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BINDT President's Honour Lecture, 2019

The Future of NDT -

Crisis or Opportunity?

Professor Robert Smith,

University of Bristol

Director of the UK Research Centre for NDE

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Content

- Introduction
  - Main premise of the talk
  - Previous industrial revolutions
- 4th Industrial Revolution / Industry 4.0 / NDT 4.0
  - Description
  - International response
- What will change?
  - Human-machine interaction in the era of NDT 4.0
- How should we respond?
- Crisis or opportunity? – the way forward

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Introduction

- Main premise of this talk:
  - That changes ahead for the NDT community can either be:
    - regarded as a threat and resisted, resulting in **crisis**, or
    - embraced as an **opportunity**, driving change and resulting in growth of the NDT industry in the UK
  - That all previous 'industrial revolutions' have been seen as a threat to jobs, livelihoods, way of life, etc,
    - yet we (apparently) have high UK employment.
    - jobs may have changed but they still exist.
  - We need to be ready to re-train our NDT workforce.

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Introduction – Industry 4.0

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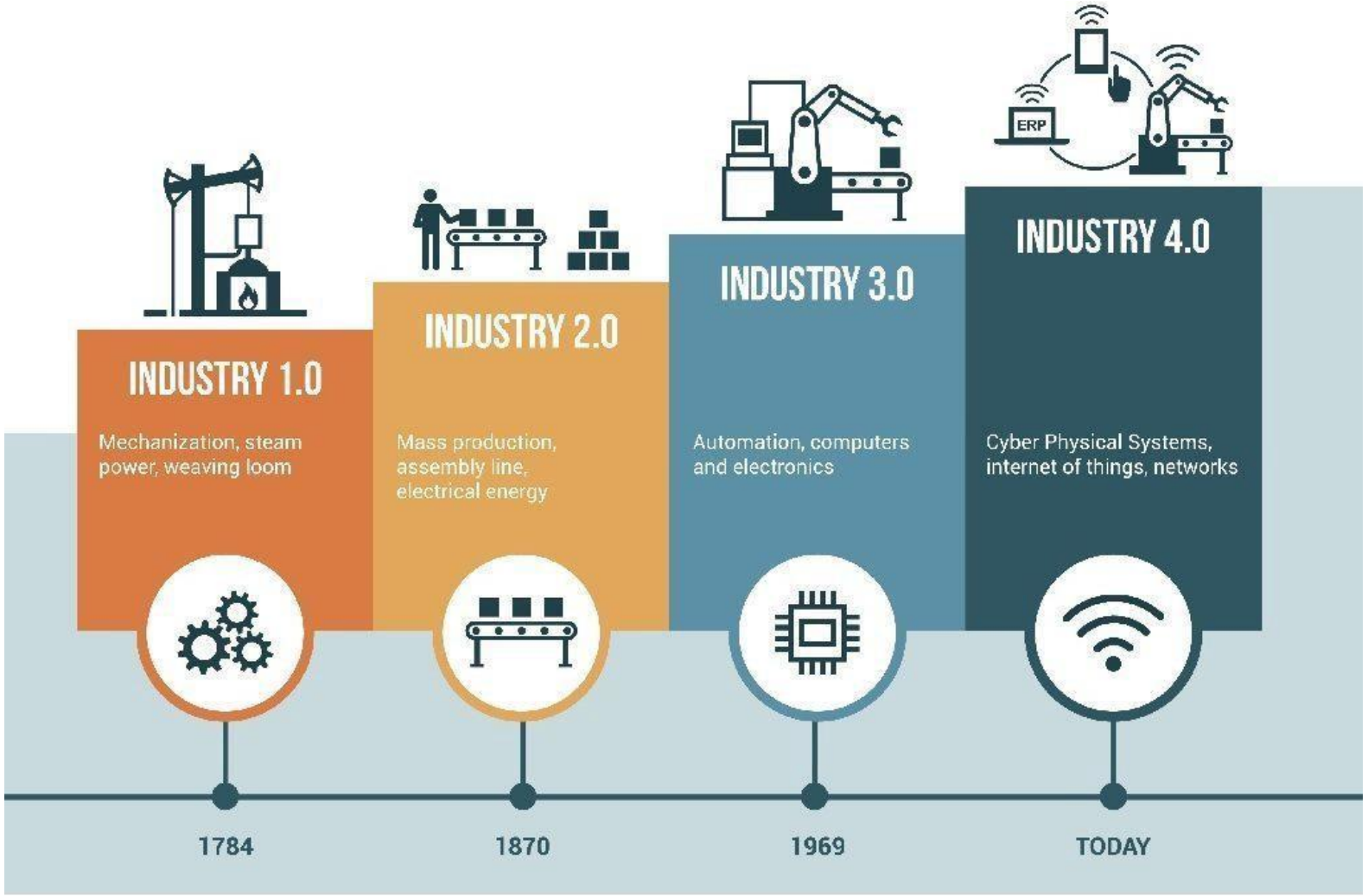
Introduction



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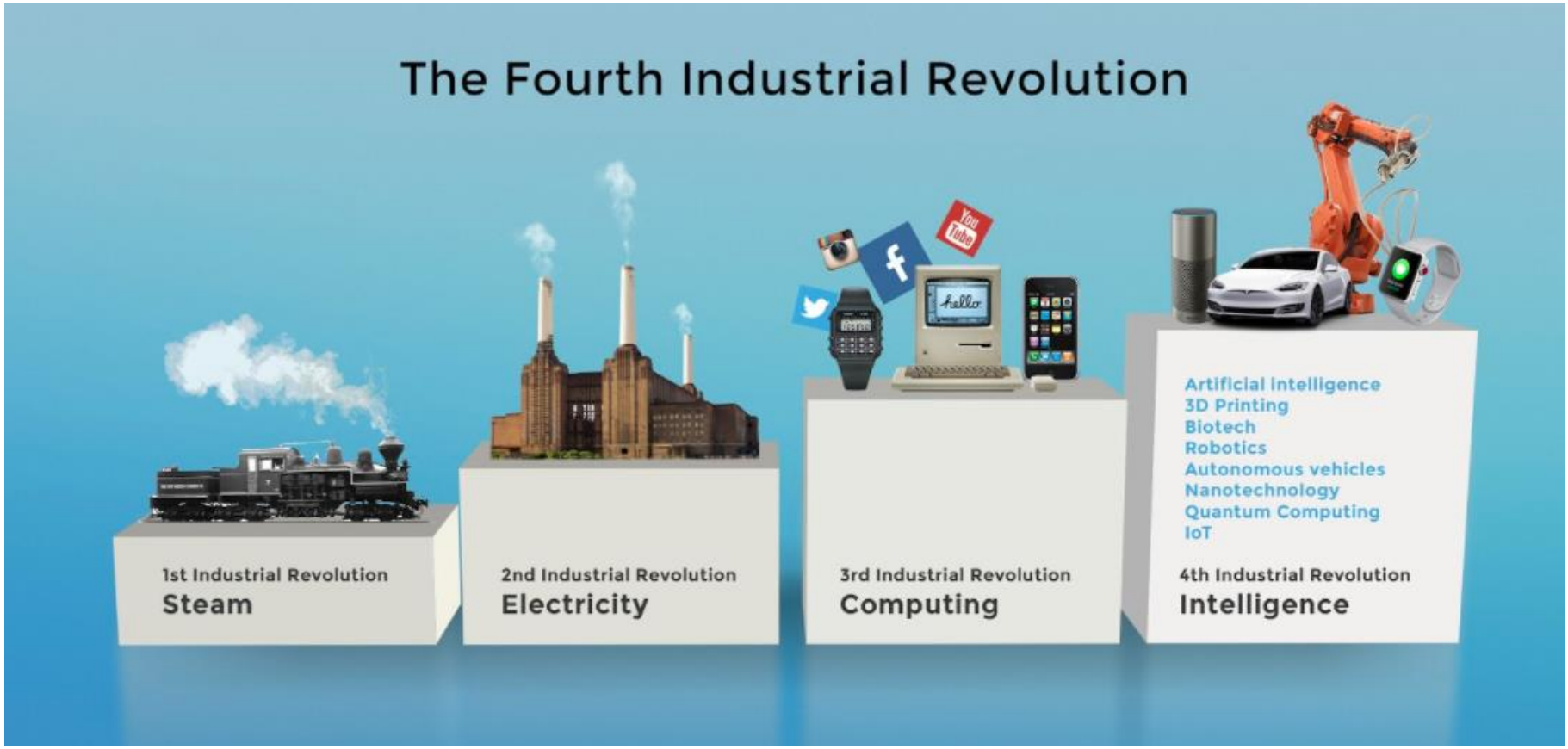
Introduction



1784 1870 1970 2015

Introduction

- First ‘industrial’ revolution.
  - Mechanisation, steam power
  - Industrial machines replace people

1784 - 1870

Introduction

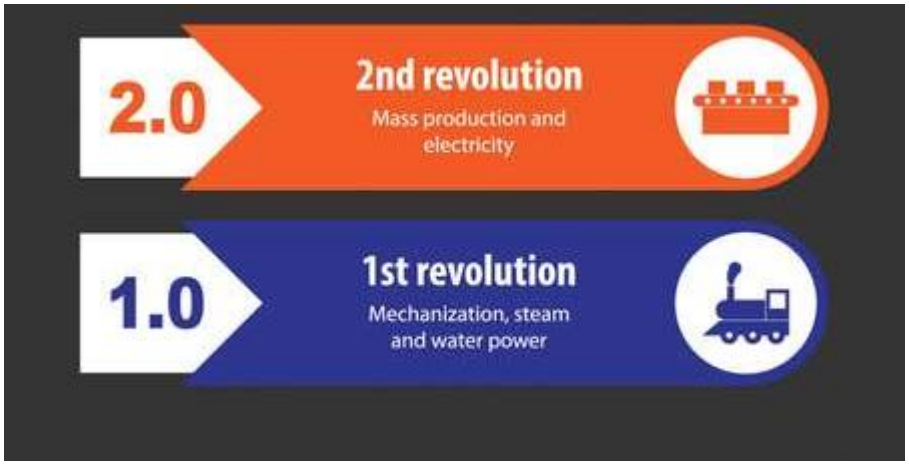
The James Watt steam engine

1784 - 1870

- First ‘industrial’ revolution
  - Mechanisation, steam power
  - Industrial machines replace people
  - An economic ‘tipping point’.
  - Unprecedented growth.
- NDT challenges:
  - Boiler integrity, fatigue, dissimilar expansion, etc.
  - Wheel tapping for cracks.

Introduction

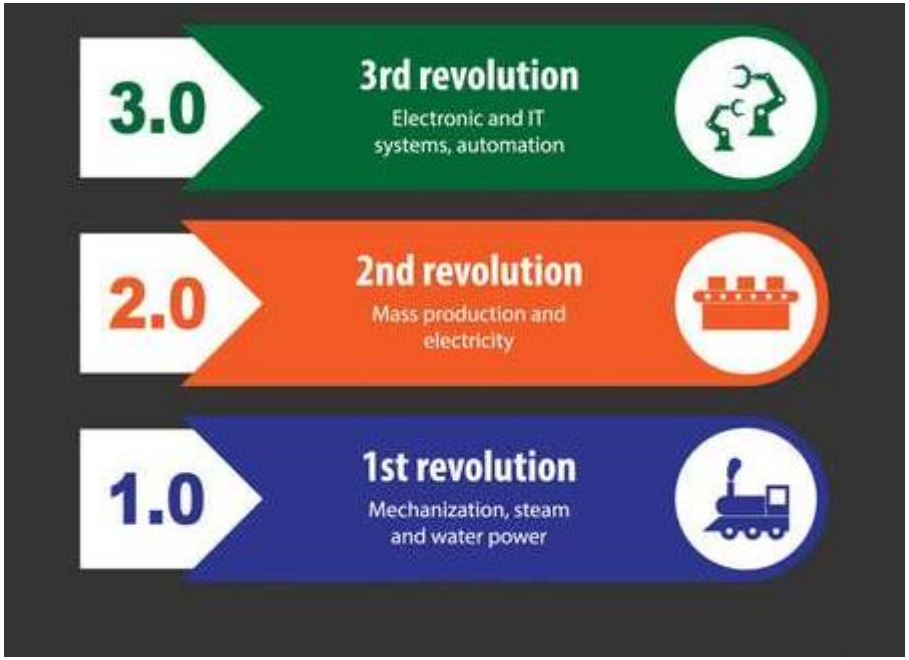
1870 - 1970



- 2nd 'technical' revolution
  - Mass production, through
    - Electric-powered efficiencies
    - First assembly line
  - Production management
    - Division of labour
    - Optimised workplace techniques and resource allocation
    - Just-in-time manufacturing
    - Lean manufacturing
  - NDT Challenges
    - Quality control
    - Speed and reliability

Introduction

1970 - 2015



- 3rd 'digital' revolution
  - Industry 3.0, defined by programmable logic and advanced manufacturing.
    - Electronics and software
    - Automated machinery
  - Management processes
    - enterprise resource planning,
    - inventory management,
    - shipping logistics,
    - product flow scheduling and tracking throughout the factory
  - NDT Challenges
    - The weakest link?
    - Production-control feedback
    - Rapid decisions required

Introduction

2015 - ?

- 4th 'Smart' revolution
  - introduced by Klaus Schwab, executive chairman of the World Economic Forum, in a 2015 article in *Foreign Affairs*
- Marked by breakthroughs in emerging technologies in fields such as:
  - robotics,
  - artificial intelligence,
  - nanotechnology,
  - quantum computing,
  - biotechnology,
  - the internet of things (IoT),
  - decentralized consensus,
  - fifth-generation wireless technologies (5G),
  - 3D printing, and
  - fully autonomous vehicles.

Introduction

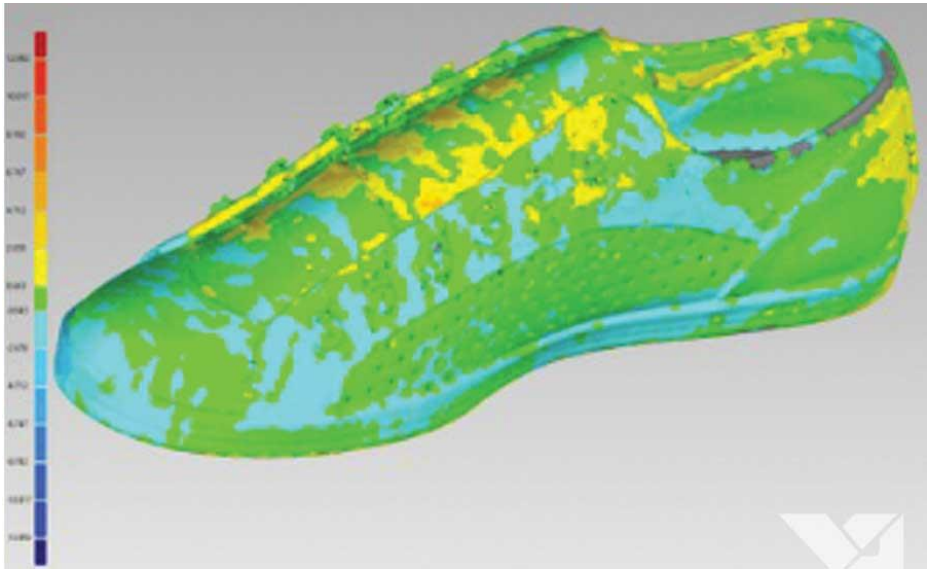


Photo courtesy of Fraunhofer Institute for Non-destructive Testing IZfP

- 4th 'Smart' revolution
  - Expected outcomes:
    - Merging boundaries of the physical and virtual worlds – 'digital twins'
    - Machines communicate more intelligently with each other, with no boundaries
    - Smart machines - continuously monitor, predict faults, suggest preventative measures, etc
    - Smart factories.
    - "*Industries must adopt the new systems as fast as possible to stay relevant and profitable.*
    - *Industry 4.0 is here and it is here to stay, at least for the next decade." Eric Howard*

Introduction

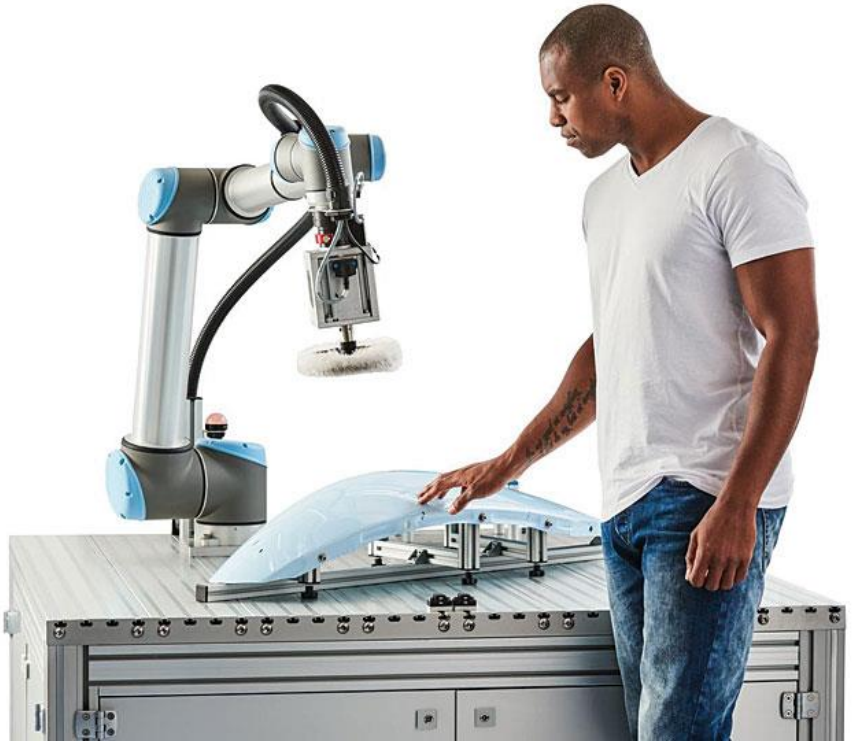
- Industry 5.0? The ‘human touch’ revolution.
  - *“…placing human beings back at the centre of industrial production…”*
  - “…the mass customization … enabled by Industry 4.0 is not enough. Because consumers want more. They want mass personalization, which can only be achieved when the human touch returns to manufacturing. This is what I call Industry 5.0.”

    - Esben H Østergaard, Quality Magazine, 8 May 2019.

Introduction

- The ‘human touch’ revolution

  “Far from fenced-off industrial robots that replace human workers with automated processes, collaborative robots enhance human craftsmanship with the speed, accuracy, and precision required to make modern products with a human touch.”
  Source: Universal Robots



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4th Industrial Revolution / Industry 4.0 / NDT 4.0

‘Industry 4.0’ is actually a German government project to support plant manufacturing of the future in Germany to make the production faster, more efficient and highly flexible.

‘NDE 4.0’ is used in the USA and ‘ZfP 4.0’ in Germany, by the NDT community.

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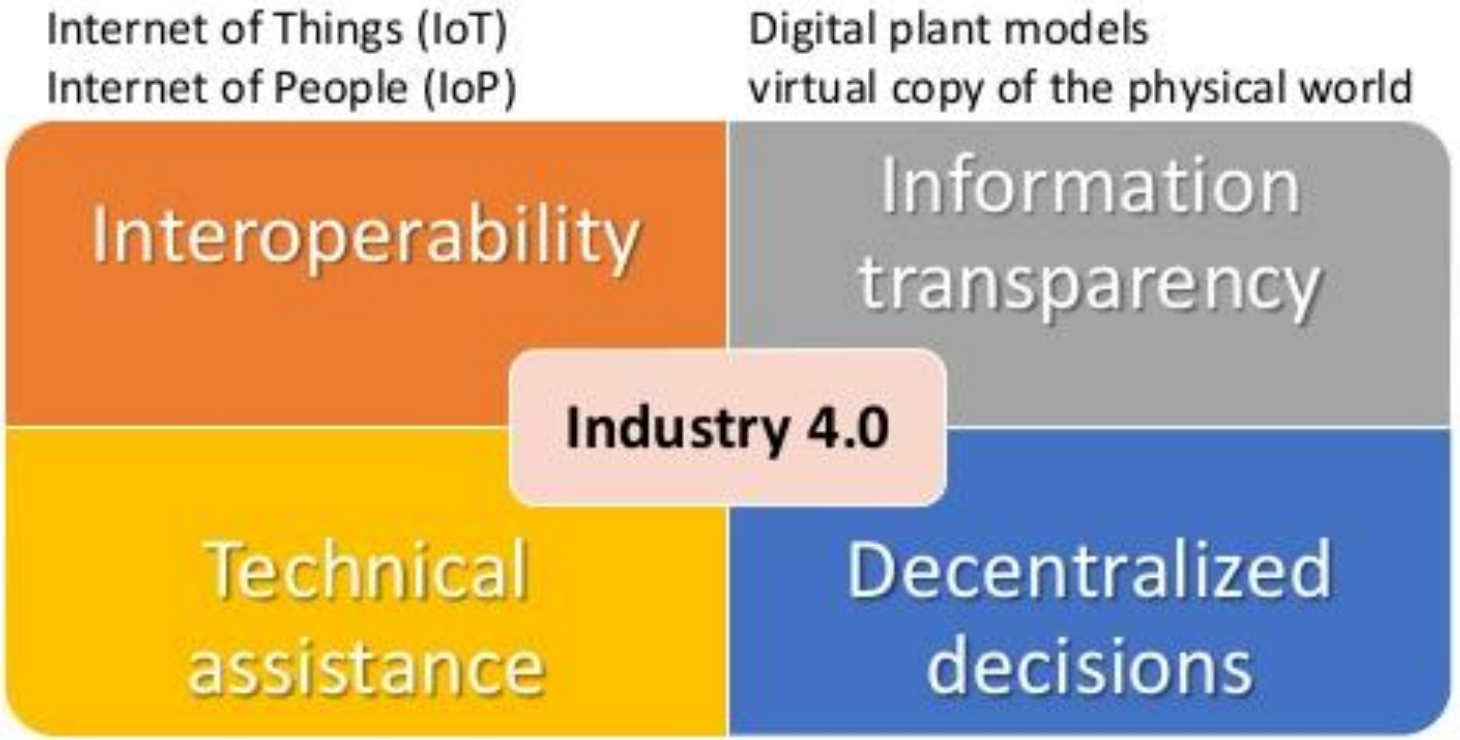
Design principles in Industry 4.0



Industry 4.0

- What will be different?

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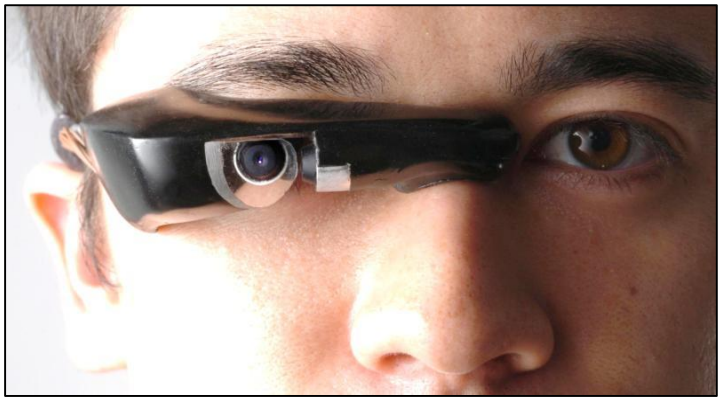
Industry 4.0

- What will be different?
  - Data sets will be large and complex (‘Big Data’).
  - Data could arrive continuously (as in SHM or CM) from multiple remote sites (‘Internet of things’).
  - Interpretation of data may/will be too difficult for an *unaided* human. (‘Technical assistance’)
  - Conversion to useful ‘NDT information’ will be automated using (‘Autonomous decision-making’):
    - Artificial intelligence (AI)
    - Machine Learning (ML)

Industry 4.0

- Technical assistance
  - Physics-based
    - Processing of data.
    - Presenting ‘information’ to the operator
    - Physics is understood.
    - Model-assisted qualification possible.
    - Already in common use in NDT:



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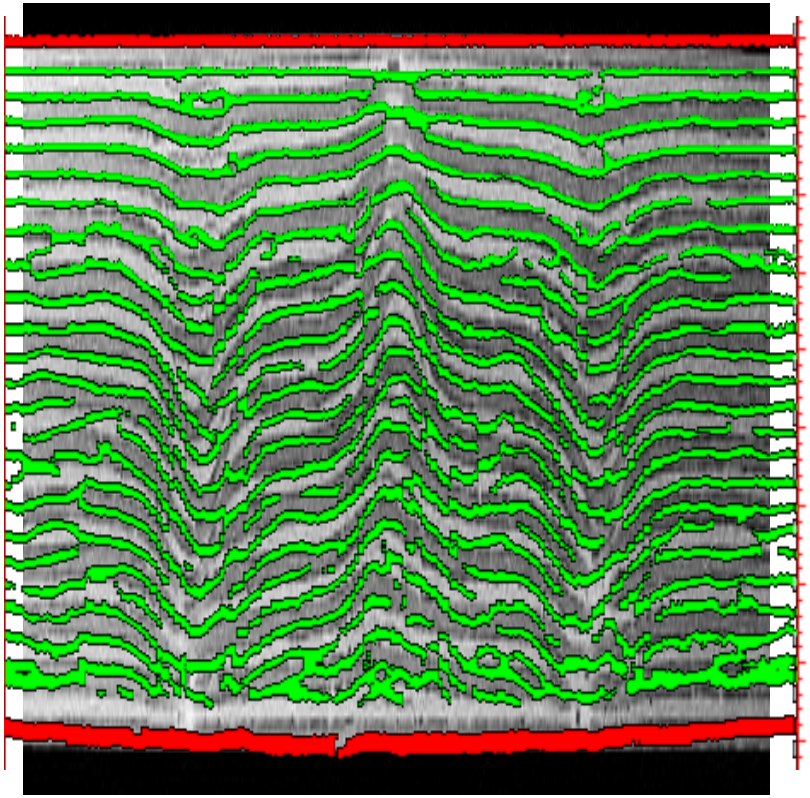
      - ‘imaging’ algorithms.
      - principal component analysis (PCA).

– Ultrasonic ply-tracking of composites



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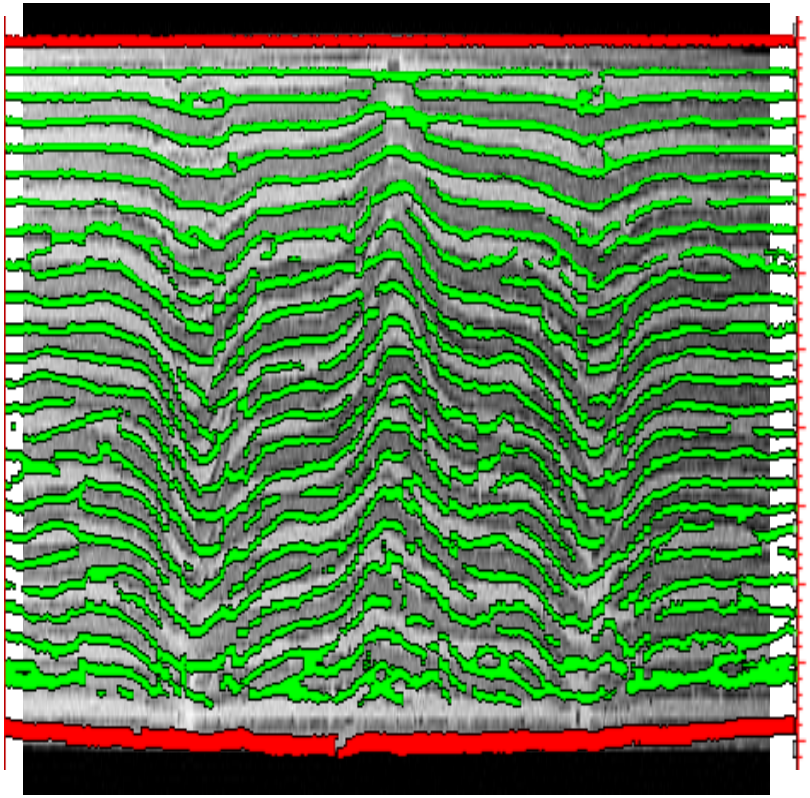

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      - FMC/TFM
      - ‘imaging’ algorithms.
      - principal component analysis (PCA).
      - Ultrasonic ply-tracking of composites
  - But:
    - Relies on humans.
    - Human factors need to be considered in qualification process.

Industry 4.0

- Autonomous decision making
  - Physics-based methods
    - Works in simple cases.
    - Physics is understood.
    - Modelling helps explore the range of parameters.
    - Capabilities and limitations are determined.
    - Model-assisted qualification possible.

- Human can intervene through ‘understanding’ the process/algorithm.

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Industry 4.0

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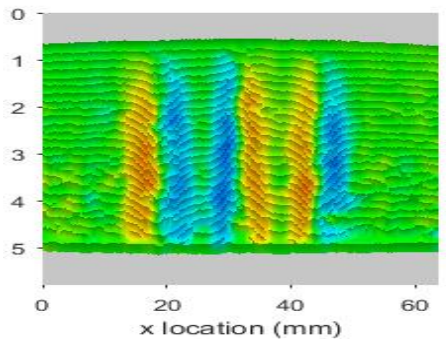
- E.g.
  - Database correlation,
  - principal component analysis (PCA).
  - Measurement of maximum wrinkle angle in composites.



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Industry 4.0

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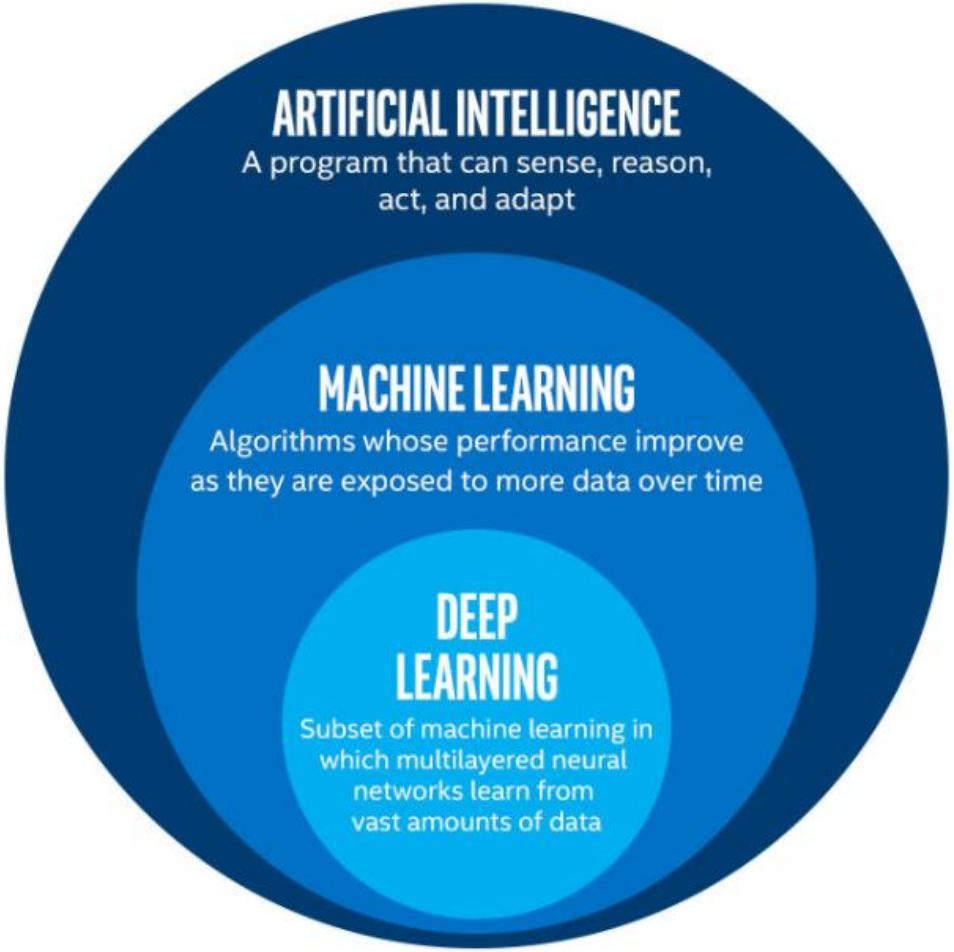
    - E.g.
      - Database correlation,
      - principal component analysis (PCA).
      - Measurement of maximum wrinkle angle in composites.
  - But:
    - Complexity and reality rapidly reduce reliability.

Industry 4.0

- Autonomous decision making
  - Artificial intelligence
    - A program that can sense, reason, act and adapt.



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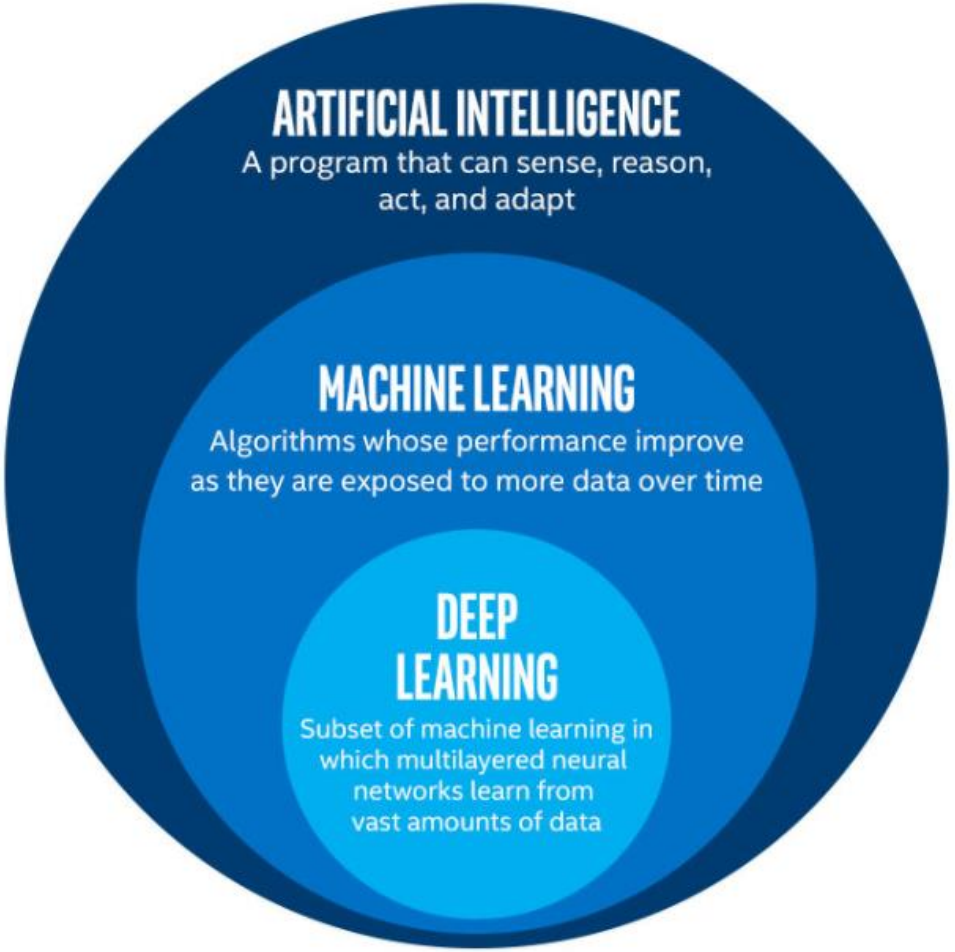
Industry 4.0

- Autonomous decision making
  - Machine Learning
    - Training data that is tagged with the ‘truth’.
    - Relies on quantity of training data and accuracy of the ‘truth’.
    - Potential for training-in human error from data sets.
    - Achieving adequate reliability requires a lot of training data.



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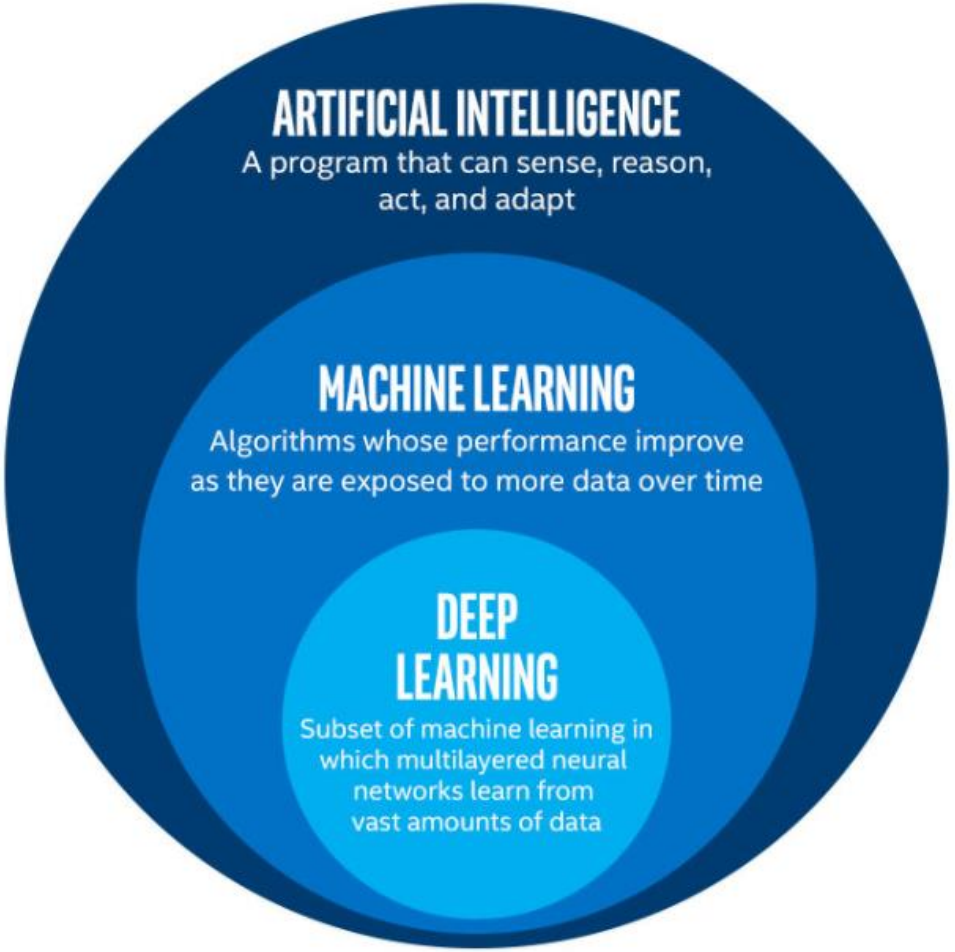
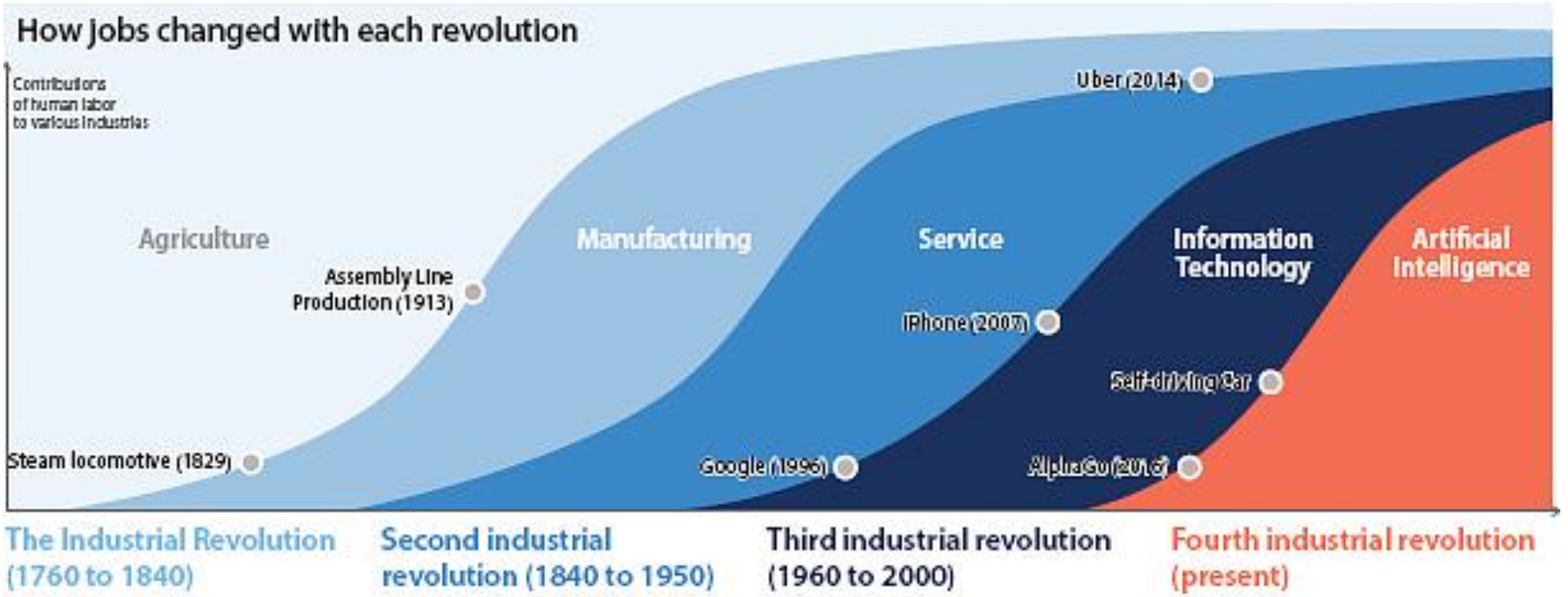
Industry 4.0

- Autonomous decision making
  - Deep learning
    - Unsupervised training on large data set.
    - Algorithm works out what is important and draws out the important features.
    - Low level of control or understanding of the final algorithm.
    - Requires vast amounts of data.



Changing jobs during Industrial Revolution

- So things will change due to the increased complexity and volume of data, as well as the required speed and reliability of the information.



Employment in Industry 4.0

- Fewer people will be needed for conventional NDT jobs…
- Stone-age ‘industrial’ revolution?...

Employment in Industry 4.0

- Fewer people will be needed for conventional NDT jobs…
- Stone-age ‘industrial’ revolution?...

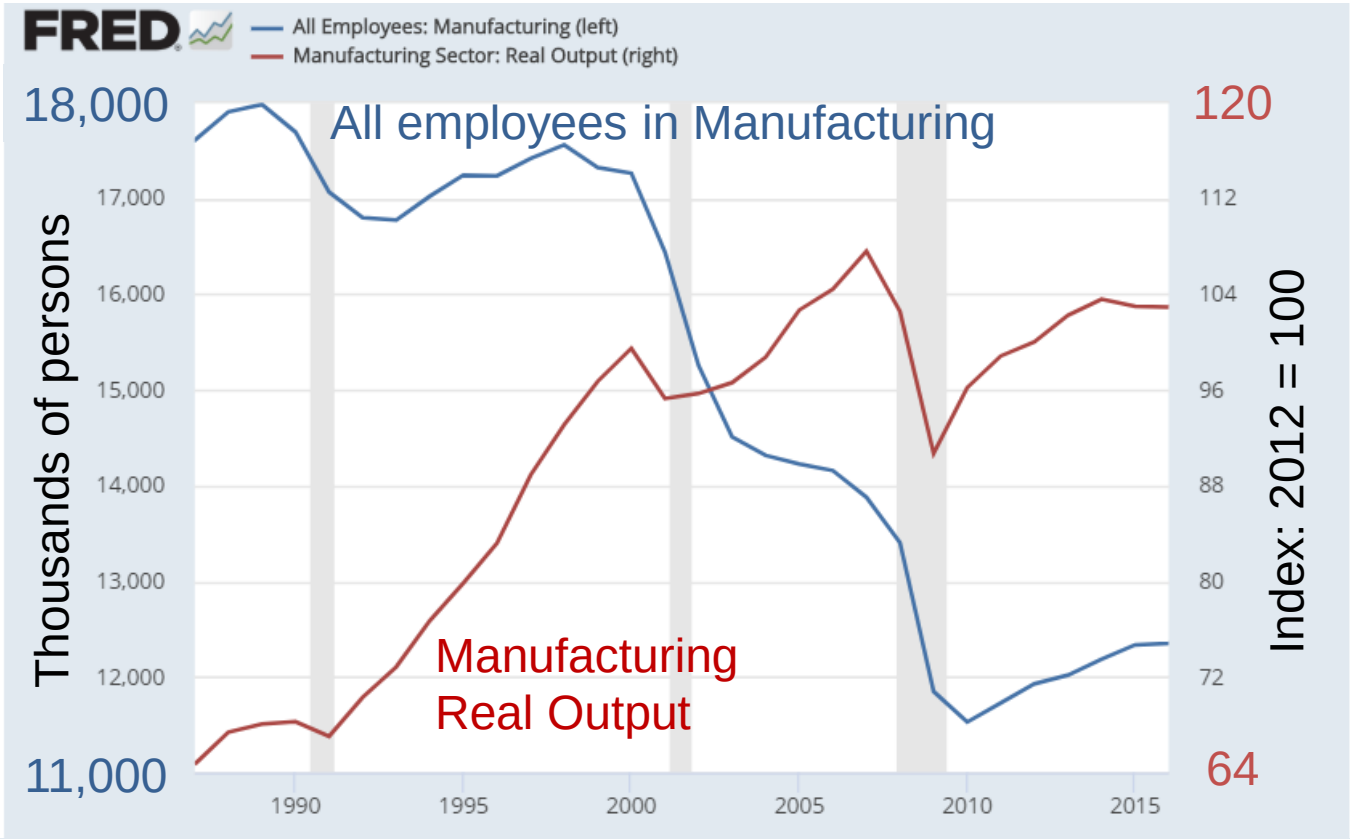
Employment in Industry 4.0

- Economists say that when technology destroys jobs, people find other jobs.
  - *"Since the dawn of the industrial age, a recurrent fear has been that technological change will spawn mass unemployment. Neoclassical economists predicted that this would not happen, because people would find other jobs, albeit possibly after a long period of painful adjustment. By and large, that prediction has proven to be correct."*
- Are these economists minimizing the historical record when projecting the future, essentially telling us not to worry because *in a century or two, things will get better?*

Employment in Manufacturing

30% reduction in employees in manufacturing from 2000 to 2010.

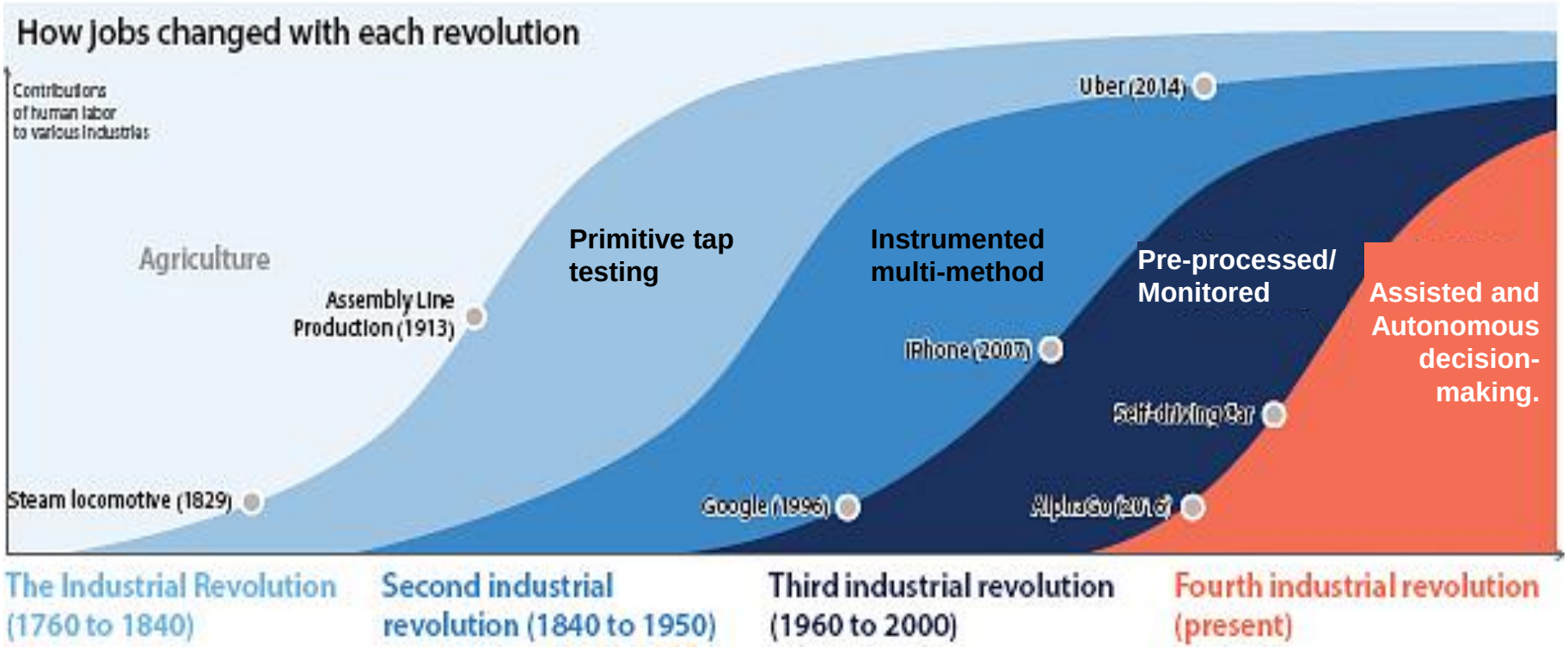
But 'output' continued to rise except during the 2008 crash.



Source: U.S. Bureau of Labor Statistics

What is changing in NDT?

- How did NDT change in emphasis during previous industrial revolutions?



International activity in NDT

- German Institute of NDT (DGZfP)
  - ZfP 4.0 Technical Committee (Chair: Prof. Bernd Valeske) with 5 groups:
    - Additive Manufacturing
    - Intelligent sensor technology
    - Interfaces and documentation
    - Human-machine Interaction (Chair: Dr Marija Bertovic, BAM)
    - Training
- ASNT Response
  - New NDE 4.0 Committee – Chair: Dr Ripi Singh
- ICNDT Response
  - Proposed Special Interest Group on NDT 4.0

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NDT and Industry 4.0

- NDT *for* Industry 4.0
  - NDT information→Digital twins
  - NDT of Additive Layer Manufacturing
  - Real-time feedback into production process
- Industry 4.0 in the NDT industry
  - NDT opportunities using Industry 4.0 advances
  - Sensors→Big Data→Analysis→Information
  - Use of Artificial Intelligence (AI) and Machine Learning (ML)

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Following 7 slides from BINDT Aerospace Event session on Industry 4.0, 2019
By permission:

Human-machine interaction in the era of NDT 4.0

© Dr. phil. Marija Bertovic

Department 8: Non-Destructive Testing

Probabilistic Safety and Reliability Analyses/Human Factors Analyses

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Human-Machine Interface

The human being remains as a major player in the human-machine interaction

- *People* will **design** and **monitor** the networking of machines with machines
  - Human as a supervisor vs. human as an operator
- Proportion of **routine** work will most likely decrease
- People will continue to **actively shape and change** the Human-Machine Interface
- **Automation gaps** are handed over to the human to help/decide

Human-Machine Interface

- **Maintaining "marginally skilled"** workers and integration into the new working conditions
- Digital development increases **complexity** and resource consumption
- The world of **work and life** are boundlessly merged
- Constant maintenance of **situational awareness** required (current system status must always be reported back)

Human-Machine Interface

Demands

- With increasing complexity of production and automation, the **cognitive demands** on human resources are increasing
- Digitally networked machines expand **human competences** (e.g. deep learning in artificial intelligence)
- Increase of **organisational complexity** through the integration of machines and communication technologies
- **Practice-relevant knowledge** is very much in demand
- Emphasis on **problem solving and decision making**
- Decisions need to be made in **less time**
- More **attention resources** are consumed

Human-Machine Interface

Problems

- **Task allocation** and **transfer** in human-machine systems not always efficient
- **New errors and error sources** (operational errors are often developmental errors)
- **Loss of skill** – 'out-of-the-loop' phenomenon. Don't see defects any more
- Problems associated with **monitoring**
  - Humans can not always monitor 100%
  - Loss of situation awareness
- **Over-reliance** on automation
- Demands for **requalification** of existing personnel
- Needs for new **training**
- **Acceptance** of new technologies

Human-Machine Interface

Ironies of automation (Bainbridge, 1987)

- Human as the primary source of error / operative errors
- Non-automatable / highly complex activities are transferred to humans
- Automation replaces people, but human beings constantly have to monitor technical systems and eliminate errors
- The higher the reliability of the automated systems, the more training required

Study on risks in semi-automated testing (Bertovic, 2016)

- **Critical defects could be missed**, even if the inspection process is semi-automated
  - The causes of that risk lie in the **technology**, **people** and in the **organisation**
  - Currently installed preventive measures are **insufficient to prevent** from risks
  - **New preventive measures** could be installed, e.g. further automation, installing alarms, implementing human redundancy, developing software and hardware solutions, optimising procedures, etc.

What happens after we implement a preventive measure? → Prevention, but… **New *unknown* risks can arise!**

The lumberjack analogy (Onnasch et al. 2014)

- The higher the degree of automation (DOA)

→ the greater the benefit when the automation **works**

→ the greater cost when it **fails**.

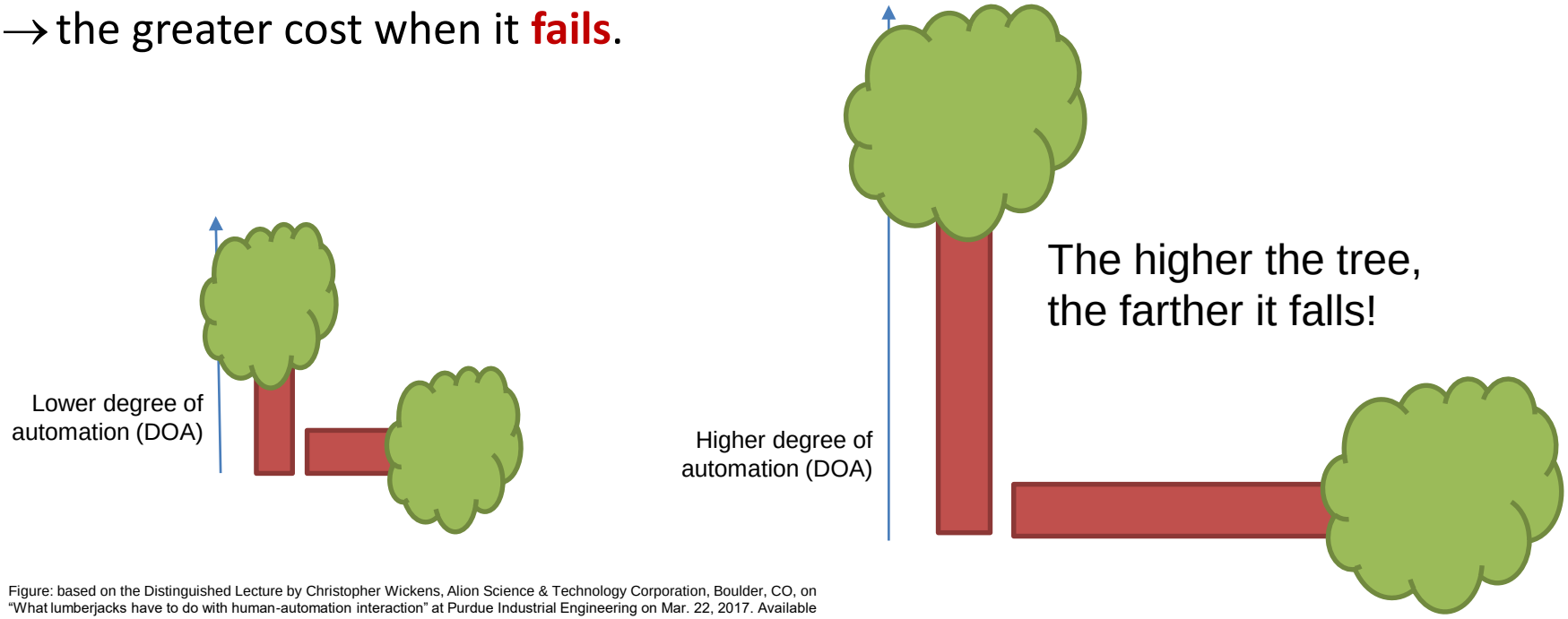

Figure: based on the Distinguished Lecture by Christopher Wickens, Alion Science & Technology Corporation, Boulder, CO, on "What lumberjacks have to do with human-automation interaction" at Purdue Industrial Engineering on Mar. 22, 2017. Available on https://youtu.be/HkYanYTffWM.

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End of slides from Marija Bertovic

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NDT and Industry 4.0

- Opportunities (Ref: R. Link, "NDT 4.0 -…", 12th ECNDT)
  - Increase of production
  - Digital connection within all internal and external procedures
  - Completely Automated NDT Systems
  - Real time analysis of all data including big data analysis algorithms
  - Detection of strength and weaknesses in development, production, inspection procedures
  - New service activities through structural health analysis (SHM)
  - New training and education tasks

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NDT and Industry 4.0

- Threats (Ref: R. Link, "NDT 4.0 – …", 12th ECNDT)
  - Acceptance by society and individuals
  - Increase of unemployment
  - Potential loss of know how through internet connectivity by clouds and/or platforms to competition, suppliers and customers
  - Lack of qualified personal
  - Hacker attacks

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How should we respond?

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How should we respond?

- BINDT Advisory Group on Strategic NDT Leadership
  - Will form the ‘NDT Leadership Forum’
- BINDT’s NDT and CM Technical Committees
  - Will form Industry 4.0 working group(s)
  - Run a ‘requirements workshop’ to establish needs.
- RCNDE will be focusing on
  - Technologies for Industry 4.0
- BINDT should focus more on:
  - Technique and Technology Validation.
  - Validation of automated and AI/ML systems
  - Training & qualification of personnel for the new era.

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Strategic Leadership

Barriers to new NDT technology: Benefit vs Burden

Requirements workshops

Technology User Groups

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Potential NDT Leadership Forum

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Communicating the future landscape

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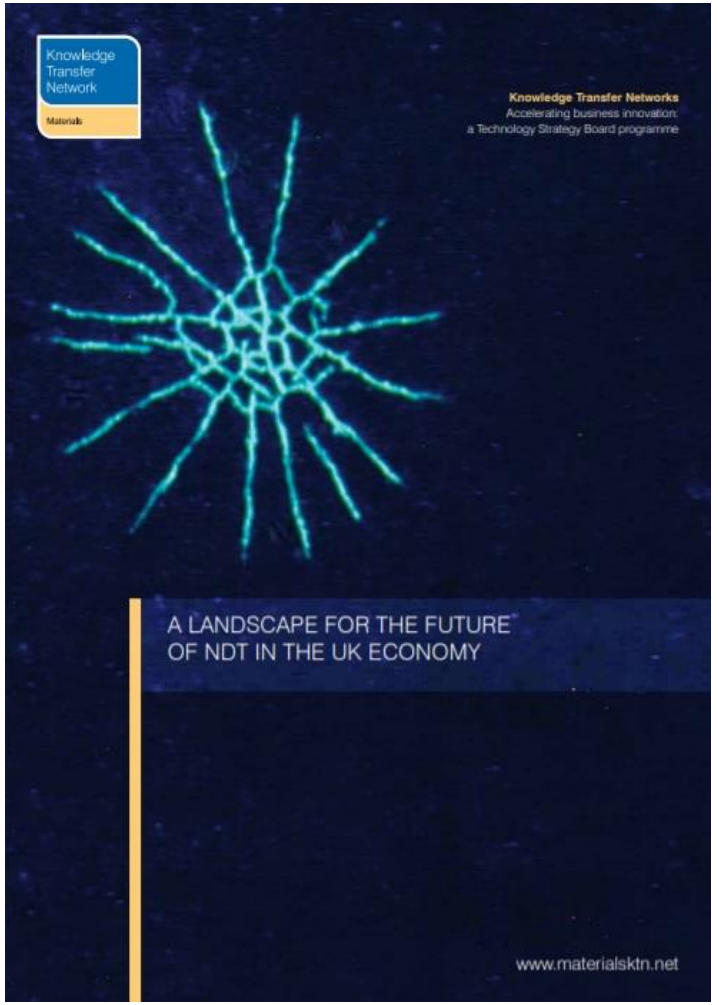
Communicating the future landscape

- UK NDT Landscaping report: “A landscape for the future of NDT in the UK economy” (March 2014)
- Unfunded BINDT group.
- Printed by the Knowledge Transfer Network.
- **Update required.**
- Who will do this?



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Communicating the future landscape

- NDT/SHM/CM are underpinning technologies
  - Cross-sector
  - Not perceived as ‘grand challenges’ like:
    - Controlling biological cells
    - Suprastructures (integrating resource infrastructures under constraint)
    - From atoms to applications
    - Big Data for Engineerng Futures
    - Bespoke Engineering
    - Risk and reliance in a connected world

Strategic message to government

Analysis of big data.
Use of digital twin, machine learning, AI

Maintains risk level *affordably*.

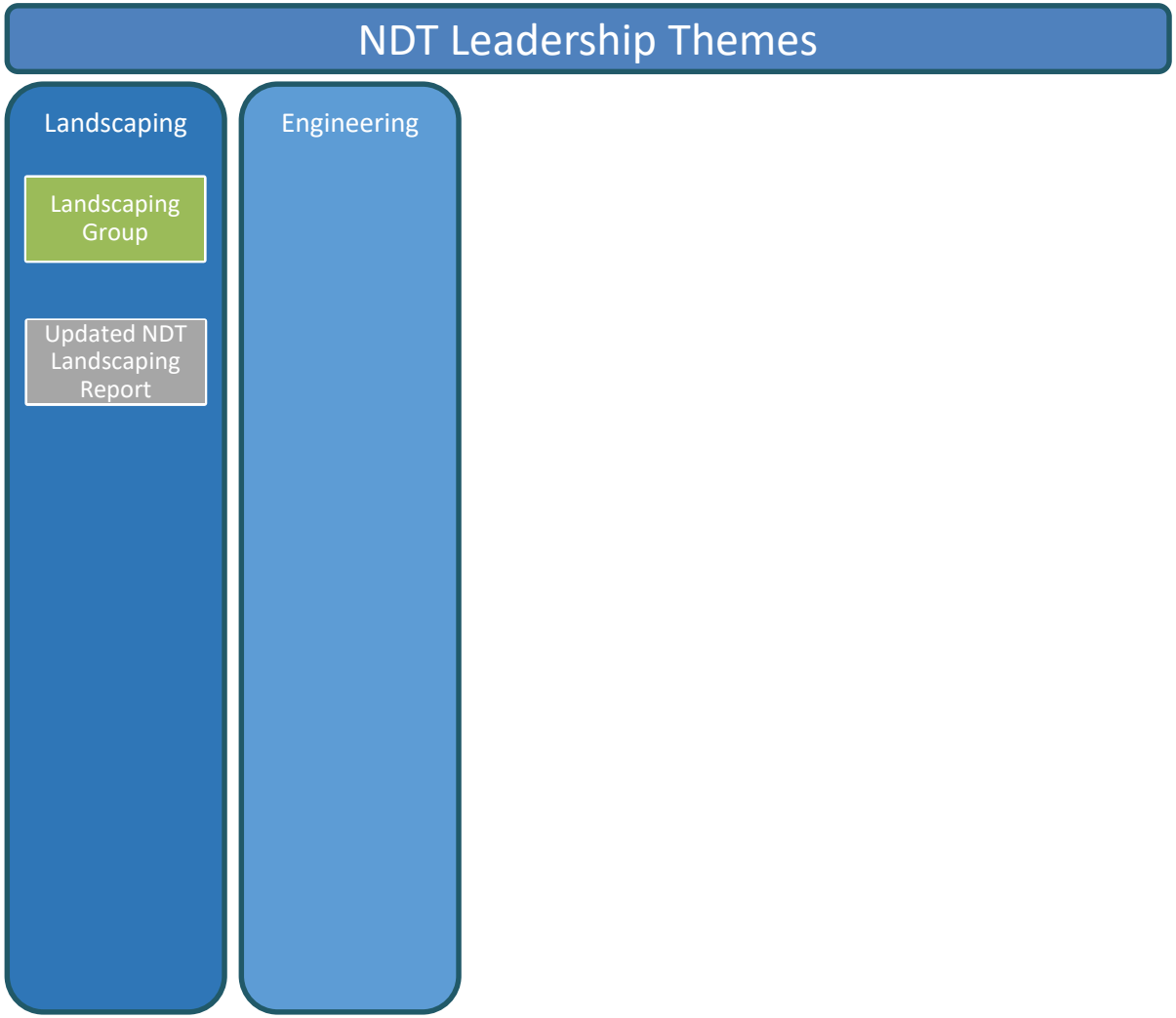
Increasing confidence.
Reducing risk.

21st-century digital NDT will accelerate affordable 4IR in a risk-averse society

Opens up the design space.
Increases acceptance.
Realises benefit.

4th Industrial Revolution.
Digital economy.
Big data.
Internet of things

NDT Leadership Forum



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Engineering

- Linking with the design and integrity communities
  - Design for Inspection – educating designers
  - Understanding risk – how NDT is part of a big picture
  - Sustainable design – NDT as a benefit not a burden
- Predictive analytics for asset management
- Training and qualifying ‘NDT Engineers’
  - Equipped to validate technologies and specifications
- Link with ASNT’s Engineering Council?

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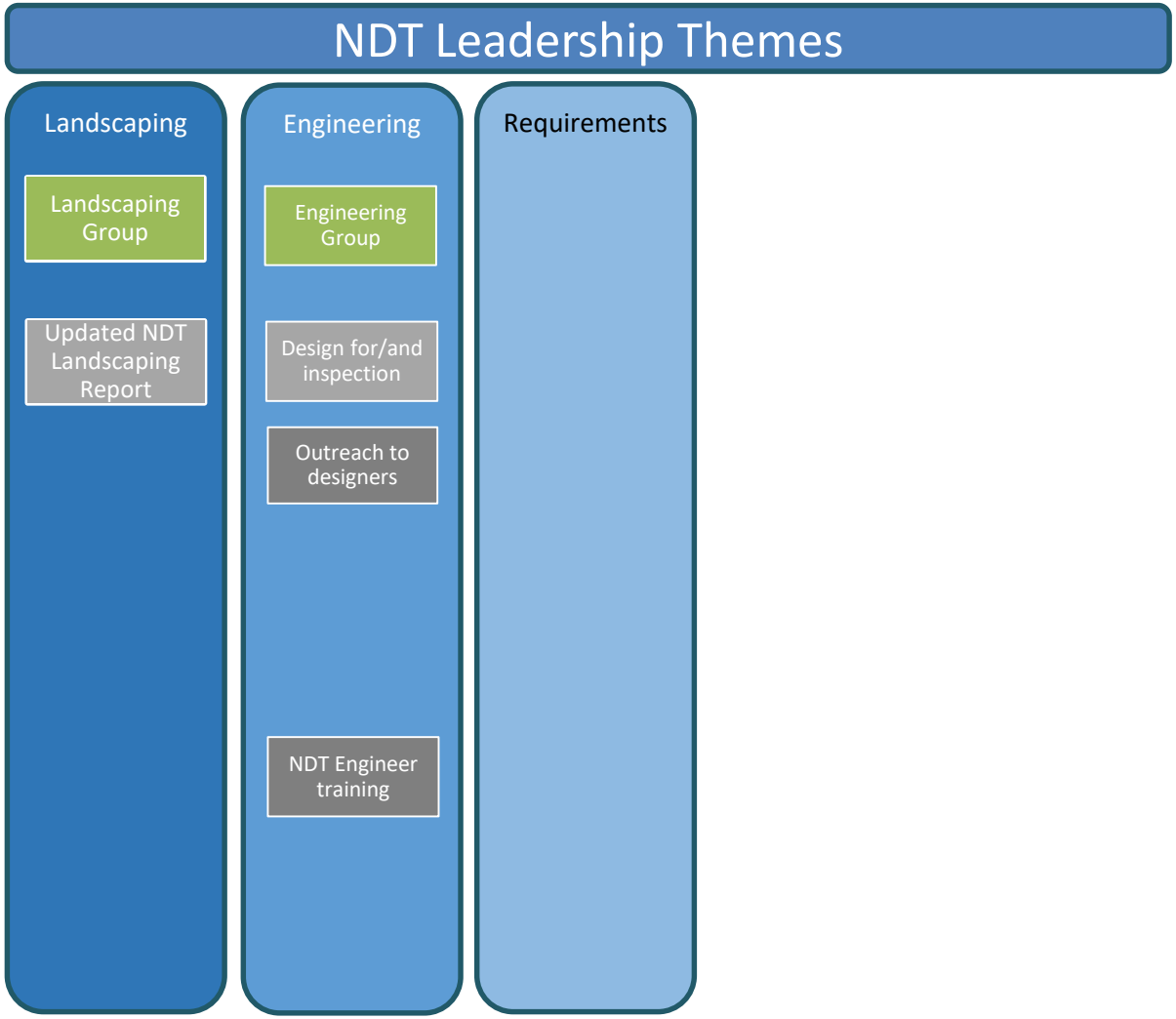
NDT Leadership Forum

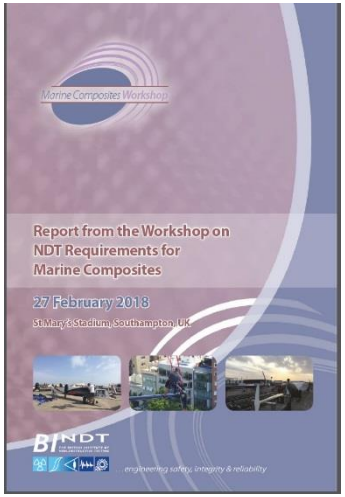


Capturing NDT/SHM/CM Requirements

- ‘NDT Requirements’ workshops & reports
  - regulators, insurers, researchers, designers, manufacturers and end-user operators.

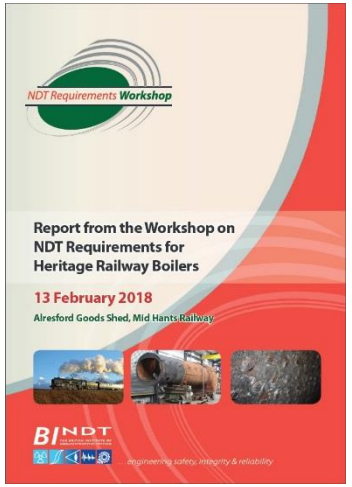
Aerospace Composites February 2016

Automotive Composites March 2017



Marine Composites February 2018

Wind turbines February 2019



Heritage Railway Boilers, Feb. 2018

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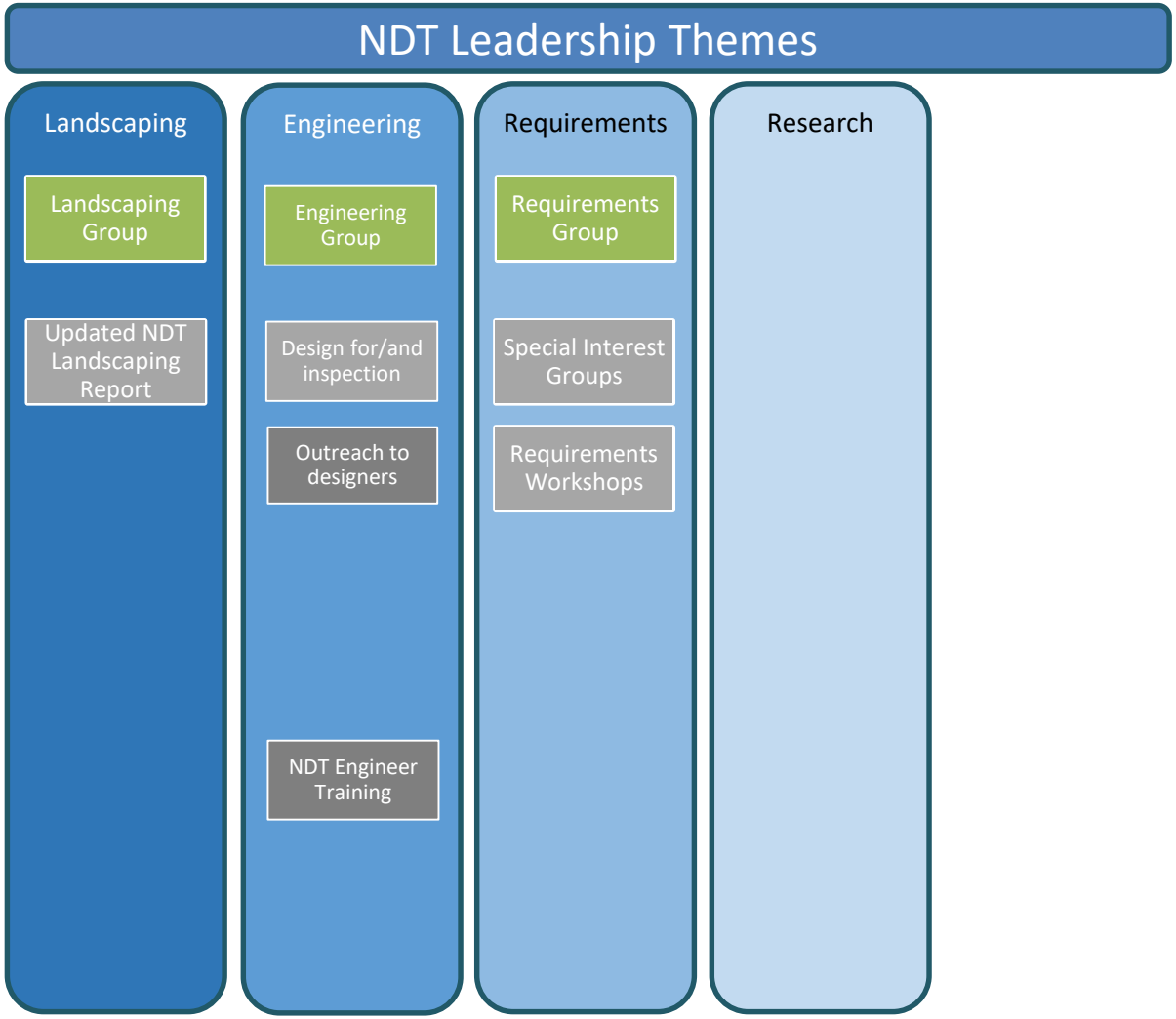
Capturing NDT/SHM/CM Requirements

- Most of these workshops have resulted in:
  - a list of ‘requirements’ including:
    - joining up NDT with structural integrity and effects of defects.
    - NDT qualifications and training in specific sectors and materials.
    - Routes for validation of new technologies.
    - Databases of experiences
  - A call for a working group to pull together solutions
- What is the next step? Who funds the group?

NDT Leadership Forum



UK Research Centre in NDE

- Collaboration between universities & industry to make a significant impact through NDE research and training
- Established in 2003, it has EPSRC funding until at least 2020 *(£5.4M 2014-2020 with matching industry funds)*
- ~50 Industrial members & Associate members – multi sector
- 6 main university partners:

University of Strathclyde Glasgow

MANCHESTER 1824 The University of Manchester

University of BRISTOL

THE UNIVERSITY OF WARWICK

Imperial College London

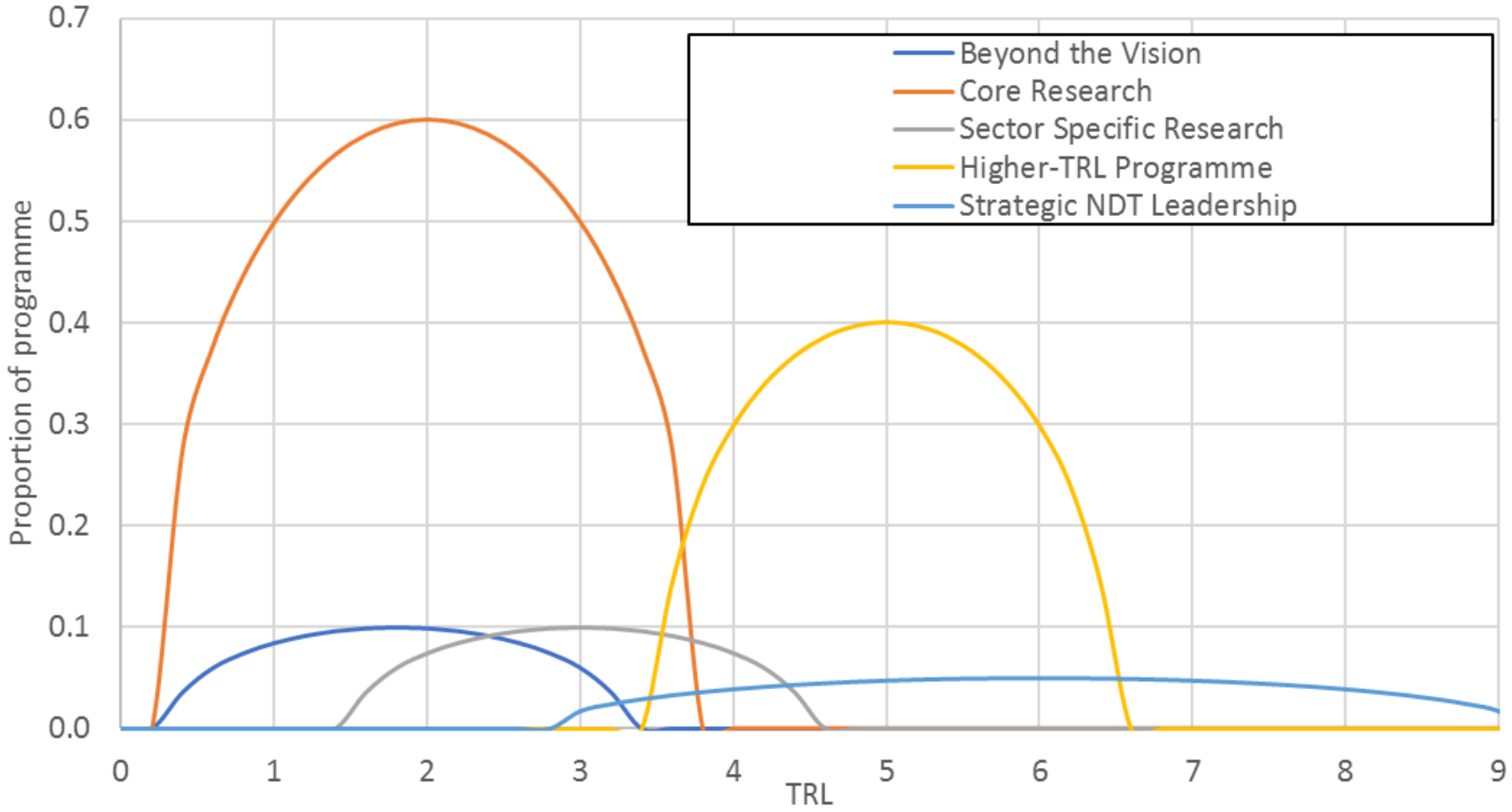
The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

EPSRC Pioneering research and skills

EPSRC Engineering and Physical Sciences Research Council

RCNDE 4.0

- TRL 1-6 within proposed RCNDE 4.0



Research

- NDT Research Network
  - Potential 3 years of funding as an EPSRC Network
  - Open to all universities
  - International
  - Could be led by RCNDE

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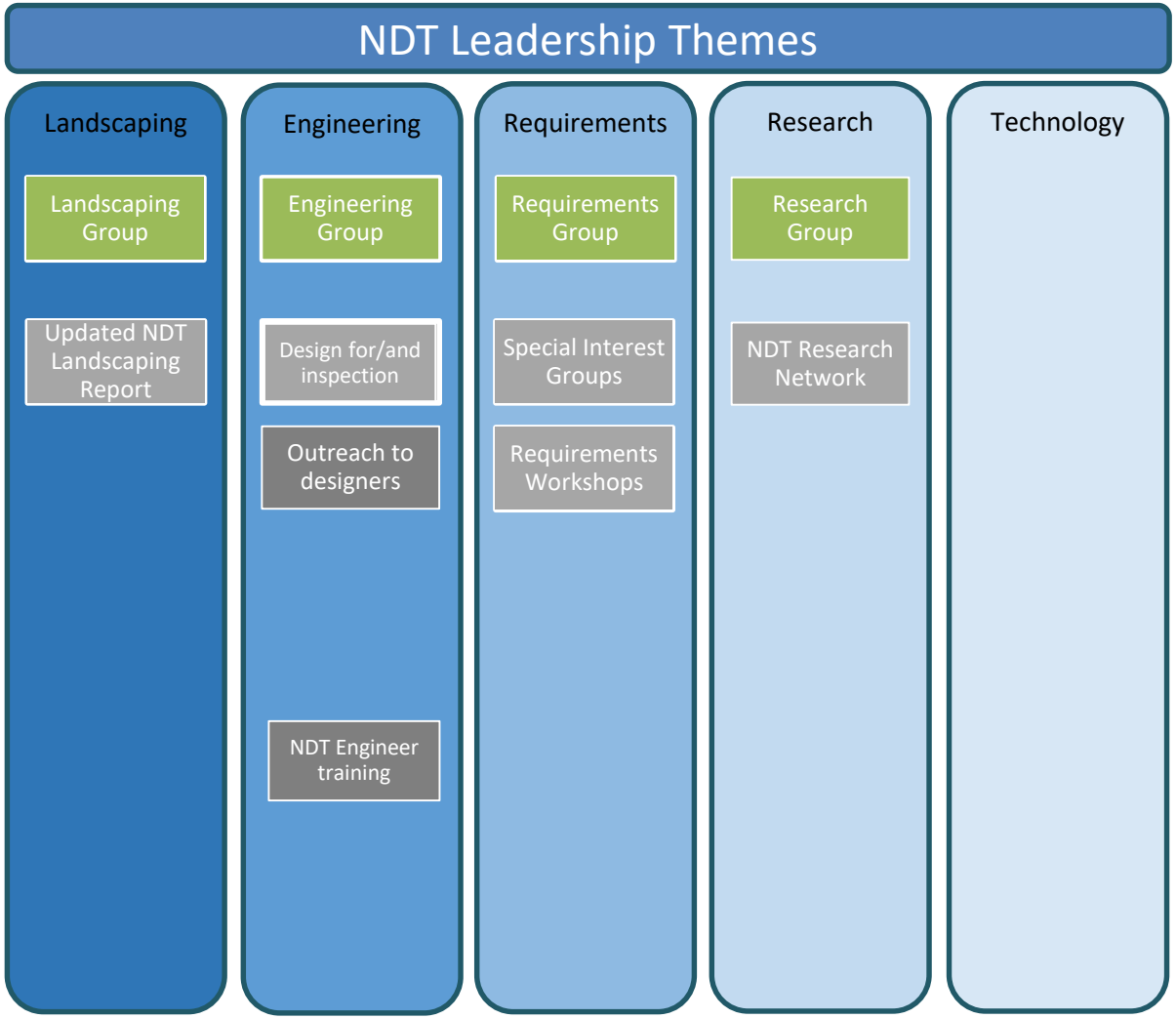
NDT Leadership Forum



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Technology User Groups

- BINDT Technology User Groups
  - Technique Validation and Qualification User Group
  - FMC User Group – now an ICNDT SIG
    - Truly international with about 30 members including from academics through supply chain, to end-users
    - Multi-frame FMC File Format Specification published based on HDF5
    - Terminology document finished and considered for inclusion in a standard.
  - Terahertz User Group (link to ASNT microwave group)
  - Air-coupled Ultrasound User Group
  - Laser Ultrasound User Group
  - Nonlinear Ultrasound User Group

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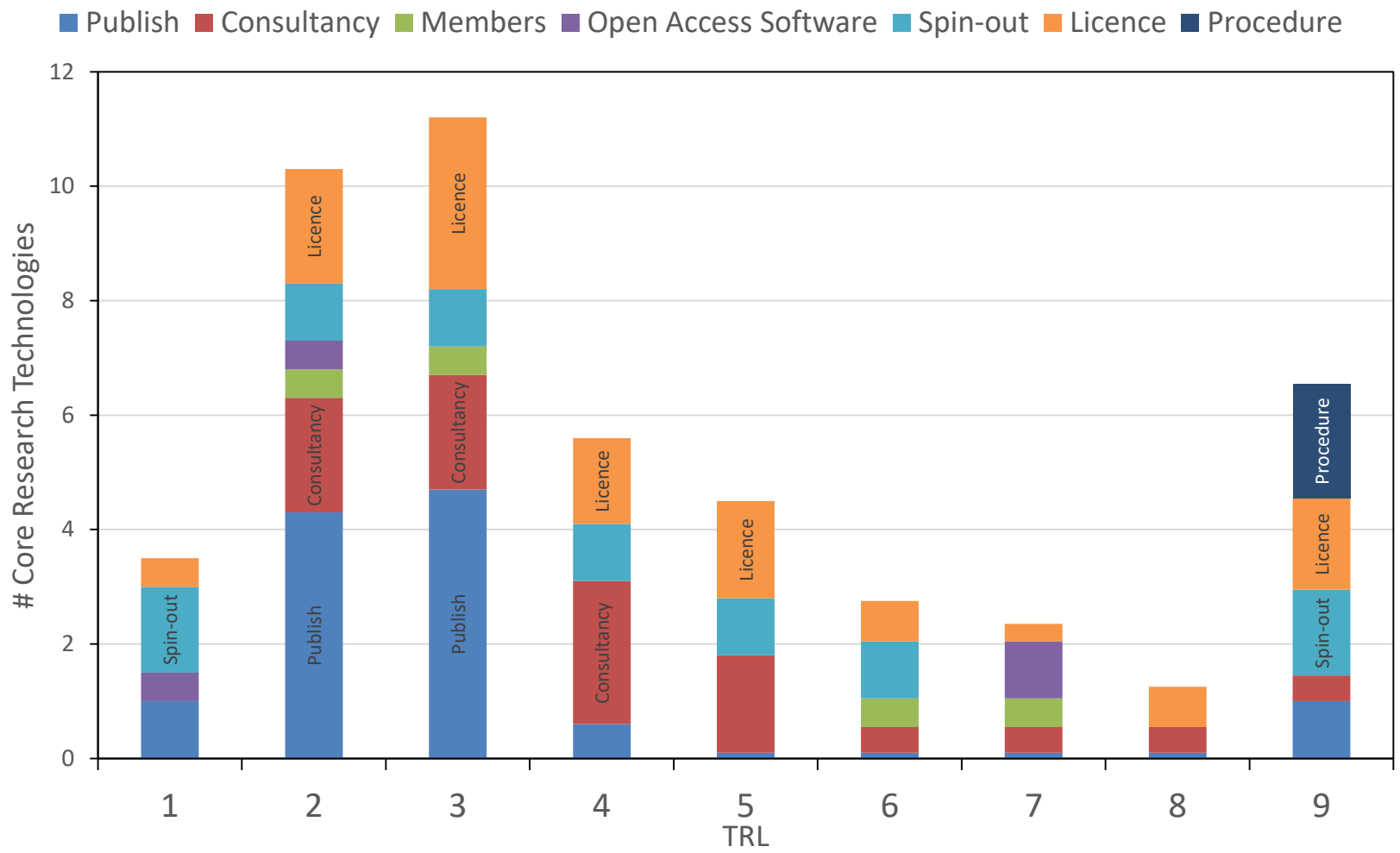
RCNDE Technology Transition



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Summary of transitioning methods

- Initial study of relative benefits of different transitioning methodologies

Suppliers	Validation	Hardware	Algorithms	Procedures
Single supplier	Low control	Exclusive Licence	Exclusive Licence	Provide report to ind. member
	High control	Spin-out	Spin-out	Work with RCNDE ind. member
Multiple suppliers	Low control	Publish, non-exclusive licence	Publish, Open-source.	Publish
	High control	(Hardware equiv-alent of ADSS)	Publish + Consultancy + ADSS	Standards and regulation

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Technology

- Technique Qualification
  - BINDT Aerospace Group is producing a guidance document.
- Model-assisted Qualification
  - A linked MoD programme is producing a protocol for Model-assistd Qualification
- Standard file formats
- Development of standards

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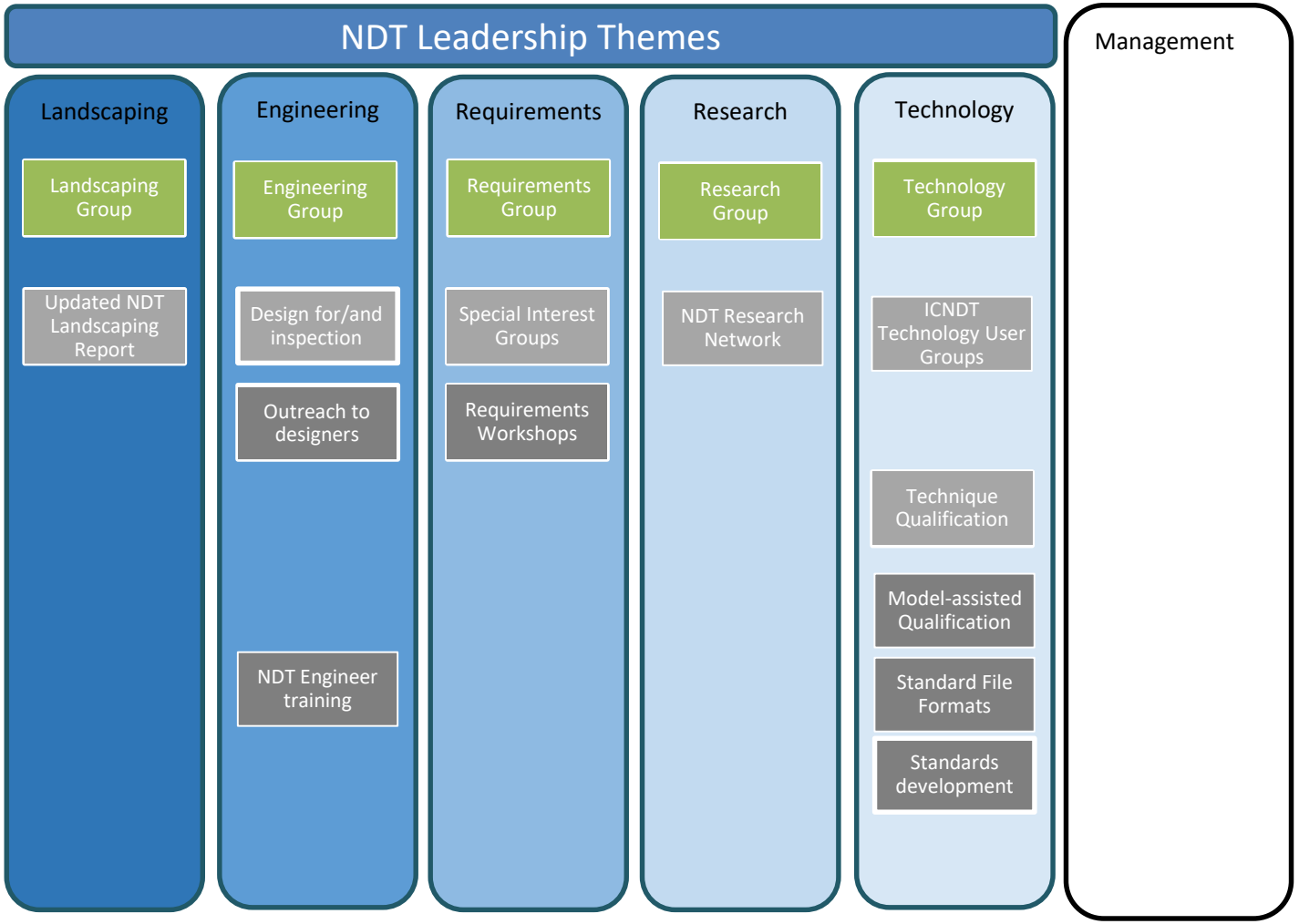
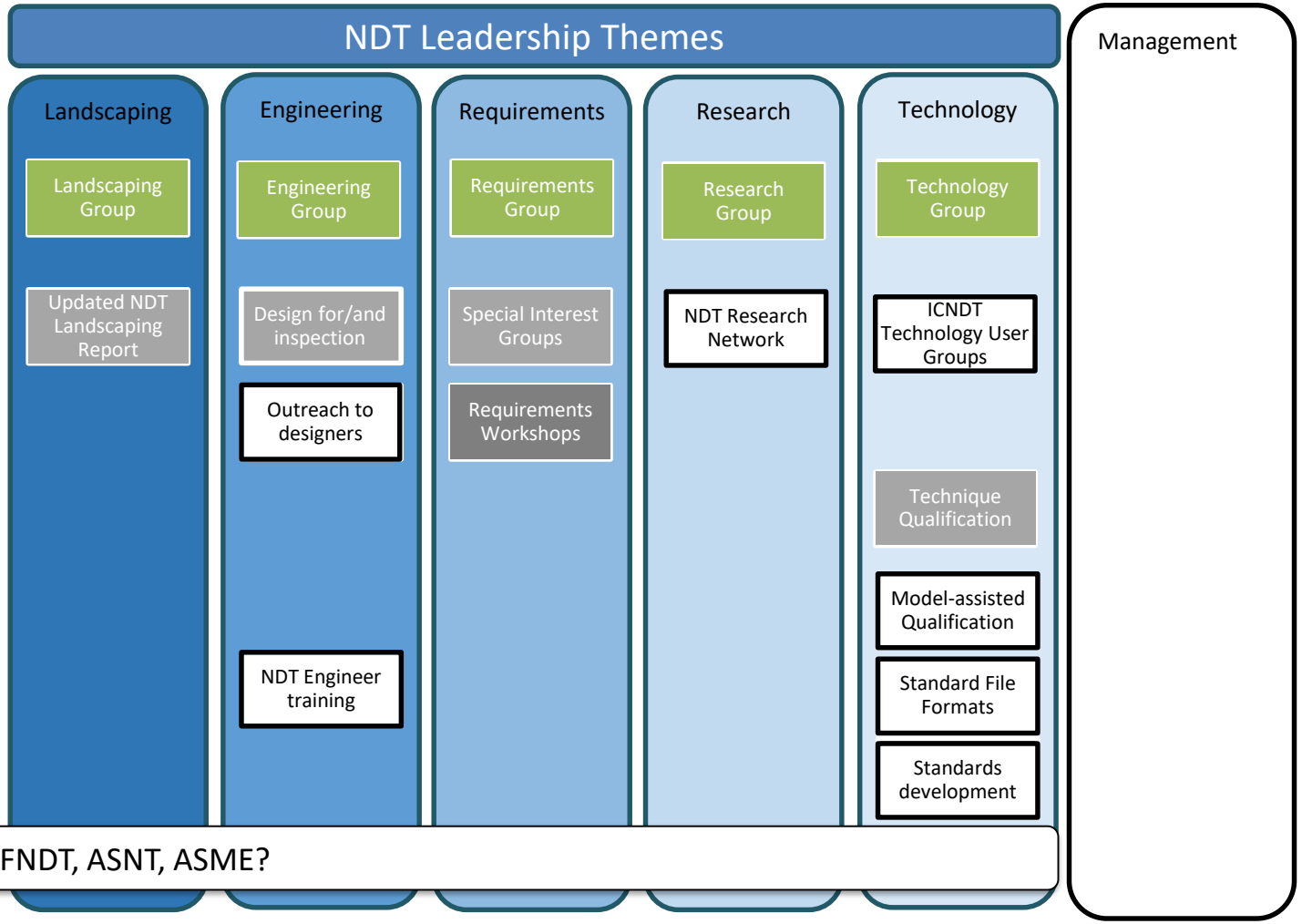
Possible NDT Leadership Forum



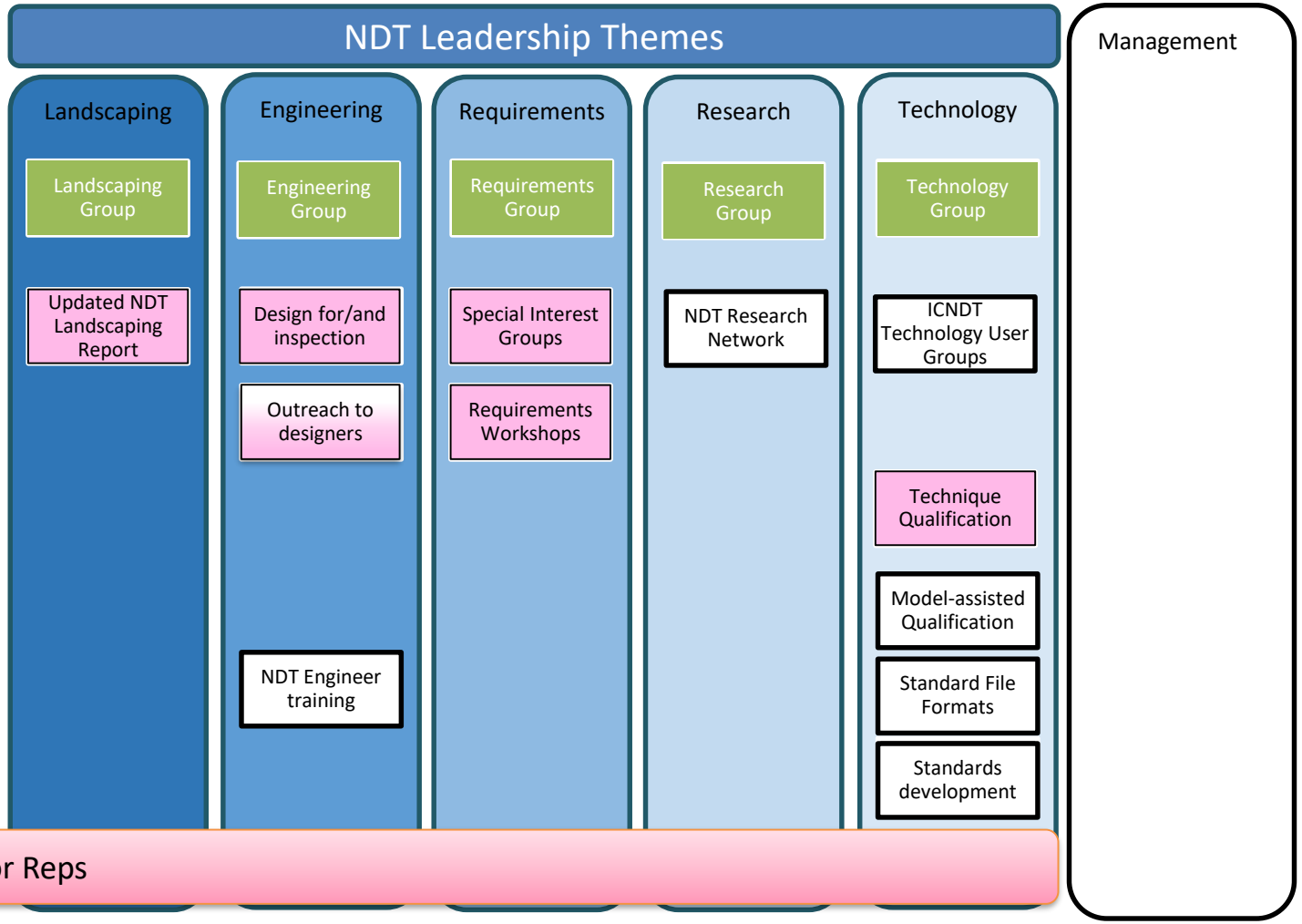
Possible NDT Leadership Forum

- International (in white)



Possible NDT Leadership Forum

- International (in white)
- Other institutes (in pink)



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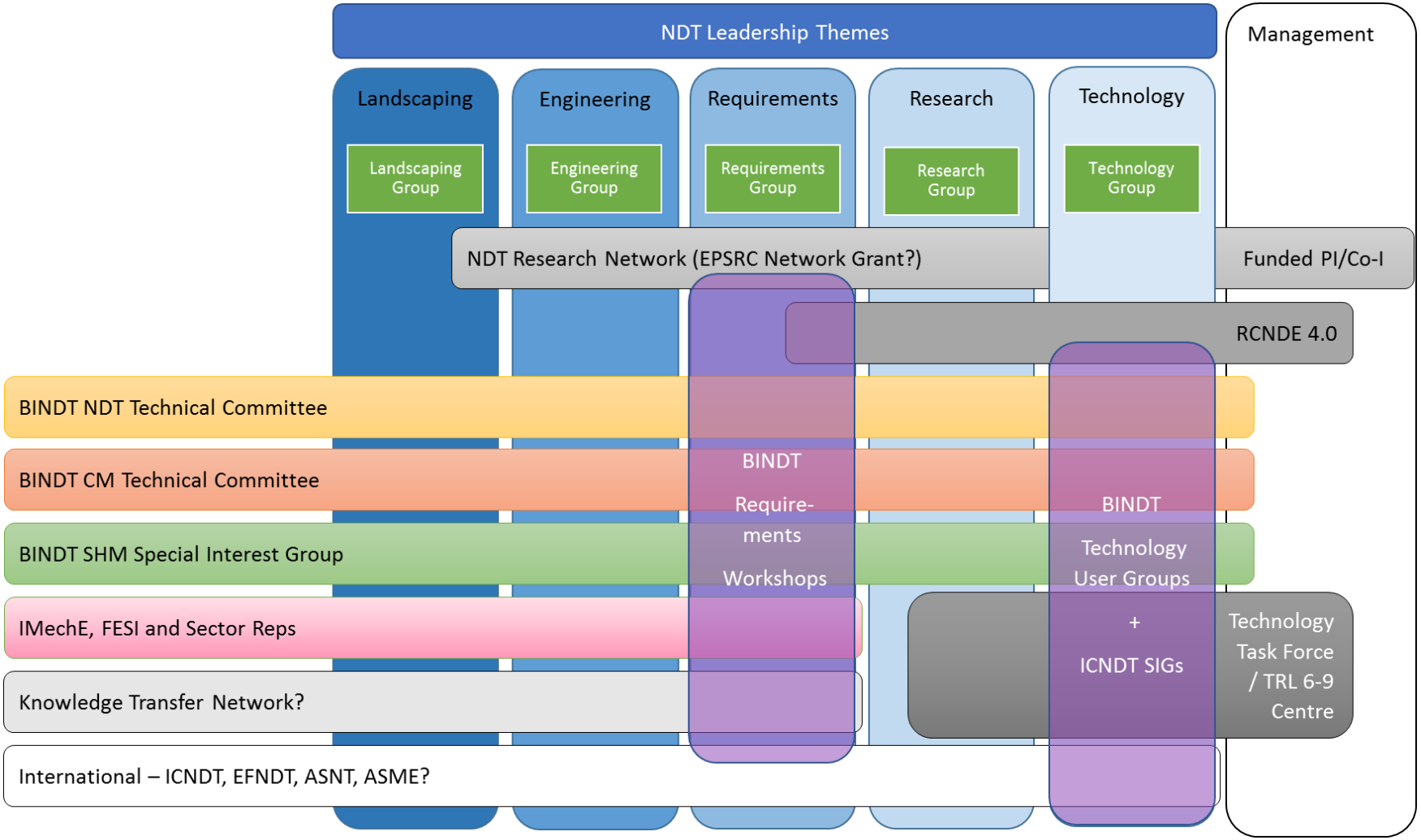
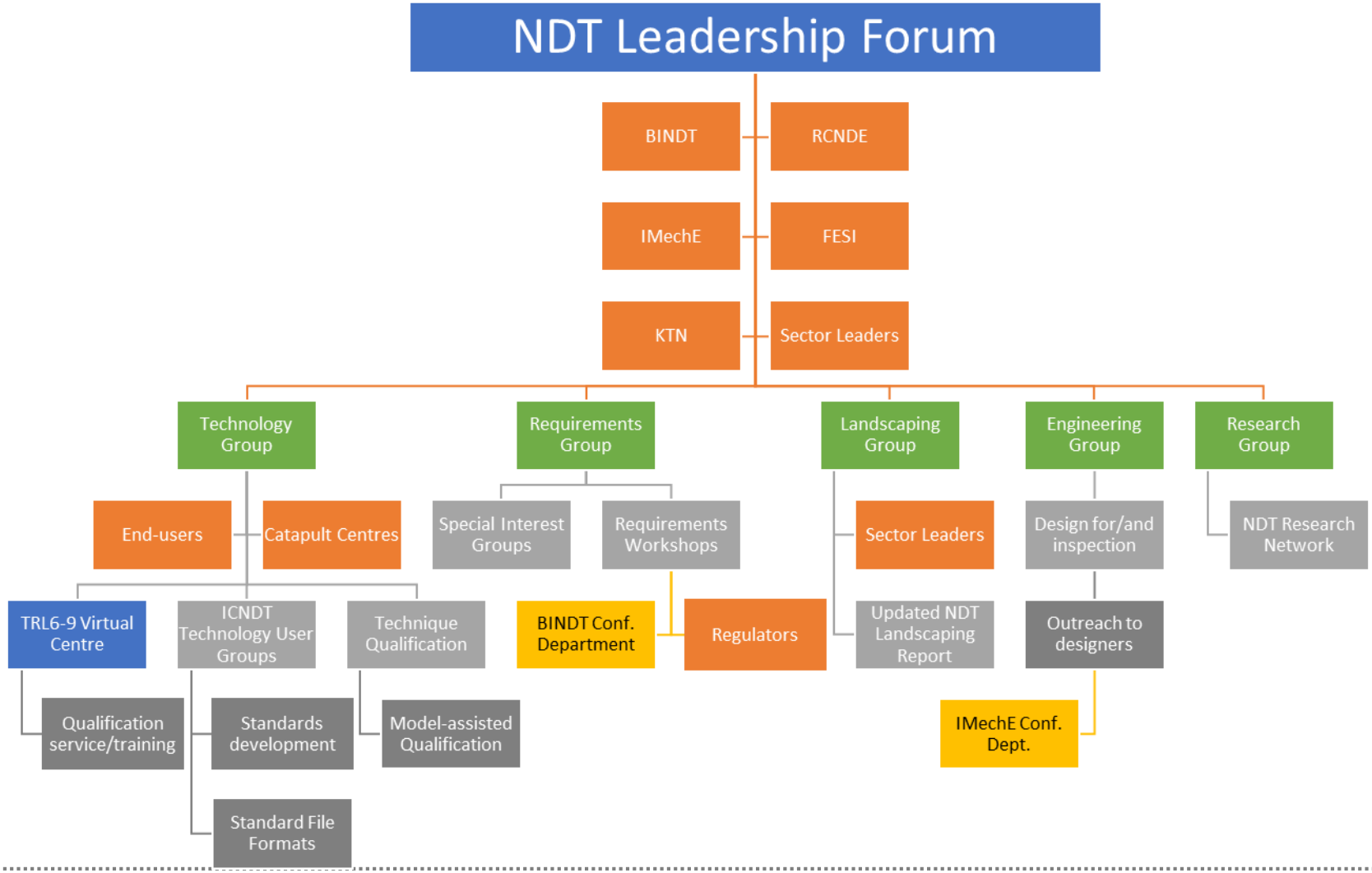
Possible NDT Leadership Forum



Possible NDT Leadership Forum



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Summary of NDT Leadership Forum

- An NDT Leadership Forum has a role in:
  - Maintaining a current landscape document to inform government
  - Establishing a sound engineering basis for the application of NDT
  - Determining the NDT requirements across all sectors
  - Overseeing the body of research undertaken in the UK and building an international academic network.
  - Easing the transitioning of NDT technology into industry by:
    - establishing technology user groups
    - developing guidance for technology/technique validation
    - specifying standard file formats
    - contributing to standards

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BINDT's new Industry 4.0 working group

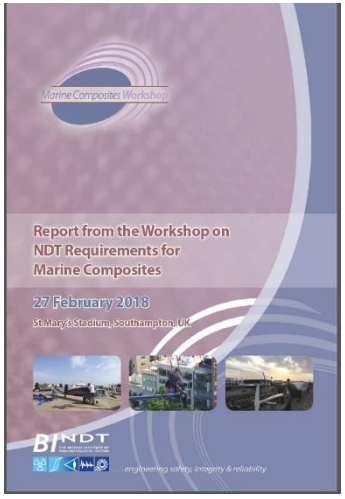
Jointly reporting to the NDT and CM Technical Committees.

How should we respond?

- BINDT / RCNDE ‘Workshop on Cross-sector NDT and CM Requirements in Industry 4.0’
  - Run by the new BINDT ‘NDT 4.0 Working Group’
  - In collaboration with RCNDE

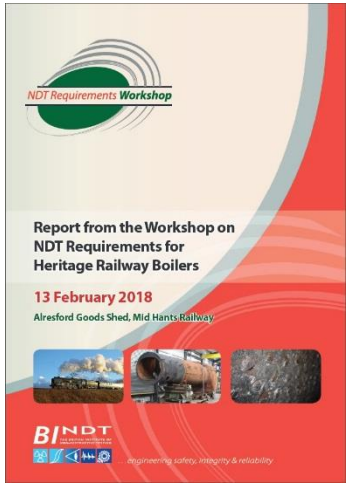
Aerospace Composites February 2016

Automotive Composites March 2017



Marine Composites February 2018

Wind turbines February 2019



Heritage Railway Boilers, Feb. 2018

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Technique and technology validation

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Technique and technology validation

- NDT Technology validation
  - This is a scientific study of capabilities and limitations
  - It is rarely done well
- Technique validation
  - ENIQ principle relies on a ‘Technical Justification’ document but who is qualified to write/approve it?
  - Aerospace Group protocol on technique validation seeks to provide guidance on this.
  - ASNT call this person an ‘NDT Engineer’.
  - BINDT should consider offering an ‘NDT Engineer’ qualification or guidance on specifying a level of competence.

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Technique and technology validation

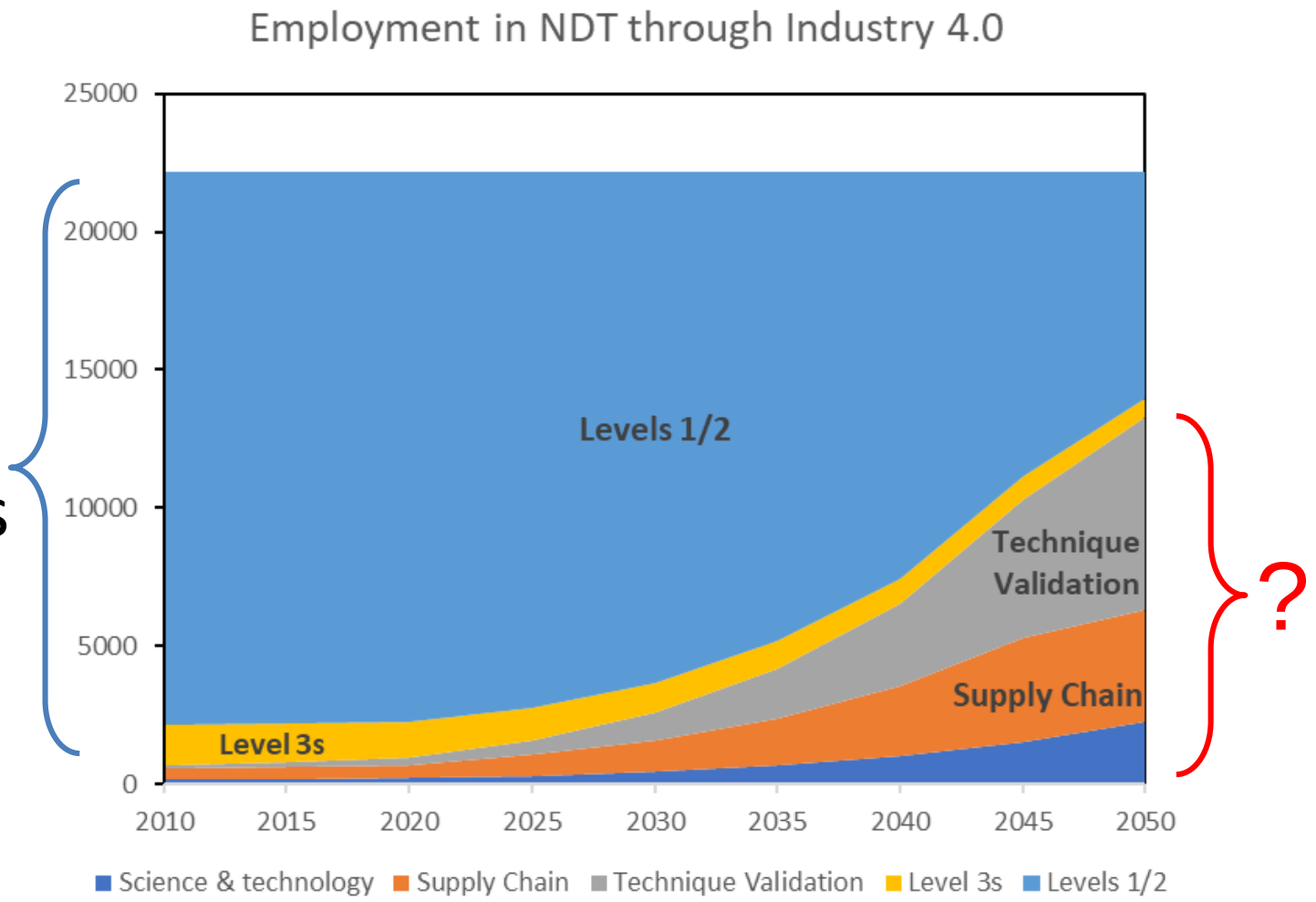
- Autonomous decision-making qualification?
  - ENIQ's Qualification Committee is developing guidance on qualifying machine-learning methods.
  - Rolls Royce now have an internal document on validation of machine-learning and artificial-intelligence methods.
- Numbers of training data sets is orders of magnitude greater
  - Simulation of data sets will be key to validation methodology.

Technique and technology validation

- BINDT's role?
  - Collaborate internationally
  - Industry 4.0 Working Group remit
    - Work with ENIQ and industry members of BINDT
    - Work with the new NDT Leadership Forum
    - Review proposed validation protocols
  - Work on training and qualification *for* technique and technology validation

Employment skills and training

BINDT emphasis



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Crisis or opportunity? – the way forward

- We need to treat NDE 4.0 as an Opportunity.
  - BINDT has excelled at personnel certification, but the future of NDT will be different.
  - We need to change emphasis so we are ready for Industry 4.0 / NDE 4.0
  - In the UK we are leading in many areas in the NDT field, but *not* strategically.
  - Other NDT societies are ahead of us but we need to engage internationally, and catch up!
  - Plans are in place but BINDT needs to do more.