54.000 extra jobs in the coming five years.

TNO contributes to the solution of these issues one the one hand by improving the understanding of environmental problems and on the other hand by developing technological solutions. Enhanced measurement methods (from developing sensors to improved use of satellite data to the use of big data) and models (for instance the coupling of large scale models to local models to improve the insight in individual exposure) help to better understand the origin and causes of environmental pressures. This enables the development of better and more efficient techniques and measures. Most cheap and relatively easy measures are already implemented, what results are the more radical, complex and expensive options. We develop improved decision support tools, design circular chains and we rank new technologies and chain solutions on sustainable indicators. Also, we are developing new technologies for recycling of, to start with, plastics and building materials that have a sustainable contribution to the circular economy.

Program P512 Environmental Technology focuses on the development of new technologies for recycling of plastics and development of environmental sensors. The main results for 2019 are on circular plastics: the scale up of the recycling technology to TRL4 for two plastics and on environmental sensors: a pilot with a commercialised version of the SensAbox (=mobile air quality measurement).

This program is closely related and interacts with program P510 Environment and Sustainability and P515 Circular Economy and P504 Water technology.

10.2 Short description

Circular Plastics

One of the main challenges of the Circular Economy is to achieve a closed loop for oil-based plastics, which have a high economic importance, globally and for the Netherlands (that exports 75% of its production), and large environmental impacts in terms of waste (litter and plastic ocean soup), resource depletion, climate change and dispersion of toxic substances. Forecasts predict that the use of plastics will maintain to grow at rates higher than the economy. In the long-term plastics may be produced from renewable feedstock, from biomass and from captured carbon with the use of green electricity.

Nowadays, waste plastics are mostly incinerated, at best with energy recovery, deposited in landfills or recycled into low-grade materials and products (downcycling). The Dutch TransitieAgenda Kunststoffen, one of the five agendas in the “Nederland Circulair in 2050”, but also the roadmap of the TS Chemistry, acknowledges that innovation is needed notably in design, recycling and cross-chain collaboration.

TNO’s concept is to set up a Fieldlab Circular Plastics that combines multidisciplinary research on plastics regarding (1) new recycling technologies; (2) design of circular products; and (3) sustainability impacts and transitions. The focus of TNO’s Field Lab Circular plastics is chemical recycling of PE, PP and composites, viz. electronics plastics (6% of total plastic production), packaging (PE and PP being 25%) and engineering plastics and composites (part of automotive 9% and 19% of building & construction), in total in the order of 30% of plastic production. Assuming monostreams to be 50% of plastic waste, it means that potentially 15% of Dutch production or 80 PJ of crude oil and 6 Mton of CO_2 can be avoided by full deployment of chemical recycling technology or alternative design of the products on the long term. It should be noted that composites (thermosets, thermoplastics) are being researched in P515.

Development of new environmental sensors

Mitigating climate change and improving the quality of environment with associated health, safety and ecological issues requires informed decision making with ‘ex ante’ and ‘ex post’ evaluation. This also entails the evaluation of transition scenarios on environmental effects. The objective of TNO is to facilitate this with the development of decision support systems for governments, companies and citizens. These decision support systems combine measurements from sensors, satellites and model and simulation tools. The development of the model platforms takes place in program VP Environment and Sustainability (P510). In this program VP Environmental Technology (P512), the focus is on the development of new environmental sensors that are required for these platforms.

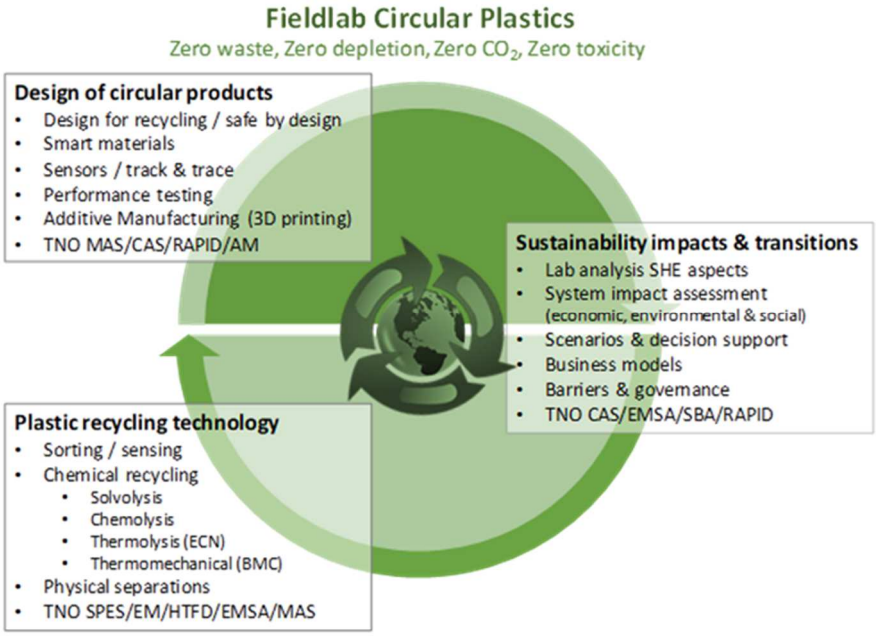
The presence of polluting species in air is considered as a major reason for people’s health in occupational and urban environments. The top of the regulation list of polluting species is dominated by particulate matter (PM), such as black carbon, crystalline silica, wood dust, etc. Three parameters determine the toxicity of PM: 1) size; 2) shape; and 3) chemistry. All these parameters should be assessed to fully characterize the health effect of inhaled particles. Many solutions exist that assess the size of air-borne particles. However, particle shape (spherical or fibrous) and especially chemistry is currently lacking in all particle sensor solutions. TNO is combining smart particle sizing solutions with an approach to assess the shape of these particles, based on a combination of smart flow channels and electronic detection. This opens the route towards the recognition of fibrous particles, such as asbestos, glass or stone fibres, nanotubes, or polymer fibres. This detection of

fibrous particles is not only relevant for air quality assessment but may also be introduced in recycling processes for composites, in which glass or carbon fibres are processed. Part of this work is done in this program in close interaction with the Early Research Program (ERP) “Exposense”.

We target specifically on the development of low cost wearable particulate matter and benzene sensors, as well as methods for on-line validation and calibration of sensor data (SenSa platform).

10.3 Results 2019

Circular Plastics
In 2018, TNO started the research on circular plastics. TNO explored a recycling technique for different types of plastics based on solvolysis. The process has the potential to recycle currently untreatable plastic waste streams and reduce energy use compared to existing solvent-based recycling routes. The impact assessment started in 2018 will be further developed in 2019 and next to recycling the current waste streams, also alternative product design will be involved to improve high value circularity on the longer term.



Results expected for 2019 in the program P512 are:

- Scale up of recycling technology Moebius from 0.1 version to 1.0 version (TRL 3 to TRL 4) for 2 types of plastics that nowadays are difficult to recycle based on composition, such as derived from waste electronic and electrical equipment.
- Development of sensors for offline or inline measuring and detecting of critical process factors.
- Development of alternative (material) design options for WEEE and multilayer packaging products which facilitate circularity (i.e. avoiding the loss and mixing of polymers and pigments, use of toxic flame retardants and irreversible glues).
- Socio-economic and environmental assessment method applied for the recycling technology compared to state-of-the-art waste processing routes as

well as alternative product designs for selected key materials and products in the chosen categories (WEEE plastics and multilayer packaging plastics).
- Medium and long-term scenario study on production and recycling of plastics in the Netherlands.

External connections:
- In 2018 a string of external connections with industry and research partners have been built in the framework of the NWA routes Circular Economy and Measuring and Detecting as well as TS Chemie, strongly connected to the program “NI Circulair in 2050”. We expect this will result in a joint NWA proposal on circular plastics and textile as well as joint proposal for the NWO crossover call on Circular Society. Here we work closely together with NRK, NWA Measuring and Detecting, TI Coast, TS HTSM (composites), universities, WUR/FBR, RIVM and Hogescholen. Part of this network has already been assembled in the granted proposal NWA Startimpuls 2 Circular Plastics and will be expanded in 2019, notably to better include socio-economic research for business models.
- HORIZON 2020 calls: connection with Fraunhofer ICT, GAIKER, Industry, SMEs.

Development of new environmental sensors
For 2018 we targeted the development of low cost wearable benzene and particulate matter sensors, as well as methods for on-line validation and calibration of sensor data – thus continuing the research from the previous strategy period.
As for 2019, following results will be expected:
- Further miniaturisation and cost reduction of the benzene sensor, based on the formation of a fluorescent exciplex.
- Exploration of the possibility of extending the benzene sensor technology for other gases relevant for exposure on the workplace.
- Developing a robust and sensitive platform for detection of gaseous compounds based on PAS (photoacoustic spectroscopy) and quantum cascade lasers.
- A business case for the SensA platform (mobile measurement networks, data analytics and interpretation).
- Translating results from the modelling to a design of a virtual impactor (i.e. a complex system of flow channels separating particles according to size, mass and shape, optimized for fibres). A demonstrator will be built to show the proof of- concept of the selective detection of fibres in air.
- A theoretical study to assess the possibility for the implementation of a fibre sensor in composite recycling to determine the amount and/or orientation of fibres in polymer composites.

A pilot with a commercialised version of the SensAbox (=mobile air quality measurement). Together with a business partner, a commercial version will be launched. TNO will guide and guarantee the quality of the measurement by confirming measured values.

External connections:
- In 2018 the collaboration with TI Coast scientific and industrial community on sensor development has been formalized and will be expanded in 2019 in joint projects, e.g. NWA or NWO calls.
- TNO actively participates in Horizon 2020 calls with industrial partners and research partners.

10.4 Dynamics

The TNO unit Circular Economy and Environment (CEE) started at January 1st, 2018, giving an extra boost to the research on circular economy. Also, during 2018 an additional new program P 515 Circular Economy started. This program is still under development and the alignment between that program and this VP will be further elaborated in the coming period.

There is significant turbulence within the field of Circular Economy. There are a lot of actors, that have no clear position in the arena. Also, we see a lot of initiatives on several TRL levels, of which it is not clear how and if these initiatives will start, as there are:

- Follow up of the Transition Agendas (IenW)
- Accelerator house (VNO-NCW, IenW)
- Follow up on the Climate Tables (EZK)
- NWA-calls
- NWO cross over call
- Region deals
- Regional initiatives (e.g. Gelderland, Brabant, Zeeland, Limburg)
- TKI's (tenders)
- European projects and preparation of FP9

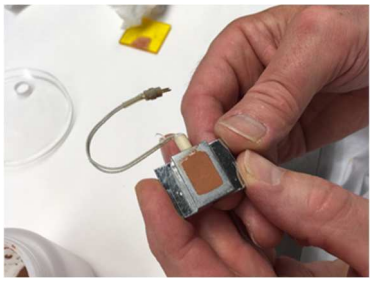
To be prepared in this not-yet mature field TNO choses to anchor in several consortia and collaborations and to develop a common vision to decide which initiative to join.

Circular economy in the Built Environment
In 2019 we discontinue the activities on Built Environment in this VP, they will continue in P510 and other programs. The primary reason is bringing more focus and cohesion between the various VPs in the unit CEE. To compensate for these activities we have enlarged the activities for Circular Plastics.

11 VP HTSM-Bouw Innovatie

Contact person TNO: Peter Paul van ‘t Veen, Henk Miedema
Contact person Topsector HTSM: Bert van Haastrecht (m2i)

11.1 Summary



Preparation for in situ XRD monitoring over time of reaction products, at different temperature and humidity

Sustainability and cost reduction in construction require reduction of the quantity of building materials used, replacement of raw materials through re-use and use of waste streams and bio-materials, increase of service life through better understanding of degradation at the material level and adaptation/addition of functionalities. The main role for TNO in this area is to predict and improve the performance of key materials through analytical techniques and advanced modelling, with a focus on cementitious materials and asphalt.
In *cementitious materials* we focus on fundamental understanding in order to predict the performance of existing as well as new materials, with application ranging from monuments to building with secondary materials. By understanding, for instance, the formation of silico-aluminate chain building blocks that make up our future concrete, the (long term) performance of building materials with new aggregates and binders can be better predicted. We develop a methodology (blend tool) with which aluminosilicate side streams can be characterized and blended to alternative binder products for concrete, with required performance and service life but higher sustainability and lower cost. This requires measurement techniques and models for describing reaction processes in alternative binders, the reaction products and their stability. The latter is crucial with respect to degradation and the design of accelerated ageing tests. After clarification of the role of activators on the dissolution of the new binders in 2018, in 2019 the focus of the research will be on the condensation mechanism. Experiments and simulations of reaction processes will be used to develop a model for predicting precipitation products and rates. On the basis of this, the blend tool developed in 2018 for dissolution will be extended by including the hardening process.
For *asphalt* we develop models for predicting material performance that take into account material ageing as well as various fatigue loading regimes over time. These models will be validated using monitoring data. The models can be used to forecast maintenance needs of existing materials and to predict the performance in pavements of innovative (more sustainable) materials. This requires a better understanding of ageing phenomena in surface layers, taking into account the use of recycled materials and application of rejuvenation techniques as well as mechanical models for translating changes in the behavior of materials to structural

performance of pavements. The step to be made in 2019 is integration of relaxation ability into the materials models, as this property is expected to be key in the development of damage in pavements. In addition, experiments on stress, strain and relaxation in asphalt will be used to calibrate the mechanical models.

11.2 Short description

Sustainability and cost reduction in construction require reduction of the quantity of building materials used, replacement of raw materials through re-use and use of waste streams and bio-materials, increase of service life through better understanding of degradation at the material level and adaptation/addition of functionalities. The main role for TNO in this area is to predict and improve the performance of key materials through analytical techniques and advanced modelling, with a focus on concrete and asphalt.
Portland cement in *cementitious materials* needs to be further replaced to reduce CO_2 emissions. By-products from the power plants (fly ash) and steel industry (blast furnace slag) are currently used to partly replace Portland cement. Other types of by-products will have to replace these side streams from non-circular processes. Many other aluminosilicate side streams (e.g. bottom ash from municipal waste incinerators, fly/bottom ashes from biomass power plants, certain types of construction and demolition waste, waste from brick factories and inorganic waste sludges from the paper recycling industry) are available. Our ambition is to make a generic blend tool for (earth-alkali) aluminosilicate side streams with which a binder can be obtained with required performance, but with a higher sustainability and lower cost. This requires measurement techniques and models for describing reaction processes in alternative binders, the reaction products and their stability. The latter is crucial with respect to degradation and the design of accelerated ageing tests. Challenging in all these steps is that both input materials and products are mainly amorphous and chemically consisting of the same elements as well as that dissolution and precipitation (condensation) simultaneously take place during hardening of the binder. Since both dissolution and precipitation can be the rate-limiting step in the hardening process, both need to be stimulated in a different way to be able to obtain a strong material within the 24-48 hours usually demanded in the building process.
Asphalt binders are derivatives of the crude oil distillation process. They are susceptible to oxidative and physical ageing. These phenomena increase stiffness and reduce flexibility, making the asphalt more prone to damage under fatigue straining due to traffic loading and thermal cycles. On the Dutch highways nearly all (>95%) surface layers are composed of porous asphalt with void content of more than 20%. This high void content is key in reducing noise, but it comes at the cost of a higher propensity to ageing due to the larger surface contact area with air. In order to build models that are able to predict future performance of existing and innovative materials, such as road surface materials using bio-based or highly polymer modified binders, it is essential to know how materials age. A number of factors contribute to aging of asphalt and pavement, varying from traffic loads to stresses caused by daily temperature variation and impact of water. The most critical load combinations will be formulated to be able to assess the performance of an asphalt material. By having insight in how and when damage develops we are able to develop tools to assist road owners, contractors and raw material suppliers to increase the overall performance of surface layer materials and reduce maintenance and societal costs. The main subject is the development of a material performance model that takes into account the material ageing, and its validation using monitoring data. The model can be used to forecast maintenance needs of existing materials and for assessing the expected performance of innovative

materials which might increase service life or reduce the CO_2 footprint. The obtained insights in ageing phenomena will also help to assess the performance of recycled and rejuvenated material. Oxidative ageing forms an essential element of ageing. In 2018 we have obtained much relevant insight on this aspect. In 2019 we hope to expand our insights into relaxation.

11.3 Results 2019

In 2017 and 2018, focus for *cementitious materials* was on dissolution and insight was gained on how to steer the composition of the solution of the dissolved precursors. In addition, this composition needs to be such that the right products are formed at a specific rate. Focus for 2019 is therefore on the role of additives/blending on precipitation and how to steer this part of the binding process. The precipitation rate depends to first order on the cation type and concentration but also the anion type, and concentrations in the solution are important since these may prohibit the cation influence on the precipitation. Unravelling these effects is targeted at the following deliverables for 2019:

D1. Model for prediction of precipitation rates. For this, a desk study is executed to develop a (empirical, mechanistic) model with which the precipitation products and rates can be predicted. On the basis of this, the blend tool developed in 2018 for dissolution will be further expanded to include both dissolution and precipitation steps of the hardening process.

D2. Dissolution - Precipitation test method. To be able to investigate cation- anion effects on precipitation (rate), the dissolution set up developed in 2018 will be extended so that it can be used for precipitation. A key design feature is that the method separates dissolution and precipitation.

D3. Experimental results validating the effect of cations and anions on the precipitation rate as predicted in D1, using the newly developed dissolution-precipitation test method (D2). The reaction products will be characterized in terms of water content, chemical composition, stoichiometry and strength.

D4. Real precursor test results relating precipitate composition and strength/performance followed by optimization of the rate and type of precipitates based on the principles learned from D1 and D3.

D5 Masterclass alternative binders. A masterclass will be developed and given for TNO material scientists and experts in related fields, to exchange knowledge on sustainable and durable binders developed in this program.

The above research will give necessary information for developing optimized binder systems that are cheap, sustainable as well as durable. Also, this will give the solid basis for solving questions on the durability and adjustment of accelerated test methods for geopolymer materials.

Producers of concrete and suppliers of bottom ashes and other secondary resources are interested in the above developments, as currently costly and less sustainable sodium-hydroxide based activators are used in new binder systems and durability is still uncertain. Moreover, provinces and cities are interested because of their ambitions regarding their CO_2 footprint and circularity. TNO and Delft University of Technology together with M2i have taken the initiative to bring those parties together to accelerate the development of concrete mixtures which not only

fulfill the CO_2 and circularity ambitions, but also the required durability performances. In addition M2i, TNO and Signify have taken the initiative to develop a NWO proposal addressing among others aging and circularity issues with respect to concrete.

In 2019 we will incorporate relaxation behavior in our *asphalt* model and improve our insights into its role in damage development. In order to do this our model needs to be able to combine the effect of ageing as well as the effect of various loads over time. This requires that mechanical models are combined with the ageing effects into a single method or model. The first step is to see how the two material aspects can be integrated and what the consequences are of such an integration. Secondly, experimental tests and data from practice will be used to evaluate whether the combined model has predictive power. Verification and validation of the model can only be achieved in close collaboration with the sector: road owners (RWS), universities (Delft and Twente), contractors and raw material suppliers. TNO's strong involvement with the currently running Asfalt Impuls initiative or Rijkswaterstaat provides an excellent position to reach this goal.

Our research on concrete and asphalt fits in the HTM Roadmap of the Topsector HTSM as well as in the Bouwagenda. The concrete research will be important for realizing the targets of the Betonakkoord.

11.4 Dynamics

Cementitious materials.
In 2017, first steps were made for better understanding reaction processes by evaluating and setting up a complete set of characterization methods. It was found that the state-of-the-art in activation is still on the level of trial-and-error and high dosages of sodium hydroxide are used, a material that is neither sustainable nor cheap and leads to uncertain durability. Therefore, in 2018, it was decided to first gain more fundamental insight in the reaction processes during activation, which involves simultaneous dissolution and precipitation. More specifically, in 2018, the role of the activation on the dissolution rate of the secondary binders has been investigated. Based on dissolution simulations and first activation tests using real precursors, very effective activator – precursor combinations were found for which dissolution was drastically improved without having to rely on the high dosages of non-sustainable activators, mainly attributed to the efficiency of the combination of precursor-activator to produce OH^--ions. Based on preliminary sol-gel experiments it was concluded that aluminum plays a network forming role similar to silica and that calcium determines the amount and rate of precipitates formed. Also, a new experimental dissolution set-up avoiding simultaneous precipitation is developed, which will form the basis for a dissolution-precipitation method in which both dissolution and precipitation (rates) can be measured separately. This research has led to the understanding of the dissolution part of the activation system and gives the basis for studying the precipitation part of activation in 2019 as well a preliminary blend tool required to develop optimized binder systems that are cheap, sustainable as well as durable.

Asphalt.
One goal in 2018 was to develop an additive that would retard oxidative ageing of asphalt. This concept has been successfully applied in other materials, e.g. plastics. However through experiments we discovered that the effect of these additives on oxidation of bitumen is very limited, while the retardant has a negative effect on other bitumen properties. It is hypothesized that the limited effect is caused by the

fact that bitumen is a very mobile material in which it is hard to inhibit oxidation of specific groups. Therefore the development of oxidation inhibitors is no longer pursued. On the other hand it became clear that relaxation is an important phenomenon while our models did not capture long term relaxation behavior. Therefore it was decided to focus on adding this aspect to the models.

12 VP Intensivering Smart Industry

Contact person TNO: Rogier Verberk, Erik Fritz

12.1 Summary

The long term TNO objective is derived from the Smart Industry initiative and is defined as follows:

The Netherlands have in 2021 the most flexible and the best digitally connected production network of Europe for the design, production and supply of smart products and associated services, with which the design and manufacturing companies involved also achieve substantial energy and material savings in production and longevity and employees continuously (able to) maintain their (digital) knowledge and skills

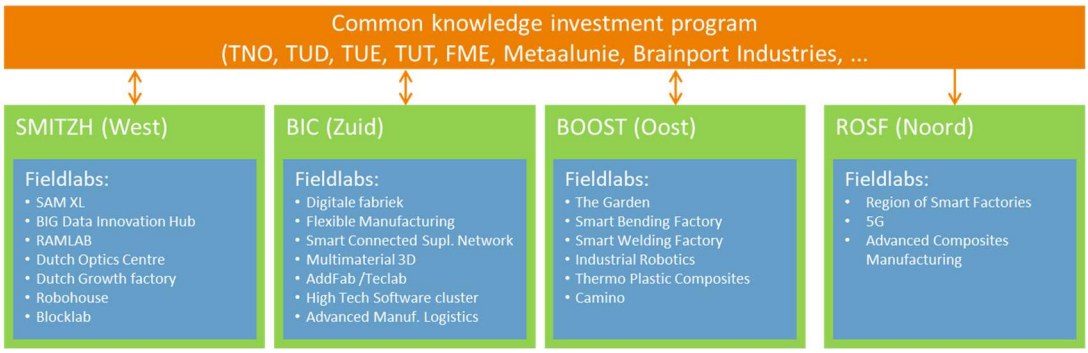
TNO worked together with multiple stakeholders to define the national agenda and mobilize partners and budgets. In the current phase of execution of this agenda, most of TNO's activities are part of the Smart Industry Fieldlabs. In such Fieldlabs parties along the value chain work together on defined topics, to stimulate knowledge transfer and alignment of ambitions. TNO's activities are concentrated in a few Fieldlabs, and on areas of expertise in line with TNO's experience:

- Flexible Manufacturing
- Digital Twinning
- Data Sharing
- Smart Work
- Smart Response

TNO aims to have achieved by the end of 2019:

- At least 3 integrations projects in BIC and SMITZH field labs on flexible manufacturing, digital twinning and data sharing.
- Setup design and architecture for TNO's open innovation model to support the manufacturing industry. Together with 3 companies and supporting European and International development of standards.
- Significant step in building the infrastructure on BIC and SMITH including Data value Center with partners.

To boost the synergy of Smart Industry initiatives in the Netherlands, to come to a quality of international standards, and to attract more private funding, TNO envisions a National alignment of the knowledge investment agenda (budget in order of 100 Meuro) with the other knowledge institutes and representatives of the industry. The Fieldlabs and regional Fieldlab Hubs will remain the executing environments.



From 2019 the Industrial Instrumentation part of the Semiconductor VP (P612) will be incorporated with this VP. This budget is used for co-funding running projects meeting the goals as described above.

12.2 Short description

TNO will concentrate on 5 propositions (product market combinations).

1. Flexible Manufacturing: focuses on the development of smart robotics, additive manufacturing, sensors, software, work cells and production network that enable fully flexible, highly automated and error-free production. Single-piece production at a cost price of mass production with zero-defect, -delay and -waste.

2. Digital twinning: digital representations of the product, production process and use phase. It is being investigated how this can be done across multiple companies. In a digital environment the product and production process is tested. In the final physical production and use, process measurements are taken to make the digital models robust; the digital twin. This makes it possible to start production quickly and flexibly without loss of time in programming or production of molds.

3. Sharing data: research into the safe and robust sharing of data between companies in the value chain on the basis of the international open source IDS (Industrial Data Space) as a software bus over a digitally connected production network including its upcoming expansion with blockhouse applications. Leading in these developments are new supply chain partnerships, new data-driven business models and AI (artificial intelligence) projects.

4. Smart Work: research and experimental setups aimed at getting employees more quickly and permanently (re) employable. This includes creating productive and instructive work environments through human-oriented technology such as augmented reality, cobots and utilization of machine learning, sensors / feedback, big data, and artificial intelligence, in full alignment with smart response program.

5. Smart Response: research into the social and economic effects of the disruptive changes due to Smart Industry, such as changes in the labor market and required skills, and how these can be used to the full as a society.

Goal is to combine and line up research activities with the universities and Sector organizations by defining a stable 5 year program. The ambition is to setup a program with a volume in the order of 100 Meuro, to reach in selected topic world leading knowhow, and attract more private commitment. (Target is roughly 25%

Private, 50% Public, 25% TNO/TU's. The Danish MADE program is an inspiring example in this context.) Steps to be taken are:

- Coordination on national level with leading knowledge institutes, which will lead to international impact.
- Be advised by Metaalunie, Brainport and FME, and have them mobilize companies.
- Define "Man on the Moon" ambitions for each program.
- TNO selects programs with highest ambitions to really make a difference, especially in the digital domain (e.g. Smart supplier network).

12.3 Results 2019

The national Smart Industry program was started in 2014 by EZK, FME, VNO, KvK and TNO. In February 2018 the Implementation Agenda Smart Industry (*) was handed over to the State Secretary. TNO is leading in a consortium of 10 universities and universities of applied sciences in drawing up the Smart Industry (NWA) Roadmap and the subsequent Smart Industry 2.0 Roadmap (Topsector HTSM and ICT).
This intensification proposal is an important additional element in the Smart Industry program 2018-2021. Leading department: EZK-B & I. Participants EZK-ICT and SZW (in relation to Smart Work and Smart Response). Topsectors: HTSM and ICT.

Within the Smart Industry initiative, TNO wants to set up concrete pilot lines, based on an independent role and knowledge position. The latter means a 'plug-in and produce' (equipment & ICT) infrastructure for commercial robots, 3D printers, machining, assembly, and measuring and inspection stations, camera systems, conveyor belts, AGVs and design, simulation and control software. Open source/TNO software ensures that new products and production units can be connected and benchmarked for productivity. Brainport and Zuid-Holland have now structurally made funds available for two initiatives with a large-scale Fieldlab with the commitment of companies; Brainport Industries Campus (BIC) innovation program (24M, 50% private) and Smart Manufacturing Zuid-Holland (SMITZH, 40M, 50% private). With this plan TNO connects to these two initiatives.

On high level the following deliverables are defined for 2019:

- At least 3 integrations projects BIC and SMITZH Fieldlabs on flexible manufacturing, digital, twinning en data sharing.
- Setup design and architecture of TNO's "Imec" model for the manufacturing industry with 3 companies, supporting European and International development of standards. This is including strategic study of the positioning of Smart Industry NL in the international context and expected developments.
- Significant step in building the infrastructure on BIC and SMITH including Data value Center with partners.

The following deliverables are defined for the 5 product market combinations:

1. **Flexible manufacturing**

    - 0-programming multiple robots
        - Development of 0-programming approach and evaluation in 3D simulation environment.
        - Realization of a research setup with several robots (first 2 and then 3).
        - Demonstration of the 0-programming approach on robot setup (first with 2 and then with 3).
        - Presentation, dissemination and the like of the achieved results.

    - [negotiations with external parties about the transfer/rollout of 0-programming propositions to the manufacturing industry].
- Industrial quality control
    - Development of industrial control strategy as a generic approach and toolbox for Smart Industry Flexible Manufacturing applications (0-defect) [This is continuation of the KIP 5b process of 2018.].
    - Identify and elaborate concrete cases for Industrial Quality control, such as production processes, production lines, assembly lines. This is really about closing an in-line control loop, based on real-time quality measurements, and with active intervention in the line/process.
    - Synthesis, and demonstration of Industrial Quality Control cases in simulation environment.
    - Cooperation proposal with Smart Industry manufacturing companies, SW development partners, etc. to implement the Industrial Quality Control approach in Fieldlab setting in a (number of) industrial application(s). First options seem to be BIC Manufacturing Pilot Line, and CADC.
    - Inventory of in-line Quality sensing needs and sensor solutions, to develop the existing strength of industrial instrumentation. It should be clear at the beginning that feedback and intervention/correction is possible, and that there is a clear industrial need and product-market combination.
    - Presentation, dissemination and the like of the achieved results.
- Advanced Operator Support
    - TBD: in connection with the Smart Work main line. It is likely that we will have to continue to invest strategically in additional knowledge areas such as those present at Opto-mechatronics and ICT, in order to develop the main line outlined by Smart Work to full potential. For that with first such a main line being covered by Sustainable Productivity.
- Broadening the Flexible Manufacturing product-market combination
    - Reconfiguration/Self-learning assembly lines: exploring TNO position on this topic. Research on state-of-the-art, missing technology and so on. Reconfiguration and self-learning have long been mentioned as a strong wish from the manufacturing industry for small series. Apart from general theory, there is still no usable industrial approach or solution in view. The question is whether TNO can contribute to this.
    - Impact analysis of new manufacturing technologies and design methodologies on flexible manufacturing. What opportunities do developments in manufacturing technology offer, such as Additive Manufacturing (AM), Digital Twin, Design Optimization, new materials etc. for the issues in Flexible Manufacturing? E.g., an advantage of AM is that integrated products are possible. This leads to fewer parts, less assembly, less logistical flow and critical connections. Does this really add something to Flexible Manufacturing? Can modern design techniques be used for Design for Flexibility? In other words, can we already take small series into account when designing?
- Impact development Flexible Manufacturing
    - Continuation of the KIP 5b 2018 process, in order to continuously keep in touch with the needs of manufacturing companies, technology developments, providers of Smart Industry services/solutions.

2. Digital Twinning

- Deliverable for 2018 is a knowledge development plan. Based on this plan de deliverables for 2019 will be determined. At this moment this plan is still under development.

3. Data Sharing

- Expansion of the Industrial Data Space test bed realized in 2018.
- Embedding on the Brainport Industries Campus.
- Expansion with blockchain functionality. Applications concern the sharing of PLM information in the chain, for example on the basis of risk management in supply chains and maintenance ('digital footprint' of products).
- Expansion of the Smart Connected Supplier Network with functionalities for sharing machine information, so that, in addition to logistic data, process and production data can be shared, including for maintenance and OEE improvements.
- Developing a vision on the application of AI within the context of Smart Industry, including for zero-defect/first time right. Concepts include edge computing/holonic manufacturing systems.

4. Smart Work

- Operator 4.0 Support products
  - Assessment tool for technology choice based on task and product characteristics and operator characteristics.
  - Cost/benefit (benchmark) tool to underpin an investment decision.
  - Guidelines and standardization visualizations.
- Remaining
  - Building objective data sets effects operator support.
  - Best practices with success/failure factors.
  - Adaptivity model and algorithm for adaptive operator support systems.

5. Smart Response

- Deliverable to be defined to be in line with EU project Rodin (Robotics).
- Deliverable to be defined to be in line with EU project NextNet (Digital Innovation Hub network EU).

12.4 Dynamics

The Fraunhofer Gesellschaft is very active in the field of Industrial Data Space. Potentially, its software platform could become an important platform for all of Europe, or even a new standard. TNO will intensify the collaboration throughout 2018 and 2019 to align developments in Germany and the Netherlands.

13 VP ESI

Contact person TNO: Henk-Jan Vink (Managing Director ICT), Frans Beenker (VP Manager)
Contact person Government: HTSM Embedded Systems/Brit Meier

13.1 Summary

The universal application of embedded systems technology in all segments of industry and society continuously creates challenging new opportunities for the Dutch high-tech industry. New industrial products are brought to the market with high speed, enhanced functionality and better cost performance ratio. These products represent a key element of the competitive position of our high-tech industry.

A rapidly growing fraction of product innovation is implemented in embedded systems which offers an unlimited number of new functionalities to be offered. These embedded systems have an increasing impact on key system qualities such as safety, reliability and performance. The consequence of the combination of competitive position and technology is that the complexity of such high-tech systems grows steeply. This ever increasing complexity requires a fundamental basis of embedded systems engineering that improves the efficiency, effectiveness, quality and costs of the architecting and design processes of high-tech systems, and the qualified workforce. This requires special attention to be paid to system engineering methodologies, especially those addressing the following aspects of system architecting and design:

- **Multidisciplinary architecting and engineering.** Although the engineering of complex high-tech systems relies on fundamentals developed in computer science, physics, mathematics, mechanical engineering and electrical engineering, the essence of system engineering is in addressing the heterogeneity and multi-disciplinary aspects of product architecting and engineering.
- **Efficient and effective product innovation process.** There is a significant need to improve on the efficiency, effectiveness, quality and costs of the product innovation process. Emerging techniques for product design have a strong formal basis, involving modelling, analysis, virtualization and simulation to achieve the desired results. Hence, there is a major trend towards model-driven system design and engineering based on mathematical fundaments.
- **Life-cycle context.** There is an increased interaction between the supplier and user of high-tech systems. Requirements changes have to be accommodated quickly and the integration in a, often ill-defined, customer operating environment and workflow is critical. On the other hand, it provides a business opportunity of service and regular product upgrades. This requires new techniques for product design that position product design in a life-cycle context.
- **Human capital development**. A systematic investment in a life-long learning program for education and training of embedded system architects.

These aspects support the high-tech industry in their shift from offering stand-alone systems as catalogue items to selling complete integrated value propositions over the life-cycle of their systems and address the main trends that are driving the

complexity of high-tech systems. Together, they represent the focus areas of the TNO-ESI Research Program for 2019 - 2022.

The target result of ESI is in driving advances in high-tech systems technology by [1)] creating impactful and industrially applicable architecting and design methodologies and [2)] providing innovation support to high-tech industry with industrially supported tools, knowledge- and experience-sharing activities and a focused competence development program. Details of the targeted 2019 results can be found in the following section.

13.2 Short description

The overall mission of the ESI program is to keep up and improve the competitiveness of the Dutch/European High Tech industry by addressing the challenge of mastering architecting and design of ever increasing complex systems through new and radically improved systems/software design and engineering methods.

It is of utmost importance that new knowledge is not only generated for individual products or applications, but that opportunities for synergy, knowledge sharing and knowledge exchange are fostered.

For successful innovation and value take-up by the ecosystem, it is essential that systematic attention is given to all required elements of the knowledge chain. ESI follows a process, with each step adding value and depth to the previous step:

1. *Agenda and programming:* translation of industrial knowledge needs into a Research Agenda and Roadmap.
2. *Applied research*: research projects based on strategic research questions from industry with a close cooperation with both industry and academic groups.
3. *Consolidation*: development of a sustainable knowledge base for general use.
4. *Dissemination*: presenting, sharing, discussing, demonstrating knowledge through network activities, seminars, workshops, publications, etc.
5. *Competence Development*: training of professional competences.

The 2019-2022 ESI key program lines are as follows:

1. **System Performance:** every system has its own, often contradictory, key performance indicators (KPIs). For example, in the printer market, pages/minute must be balanced against print quality; in semiconductor manufacturing it is the yield of good dies per wafer and the number of wafers/hour. Every system must meet or exceed, and also balance, these ever more demanding key performance indicators.
2. **System quality and dependability**: when making significant investment in a new high-tech system, customers want to be assured that it will perform effectively throughout its lifetime, delivering cost benefits in the longer term and reducing the total cost of ownership. This requires a high system quality, including verification and validation tailored to these changing requirement dynamics, to ensure that it will continue to operate without requiring overly frequent maintenance.
3. **System evolvability:** systems designed to address today's needs need to be able to continue to meet customer's changing future needs. Customer demands, processes and technologies are changing rapidly, and installed systems need to be ready for upgrades and updates to meet new and changing requirements.

4. **Exploiting System Context:** customers no longer want a system, but a solution to their challenge that exploits the context it operates in. This solution is increasingly characterized by the combined availability of data, knowledge and expertise about the system and its context. Being a solution provider means delivering a service, rather than a system – expanding the role of high-tech companies from system developer to solution provider understanding the idiosyncrasies of the context.
5. **System Architecting:** getting system design right from the start becomes ever more critical. System Architecting addresses this challenge by helping customers to translate market, product, and technology choices into system concepts.

13.3 Results 2019

The expected ESI results 2019 are aligned with the ESI knowledge chain:

1. *Agenda and programming:*
    a. *Trends versus program:* we continuously align the high-tech industry trends and the ESI knowledge areas and translate our Roadmap to long-term research programs with our industrial partners.

       Target 2019:
       - Update of the Ecsel Strategic Research Agenda.

    b. *Academic research*: we are in the process of defining an NWO partnership program (called Mascot) on the topic of “managing complexity” with a tight coupling to our research program with our industrial partners.

       Target 2019:
       - NOW TTW Mascot call in Autumn 2018.
       - Start of four academic research projects aligned with Dutch high-tech industry 2019.

    c. *Internationalization*: we expand our international horizon with strengthening our relationship with Fraunhofer IESE (Kaiserlautern) and building up a strong relationship with the System Engineering Research Center (SERC) in the USA.

       Example targets 2019:
       - Joint publication of analysis results of current status system engineering practices Dutch high-tech industry as compared to US high-tech industry.
       - Two joint IESE/ESI workshops with German/Dutch high-tech industry on selected and industrially relevant topics.

2. *Applied research*
   All ESI research projects are executed as public-private partnerships with a serious investment of the industrial partner. Also, all research projects are executed at industry location in an ‘industry-as-lab’ setting. This direct collaboration between industry and ESI gives a much better insight, understanding and appreciation of the industrial challenges. It allows the research findings to be directly validated by application to realistic industrial cases. In other words, valorization is pre-built into the process.
    a. *International research:*

Initiate and take the lead in proposals for international research. In particular this holds for Itea and Ecsel calls.

Target 2019:
- Initiate and develop Itea project proposal for facilitating new customer services for high-tech systems. Participating Dutch company: Océ.
- Depending on the Ecsel review, we start a new project on verification and validation of ai-based systems and to participate in new proposals for the 2019 call. Participating Dutch companies: Océ, Philips Healthcare, ASML, Thales.

Finish a few international research projects:
- Several earlier initiatives will be finished (Reflexion - an ITEA project with participation of Océ and Philips Healthcare), and Enable-S3 – an Ecsel project with contribution of Philips Healthcare.

Start a recently assigned international research project:
- Start a recently granted project for period of 3 years (Secredas – an Ecsel project with participation of NXP and Thales, on the topic of system security). Target 2019: white-paper on system security architectural issues in high-tech industry.

b. *National research*
Create and execute a research portfolio with Dutch high-tech companies: ASML, DAF Trucks, TFS/FEI, Océ, Philips Healthcare, Thales. We are planning to expand our industrial research network with e.g. Vanderlande and VDL ETG.

Target 2019:
Create both results and impact with new methodologies for high-tech industry in all program lines of ESI.

Example of targeted results:
- Model-based system architecting methods and tools at Océ, ASML, DAF.
- Component interface management and run-time checking at Philips, TFS and Thales.
- Run-time diagnostics and performance optimization at ASML, Océ and Thales.
- Software legacy and SW architecting methods and tools at Philips, TFS and ASML.

c. *Academic research:*
Initiate academic NWO-TTW proposals with our academic partners where possible coupled to our industrial research program and the Mascot partnership.

3. *Consolidation*:
Development and consolidation of a knowledge base for general use.

Target 2019:
- Development of professional managed-open source versions of three ESI tools and align with potential tool partners for industrial support. Tool partners are Obeo (France), Altran NL (for tool support, tool integration, tool

services) and local tool partners. The three tools are: simulation (POOSL/Trace), model-based system architecting (Design Framework), and module-interface management (ComMA).

4. *Dissemination*:
   Create access to ESI knowledge and expertise and to share experiences amongst peers.

   Target 2019:
   - Presenting, sharing, discussing, demonstrating knowledge through network activities, seminars, workshops, publications, and special interest groups. 30 ESI papers and/or conference contributions.
   - Exploit the added value of the large ESI network for exchanging experiences and insights for various target groups. Facilitating 6 different peer groups/special interest groups that each meet 2 or 3 times a year.
   - ESI symposium on April 9th, 2019. Target number of attendees: 400.
   - Transfer ESI knowledge to SW service providers for applying our results in the high-tech industry daily practices. Target providers: Altran, Sioux, ICT+.

5. *Competence Development*:
   Development of required competences at high-tech industry and align ESI research program lines with new competence development offering.

   Target 2019:
   - Creating a number of new courses and course offerings/working approach specific for our target groups. Target courses: SW legacy, module interfacing.
   - Move courses on model-based system architecting and domain specific languages from pilot phase to exploitation phase.
   - Execute and manage a competence development program for training of professional competences. Involved Dutch companies: Philips Healthcare, Signify (former Philips Lighting), NXP, Océ, TFS, ASML.
   - Specify and tune our offering and approach for various target groups (e.g. senior management, department management, system architects, domain architects, engineers, academics).
   - Optimize on learning strategies by combining our research projects, networking activities, and competence development programs.

13.4 Dynamics

The ESI program has a stable foundation and is characterized by activities and commitments that extend over multiple years. The long-term direction is in-line with the HTSM Embedded Systems Roadmap that obtains an update every two to three years The short-term (yearly) priorities are discussed and set with the ESI Partner Board, consisting of senior representatives from academia and industry. This board has responsibility for overall strategic direction and value proposition, including supervision of the yearly program objectives, embedding in the academic and industrial network and the general alignment of the ESI program with the Topsector HTSM.

Each of the ESI research projects is set-up as a yearly commitment with an agreed long-term focus. Yearly, we tune our program towards the current status of results and the observed high-tech industry trends and associated needs. The partnership with our industrial (and academic) partners is therefore stable and focuses on actual

industrial needs. Hence, as high-tech industry progresses, ESI progresses as well. The ESI success rate can be measured in terms of turn-over, academic and research partners, personnel and the actual use of ESI results in industry practice. Along each axis, ESI has realized a stable yearly growth of roughly 10%. Quality and added value of work is considered of utmost importance. Consequently, we have to build up and manage our own expertise which puts a limit on a too fast growth.

Next to a gradual growth in both research volume and in industrial research partners, an expansion in attention in our program lines is observed. Originally, the interest of our industrial customers was on the design and engineering of their high-tech systems. In 2016 and 2017 we expanded this interest towards the total product life cycle including servicing and condition-based maintenance aspects. This has included the need to integrate data and communication characteristics with embedded systems technology in which we exploited the synergy between the ICT Roadmap and the HTSM Embedded Systems Roadmap. A second expansion can be observed in our focus from single product key performance indicator (e.g. performance or quality) towards system-level architecting and reasoning for multiple KPIs. We expect these expansions to continue. Next to providing added value to our current industrial partners, we therefore target on new research partners that fit in the observed expansions (e.g. Vanderlande, DAF Trucks, Marel, Airbus Defense and Space, Bosch Thermo Technique, VDL-ETG) and a recently started new research program on system security. Together with Twente University we are planning a coordinated action to involve the Twente high-tech companies in the ESI activities (e.g. Panalytical, Nedap, Demcon, Bronkhorst) which creates the opportunity to open a local ESI office in Twente.

Finally, we target to expand on the industrial use of the ESI results. This requires both a professional support of our tools and an expansion of engineers that are trained in our results. The professional support is targeted to be “managed open source” meaning free availability of our tools however with a professional support guaranteed. The selected open-source tool provider is Obeo and the target for 2019 is to make this a success in the market. Next to the professional tool support we target to expand on the number of trained engineers that can apply the ESI results. Our strategy is to set up a community of SW service providers that is trained in our results. The initial community is consisting of Altran, Sioux and ICT+.

14 Ondertekening

Eindhoven, 1 oktober 2018 TNO

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