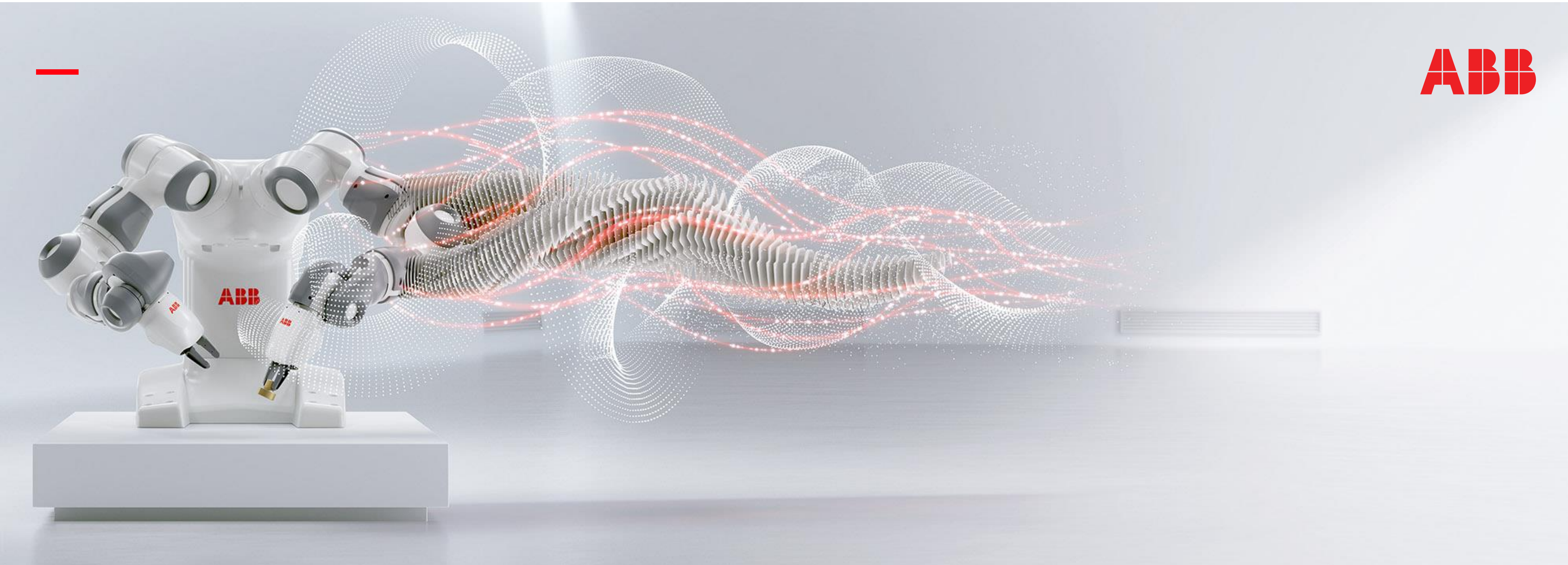


2ND IEEE CONFERENCE ON CONTROL TECHNOLOGY AND APPLICATIONS, COPENHAGEN, AUGUST 22, 2018

Control, Automation & Digitalization: An Industrialist's Perspective

Peter Terwiesch, President Industrial Automation, ABB Ltd

Introducing ABB

What *(Offering)*	**Pioneering technology**		
	Products 58%	Systems 24%	Services & software 18%
For whom *(Customers)*	**Utilities**	**Industry**	**Transport & Infrastructure**
	~35% of revenue	~40% of revenue	~25% of revenue
Where *(Geographies)*	**Globally**		
	Asia, Middle East, Africa 38%	Americas 29%	Europe 33%

~$34 bn revenue	~100 countries	~132,000 employees

Megatrends

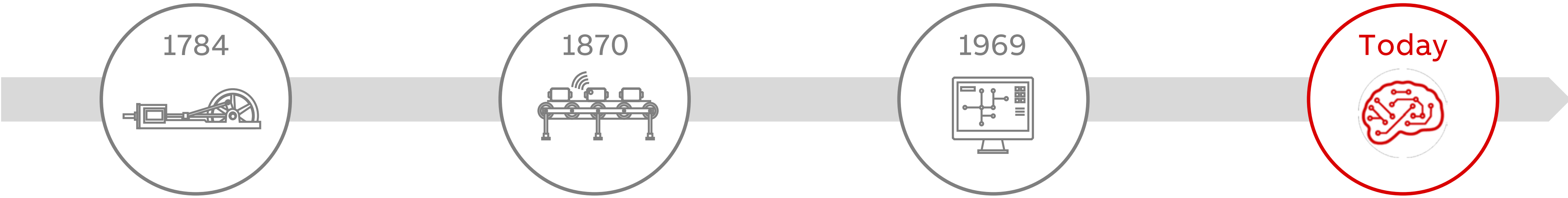
The Energy Revolution

The Fourth Industrial Revolution

Utilities | Industry | Transport & Infrastructure

“Big shift” in automation

Shaping the 4th Industrial Revolution



1st Industrial Revolution

Steam, water, mechanical production equipment

2nd Industrial Revolution

Division of labor, electricity, mass production

3rd Industrial Revolution

Electronics, IT, automated production

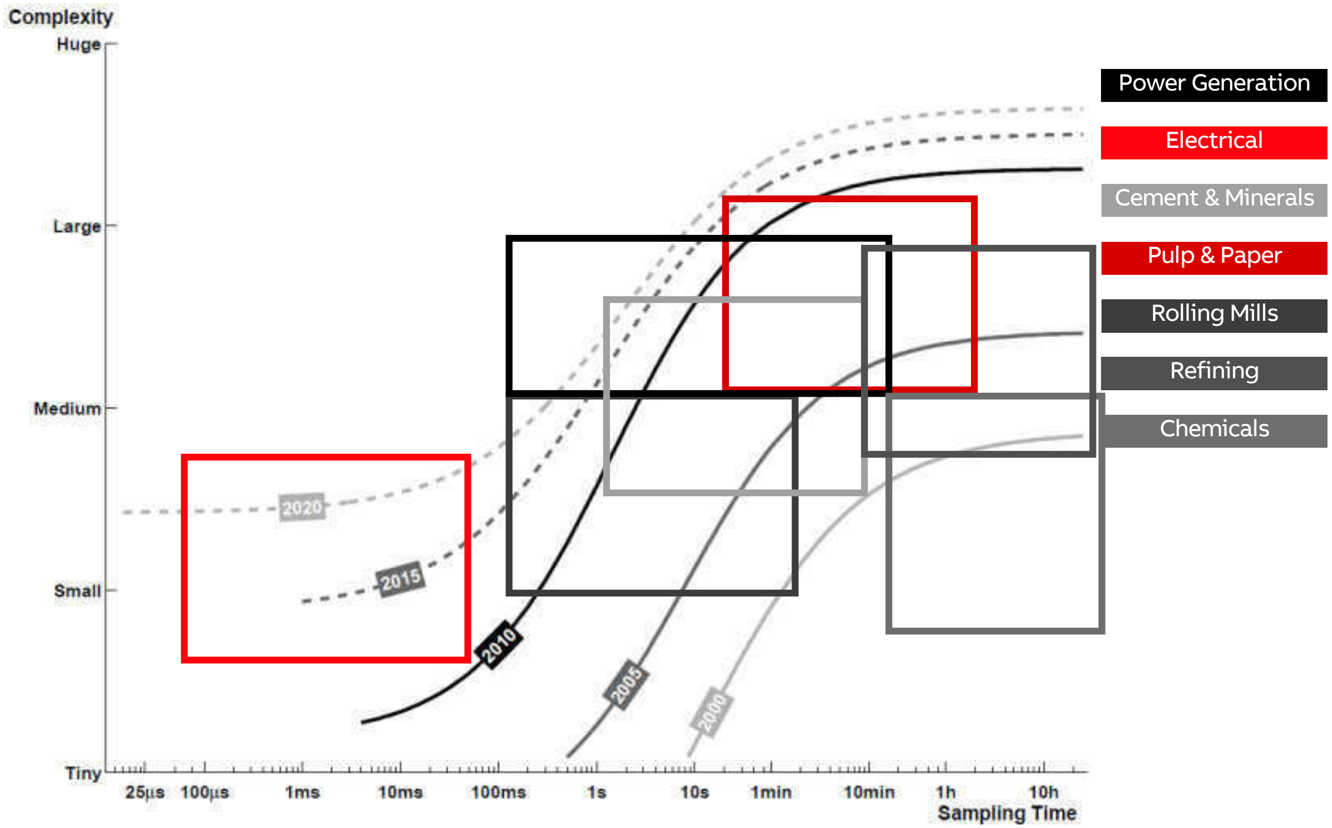
4th Industrial Revolution

Cyber-physical systems, optimized production, business transformation, automation of knowledge-work


POLAR ONYX
CEONA

Model predictive control: advancing the frontiers

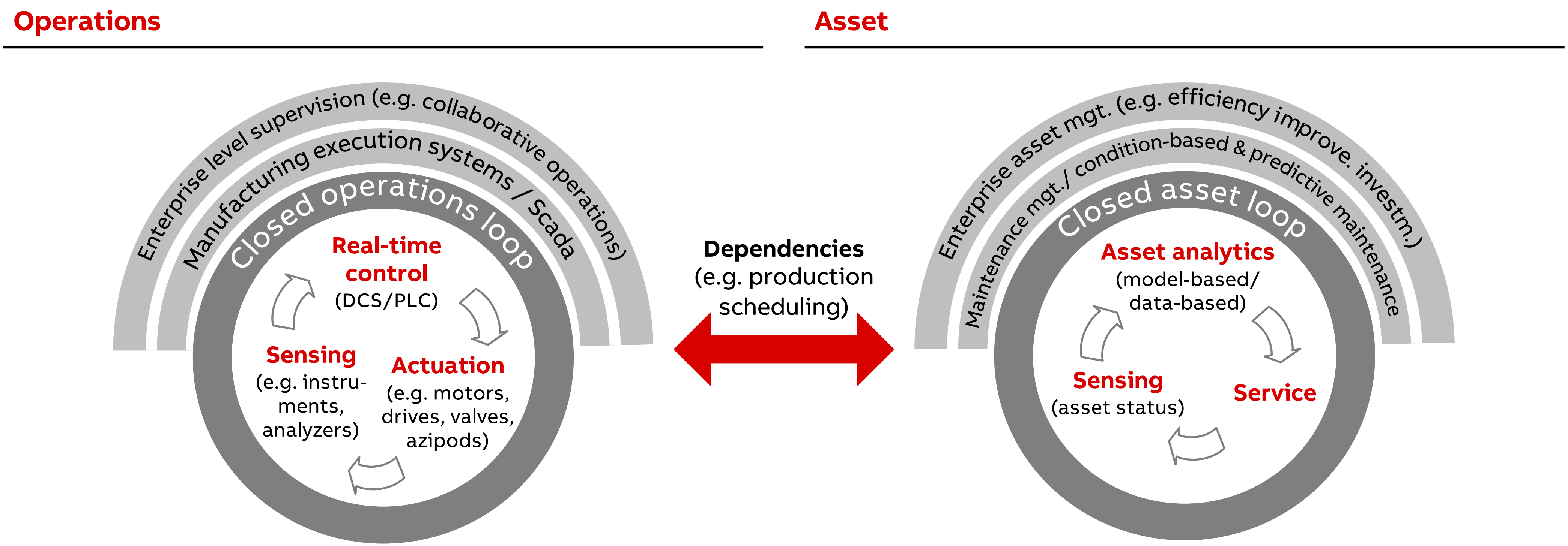
Increases in processing power allow us to address ever more challenging industrial control requirements



Source: ABB

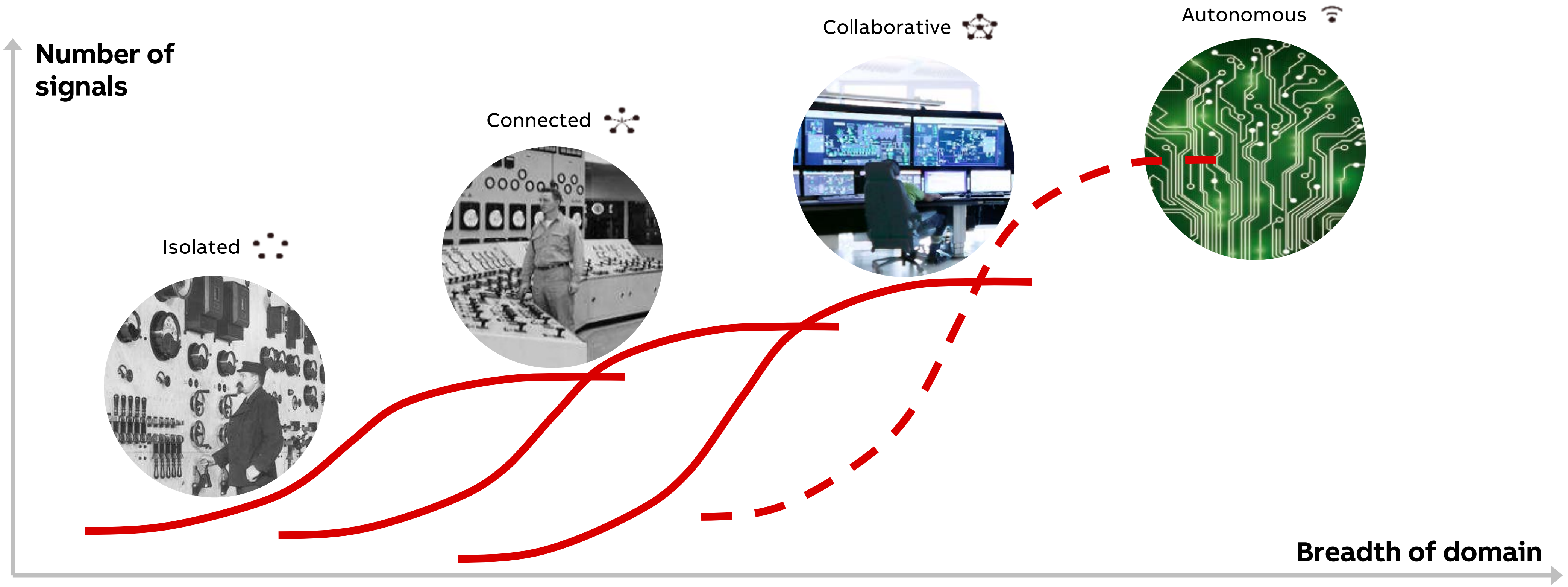
Adding value by closing new loops

Moving up the control stack, closing asset loops, coupling higher operations and asset loops



Automation was powered by “Moore’s Law”, what’s next?

Broader application space, going beyond classical control, move towards autonomous



New sensors and algorithms enable transition towards autonomous systems

Descriptive Analytics

Diagnostic Analytics

Predictive Analytics

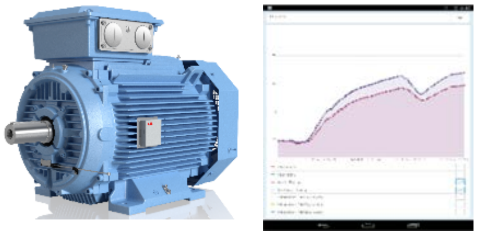
Prescriptive Analytics

Autonomous Systems

On equipment level:
Enable to **detect** and resolve problems

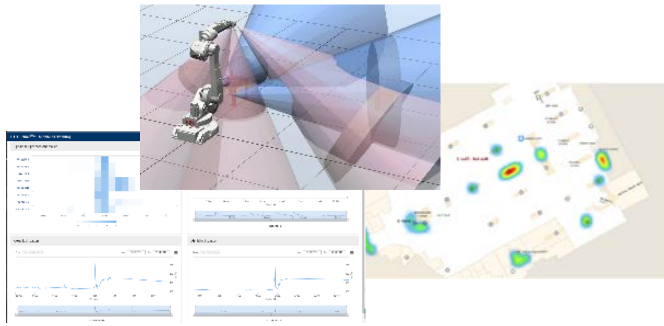
On sub-system and system level:
enable to **prevent** problems

On system level and across:
enable to **solve** problems



Diagnostic analytics for plant asset supervision for service teams

Augmented intelligence to optimize alarm management for operators



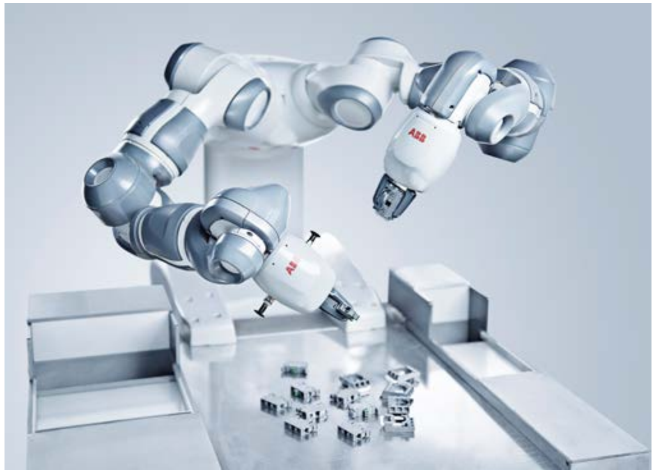
Autonomous operations, inspection, and maintenance

Today's intelligent devices are a key enabler for digitalization

Intelligent devices include sensors and control loops in themselves and generate lots of data

LV Air Circuit Breaker SACE Emax 2

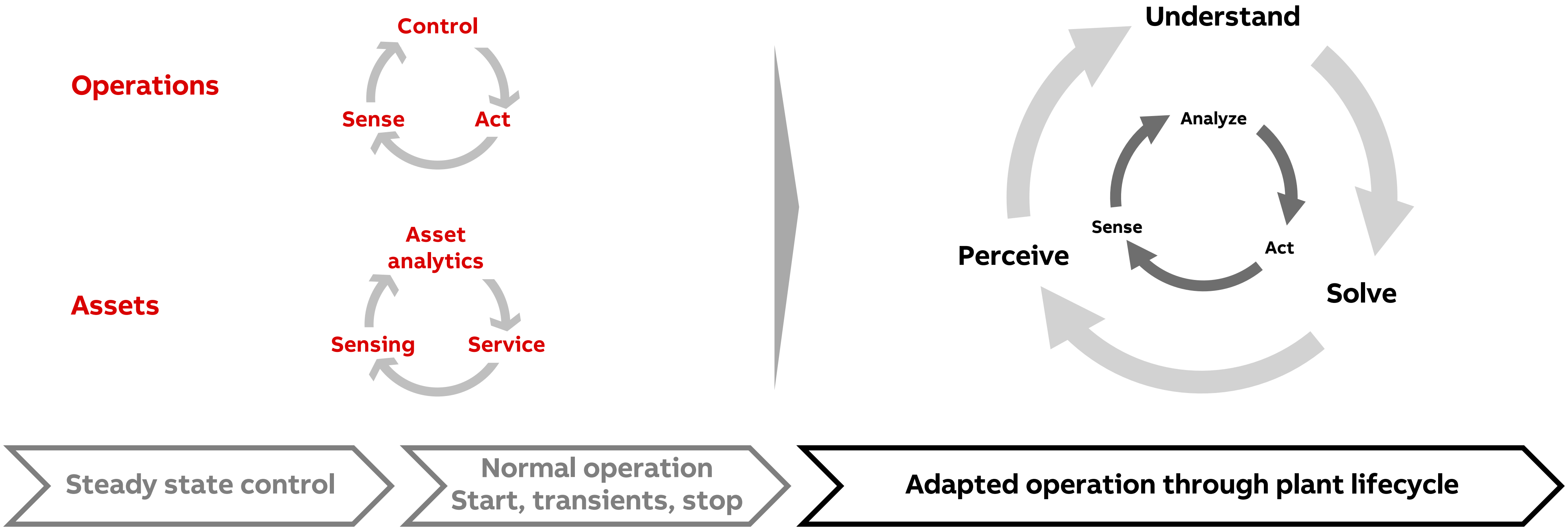
Yumi® Collaborative Robot



Mobile Natural Gas Leak Detector

Paradigm shift: from automated towards autonomous

Close higher-level operations loops, start to close asset loops automatically and take more autonomous decisions in real time



Towards autonomous systems: levels of autonomy

Going from level 2 to level 3 is a major step in terms of liability (and seems several years out in the car industry)

Level	Autonomous driving	Autonomous ships	Autonomous plant/factory
0	No autonomy: The driver is in complete control without assistance.	No autonomy: The captain is in complete control without assistance.	No autonomy: The operator is in complete control without assistance.
1	Driver assistance: The vehicle can assist or take control of speed or lane position through lane guidance.	Navigation assistance: The ship can assist in journey planning (wind, waves, currents, energy efficiency) or control speed.	Remote operator assistance: The operator can assist outside personnel or be assisted by digitally connected experts.
2	Occasional self-driving: Vehicle can take control of speed and lane position in some situations, driver always responsible.	Occasional autonomy: Ship can take control of speed and navigation in some situations, captain always responsible.	Support for operators on demand: The operator "pulls" support provided by intelligent systems and acts.
3	Limited self-driving: Vehicle is in full control in some situations and informs driver when to take control (fall-back).	Limited autonomy: Ship is in control of its course in limited situations and informs captain when to take control (fall-back).	Plant provides support to operators by actively alerting to issues and proposing solutions with the operator confirming.
4	Full self-driving under certain conditions: Vehicle in full control in these conditions (e.g. highway).	Full autonomy under certain conditions: ship in full control in these conditions (e.g. docking)	Autonomous operation under certain conditions: Actions still supervised by the operator.
5	Full self-driving under all conditions. Driver my be completely absent.	Full autonomy under all conditions.	Fully autonomous operation under all conditions

Source: Autonomous driving based on SAE & NHTSA standards.

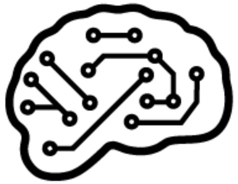
Digital technologies accelerate innovation in industrial markets

Enablers often from govt labs (1980s), IT enterprise level (1990s) and consumer mobile (2000+)

Virtual/augmented reality

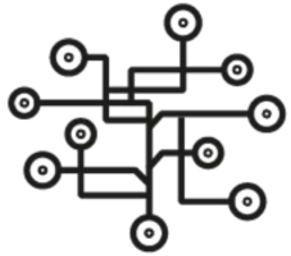
Software-defined machines

Machine learning

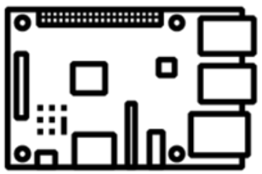


Time-sensitive networking

Big data



Inexpensive computing

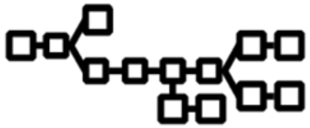


Cloud computing

Cybersecurity

Connectivity

Blockchain



Expectations towards digitalization in industry

Customer value drivers along the asset life cycle

Asset lifecycle

Plan / design → Build → Operate

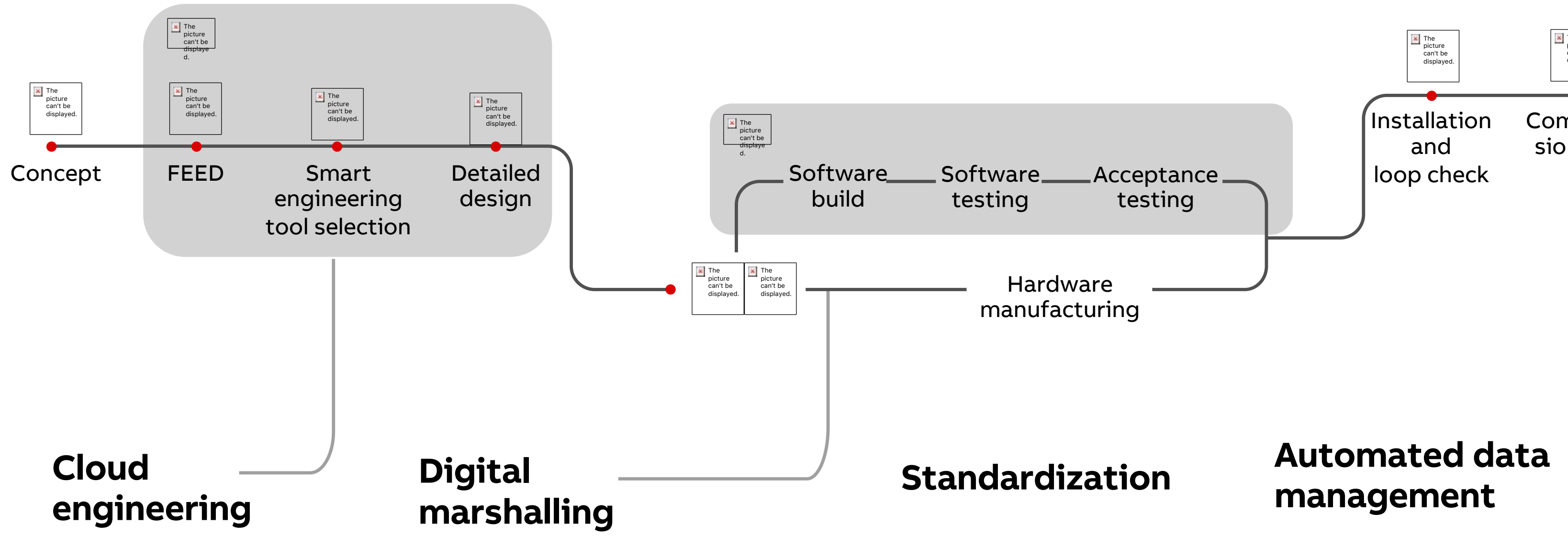
Customer value

Reduced cost, schedule, risk → **Safety, productivity and energy efficiency**

ABB

Digitalization enables new ways of working

Intelligent Projects™ to cut cost, schedule and risk



Customer benefits

25% quicker schedule completion

20–30% reduction in CAPEX and OPEX

60% space savings

40% fewer start-up and installation hours

Improvement from digitalization for green and brownfield projects

Intelligent Projects™ | **Collaborative Operations™**

Plan — **Build** — **Operate** — **Optimize**

Customer value:

25% quicker schedule completion

20–30% reduction potential in CAPEX and OPEX

40% fewer start-up and installation hours

Reduce cost, schedule, risk

Customer value:

5-10% improved uptime with intelligent solutions

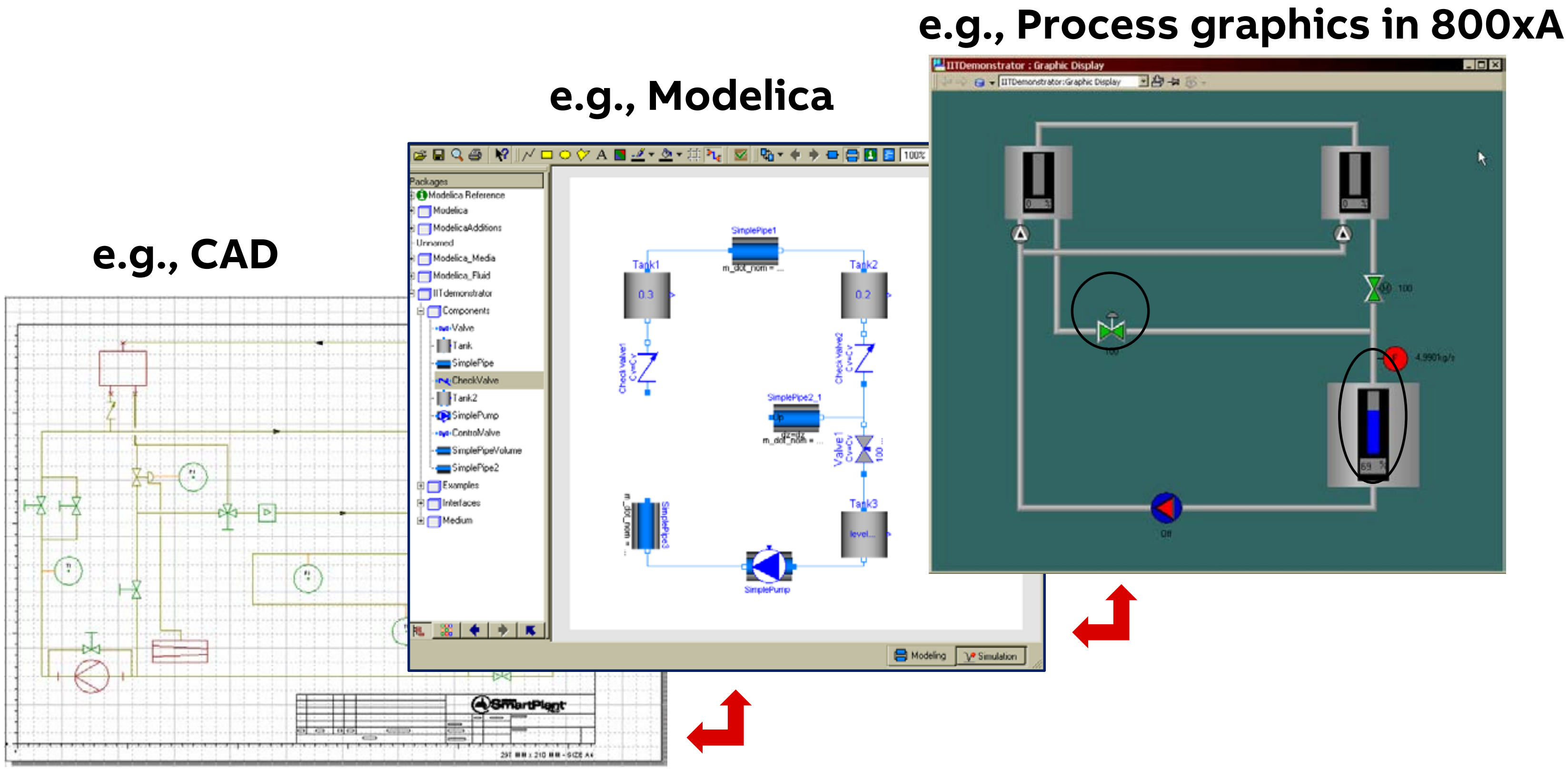
Up to 30% reduction potential in OPEX through predictive analytics

Up to 50% reduction potential in maintenance costs

Increase safety, productivity and energy efficiency

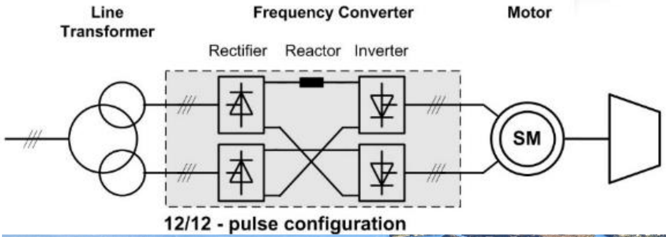
Modelling vision: automating automation

Automatically generate consistent models for control and optimization from available digital information



Model-based control: NMPC for Load Commutated Inverters

Controlling 48 MW at 1kHz sampling rate



Goal

LCIs play an important role in powering electrically-driven compressor stations. Enable LCIs to ride through partial loss of grid voltage.

Solution

- **Auto-generated NMPC algorithm** (ACADO/qpOASES)
- Running at **1 kHz on AC 800PEC**

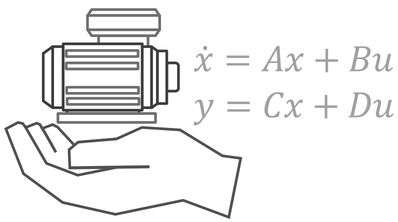
Results

Solution running at a key Statoil/GASSCO sites

- Two 41.2 MW compressor strings for gas export at first site
- Three 7.5 MW booster compressors at second site
- First successful ride-through November 2015

“Grey-box” data analytics combine physical & data-driven methods

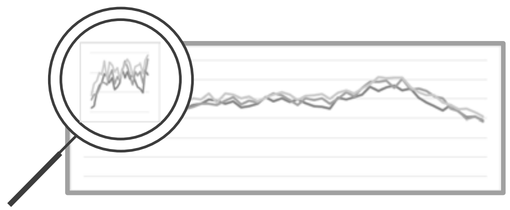
Model-based analytics



Model based on deep knowledge of the physics

+ Predict known effects that are represented in the model, even before data is available (design phase)

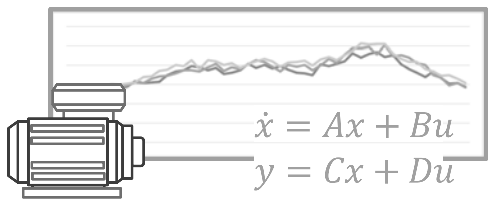
Data driven analytics



Observed behavior based on (a lot of) data

+ Predict effects that are difficult to model (e.g. ageing) but are observed in the data

Combined approach



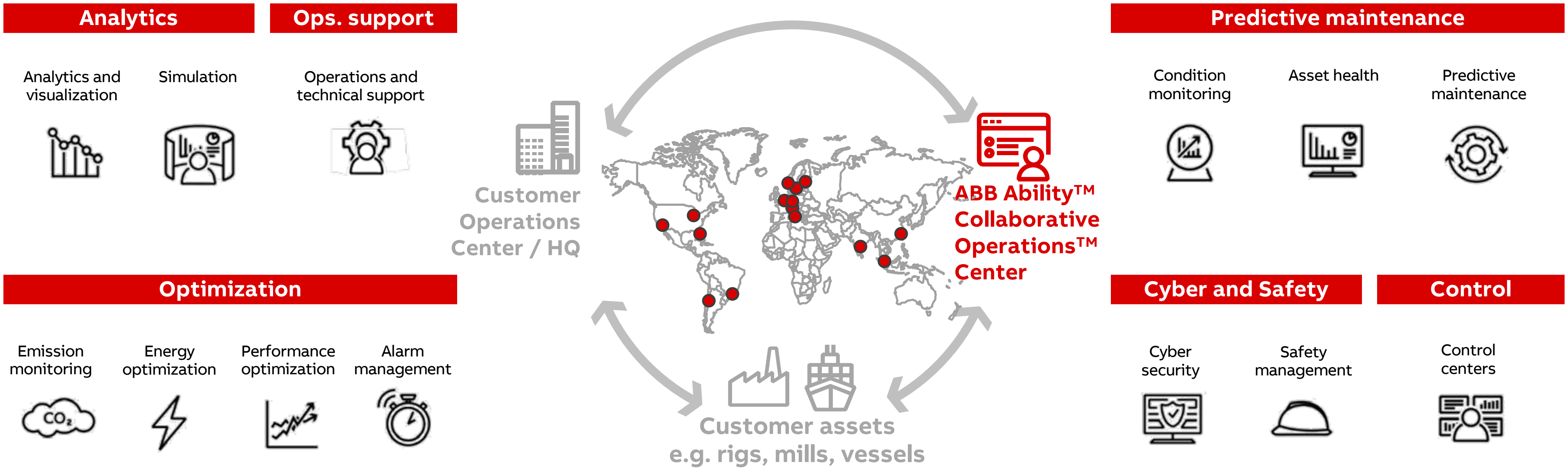
Collect and analyze data to
- Improve the models
- Detect unknown effects

Combine model-based with data-based approach to get the best of both worlds
- Domain experts to work with data scientists

Use the right analytics where it creates the best value, combining both approaches

Digitalization transforms customer collaboration during operations

Customers collaborate with ABB domain experts 24/7



Customer value: safety, productivity, energy efficiency

Collaborative Operations™

Customer examples from process industries

Aker BP (oil & gas)

Full scope of electrical, instrumentation, automation and telecom to enable digital transformation of value chain

Leading Indian cement manufacturer

Enterprise-wide digital service partner for energy efficiency and reliability enhancement

Metsä Fibre (pulp & paper)

Range of digital services for condition monitoring of critical equipment for newest Pulp & Paper plant

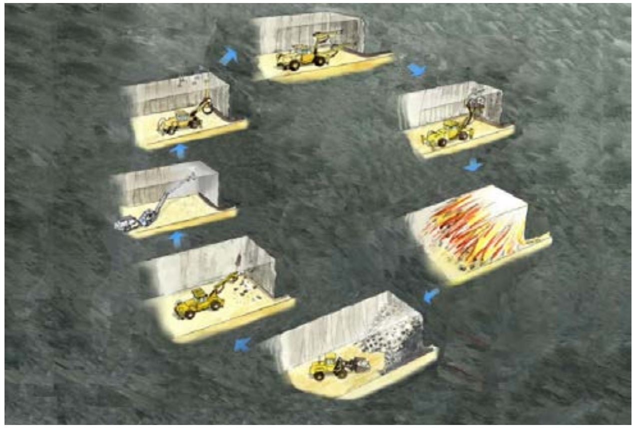
Genting (marine)

Propulsion, electric power plant, automation, software and digital services for five new cruise ships

Underground mining

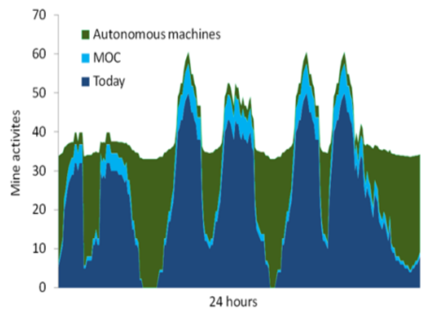
Automation keeps people out of harm's way and enables more continuous production

Production cycle



More than 50 operations in a harsh and high risk environment whereof 10% is automated*

Where automation can help



Source: A pragmatic approach to mine automation, ABB Mining Conference Cape Town, 2013

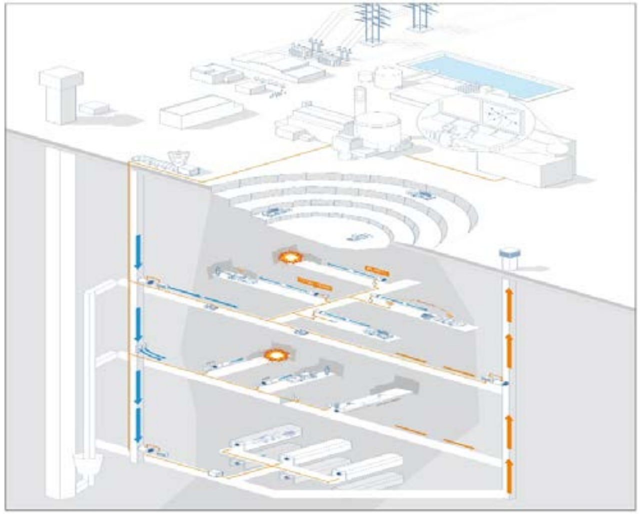
Potential for production increase of 40-50% through automation

 **Source: Final report Zepa, SMIFU Work package 1, Rock Tech Centre, 2011-12-15*

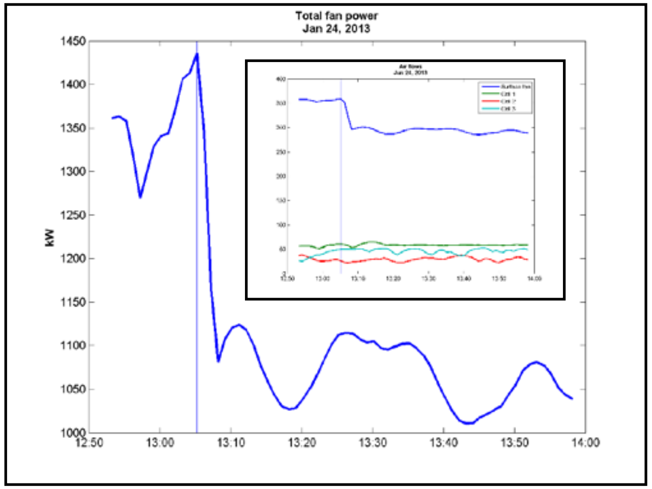
Closing new operations loops: smart ventilation

Tracking people and equipment to close loops for healthy working environment and energy efficiency

Ventilation where needed



Real-time feedback control



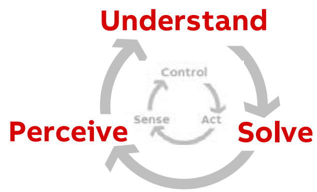
Extended lifetime of existing infrastructure
Energy consumption reduction of 30-50% validated on site

Closing new loops along the minerals flow

Mining example: increase the efficiency for ore extraction and beneficiation

Marine: from control towards autonomous vessels in shipping

Starting with docking assistance and situational awareness



Targets for the first step

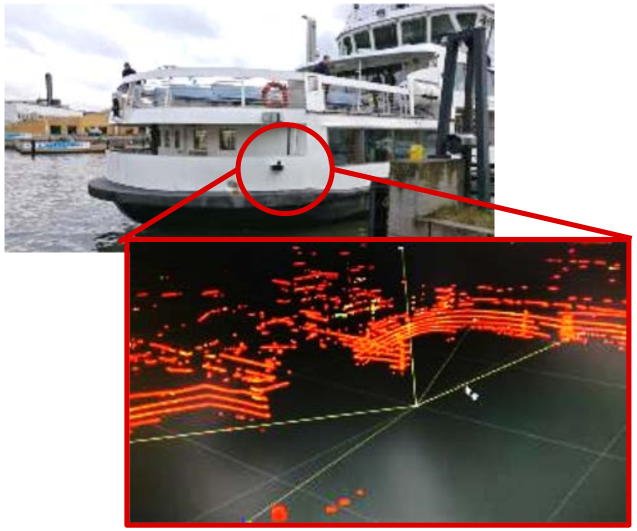
Better visibility in all weather conditions than a human can have by looking outside the window on a clear day

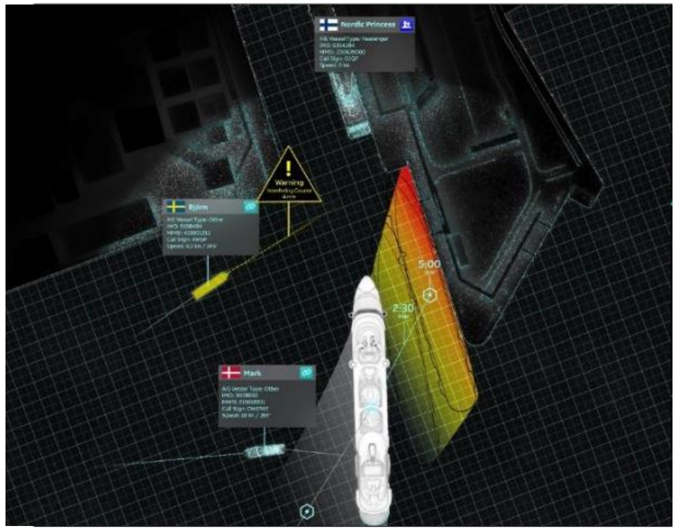
Direct access
for remote operation center

Value proposition

Safety, productivity (faster), efficiency (cost), comfort, usability, best practice sharing

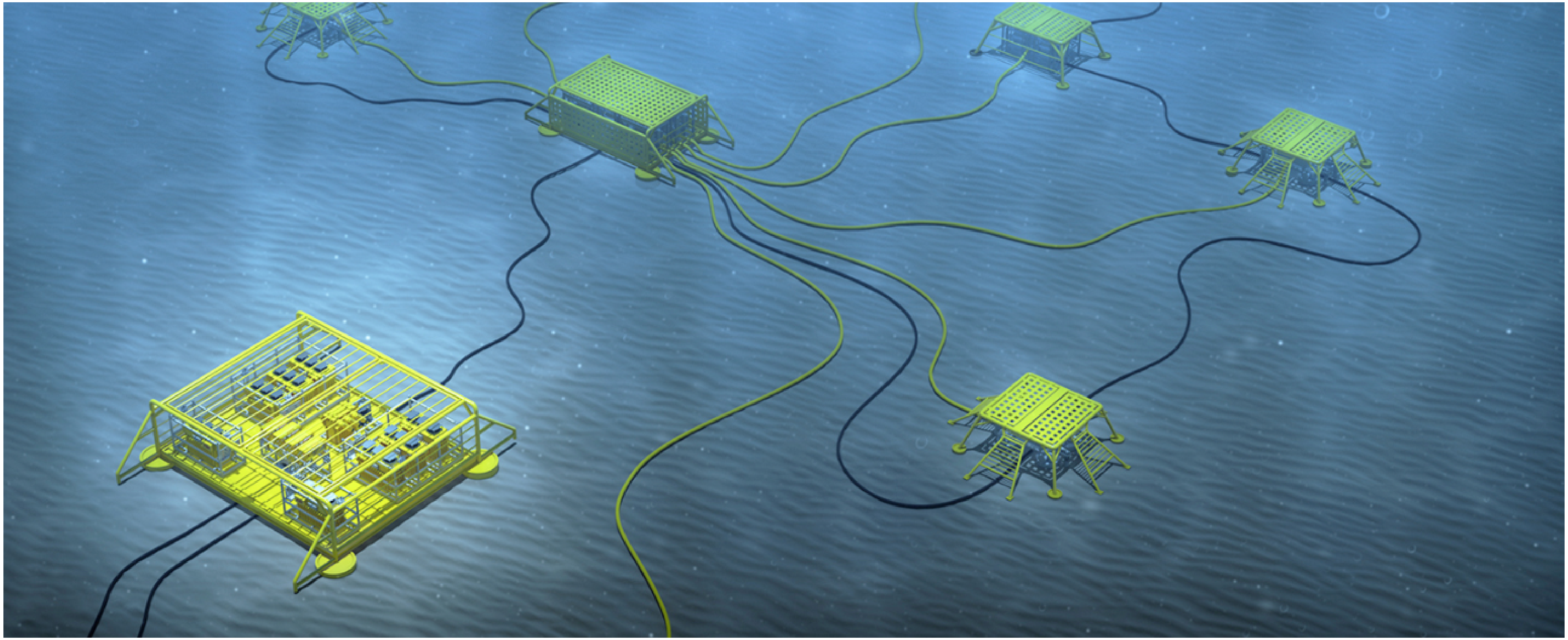
Draft control view for docking assistant pilot





Pilot: trial runs with Helsinki ferry "Suomenlinna"

Moving O&G production subsea requires increasingly autonomous operations



Robots will play a critical role in the future of discrete manufacturing

Shift from Low-mix/high-volume ➔ High-mix/low-volume needs Flexible Automation

Efficient at every level

Lower fixed costs and uncompromised quality and safety.

Reliable and available

Proactive, actionable intelligence that reduces incidents and speeds recovery.

Integrated ecosystem

Seamless collaboration across the value chain to better respond to customer needs.

Flexible and agile

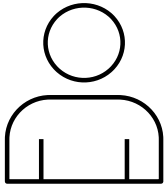
Automation processes which can quickly and efficiently adapt in real-time to new situations.

Flexibility, Collaboration & Digitalization

From robot programming to teaching and learning

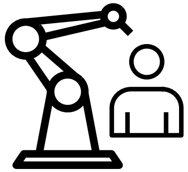
Ongoing paradigm shift in the accessibility, installation and commissioning of robots

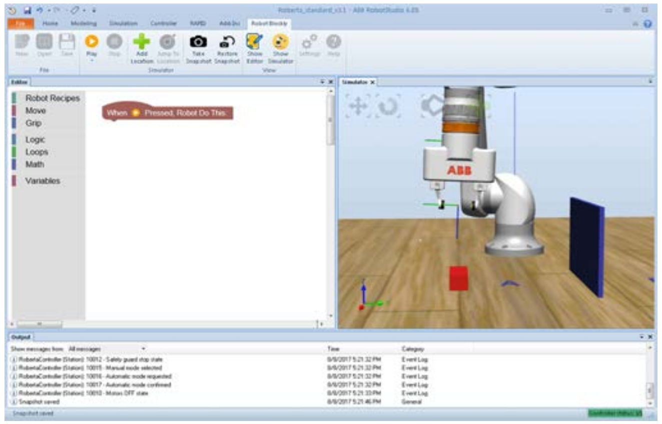
Yesterday: **programming**



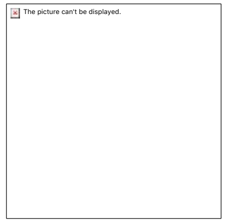
```
//Defining single location in RAPID

CONST robtarget
rb_Location1:=[[471.90028601, -
160.550088443, 259.855061587],
[0.0196845700059949, 0.999779442304461, -
0.00713127900217168, 0.00165206200050307],
[-1, -1, 1, 0], [9000000000, 9000000000,
9000000000, 9000000000, 9000000000,
9000000000]];
```

Today: **teaching**





Tomorrow: **learning**



Envisioning dedicated autonomous robots designed for target segments

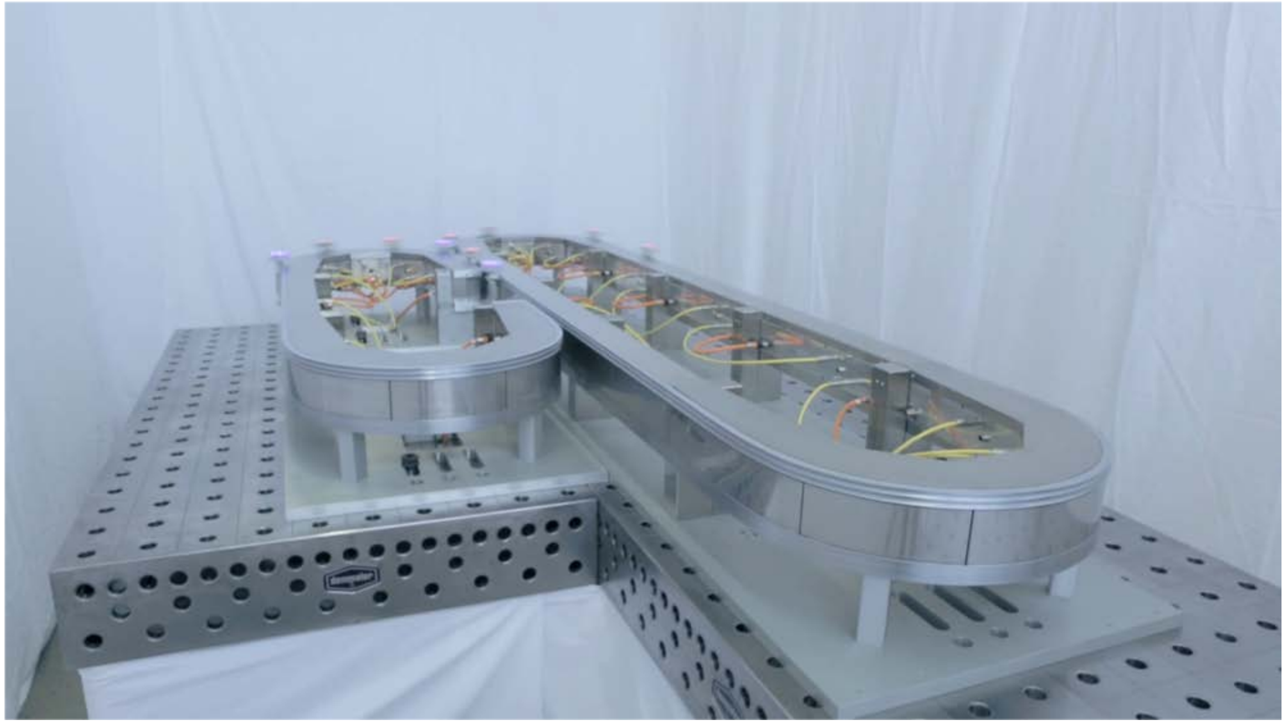
“Data center sheriff”

“Motor crawler”

“Transformer diver”

“Plant helicopter”

Complementing robotics: novel actuation enables software-defined flexibility, accuracy and speed within machines



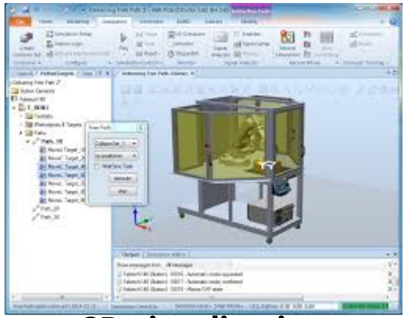
ABB

VR/AR: struggling in consumer but promising in industry

No privacy, form-factor issues and very clear ROI

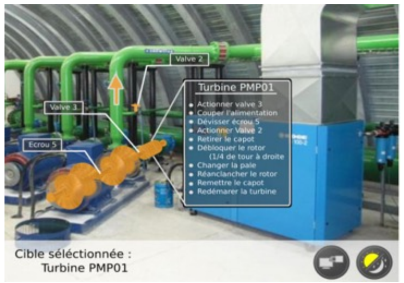
Consumer making technology pervasive+cheap

Industry has compelling use cases today



3D visualization

Improved safety, compliance



Contextualized info

Remote expert

Collaborative in discrete automation

Collaborative means different things to different people

Safety

Shared tasks and workspaces

No need for barriers or separation zones

Easy to Install

Lightweight, portable robot

Up and running in minutes, not hours

Easy to Program

Via intuitive devices or by lead through

No previous experience required

Simplification

Complete solution … not just a robot

No traditional safety infrastructure required

Flexibility via digitalization and collaboration in action

Discrete automation examples

The high cost of downtime

Connected Service’s cloud-based analytics prevents a potential motor failure from shutting down production.

Automation complexity

UKEENs are produced from interwoven cords in multiple color variations and sizes, in an organic and irregular shape

RobotStudio helps visualize and optimize an impossibly complex challenge.

Flexible automation

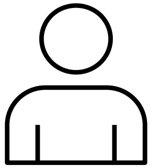
YuMi helps a small manufacturer in a high cost country stay globally competitive and grow.

Images courtesy of Saint-Gobain Sekurit, Keen and By Maryland Pride CC BY-SA 3.0 via Wikimedia Commons

Combine human and artificial intelligence for the next level of industrial progress

AI: “The ability to learn or understand or to deal with new or trying situations”[1]

Human



Systems designed by experts

+ Intuition

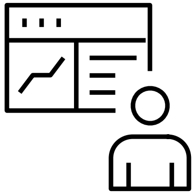
+ Creativity

+ Expertise

– Computation

Augmented

Experts supported by algorithms



Amplifying human potential

Artificial

Knowledge learned from data

– Intuition

– Creativity

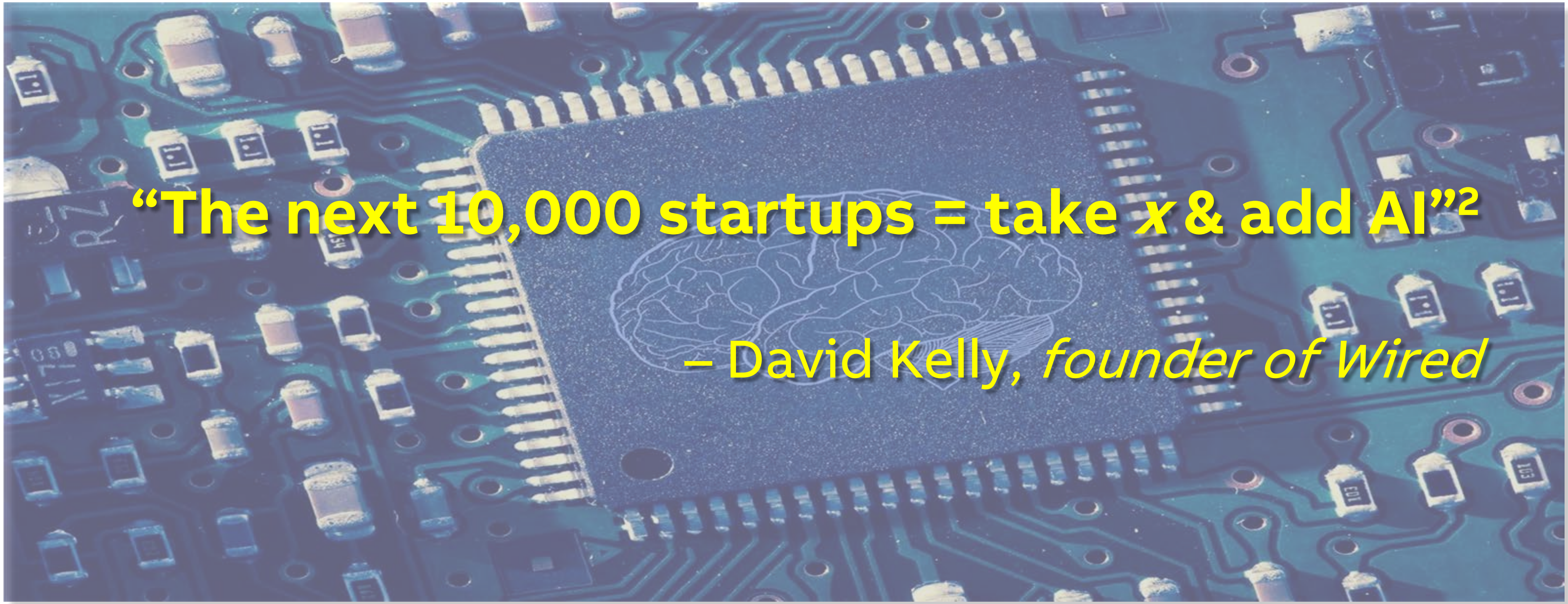
+ Expertise

+ Computation

[1]Webster referring to intelligence

AI is seen as finally taking off …

Could displace 10M jobs within 10 years (more than during the Great Depression)[1]

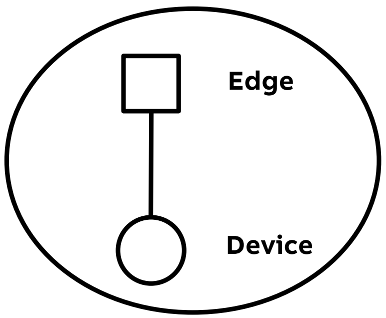


[1]Source: CB Insights, October, 2017
[2]Source: https://www.wired.com/2014/10/future-of-artificial-intelligence/

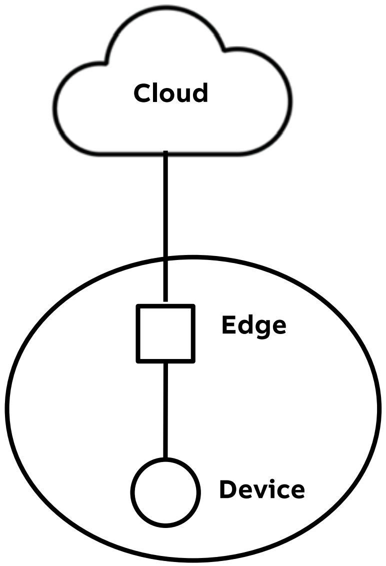
Digitalization: one size doesn't fit all - multiple deployment models

Secure digital solutions on-premise, in the cloud, and in an ecosystem

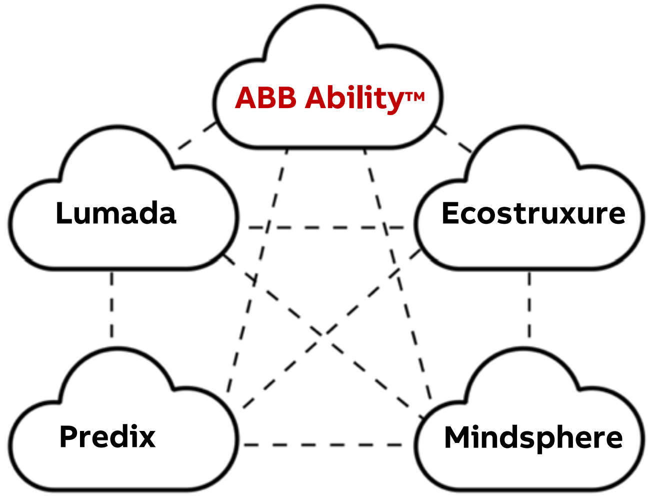
Fog



Cloud



Intercloud



Value hierarchy of Internet of Things: aka “Maslow’s hierarchy” for IoT

Where’s the money? Creating vs capturing value

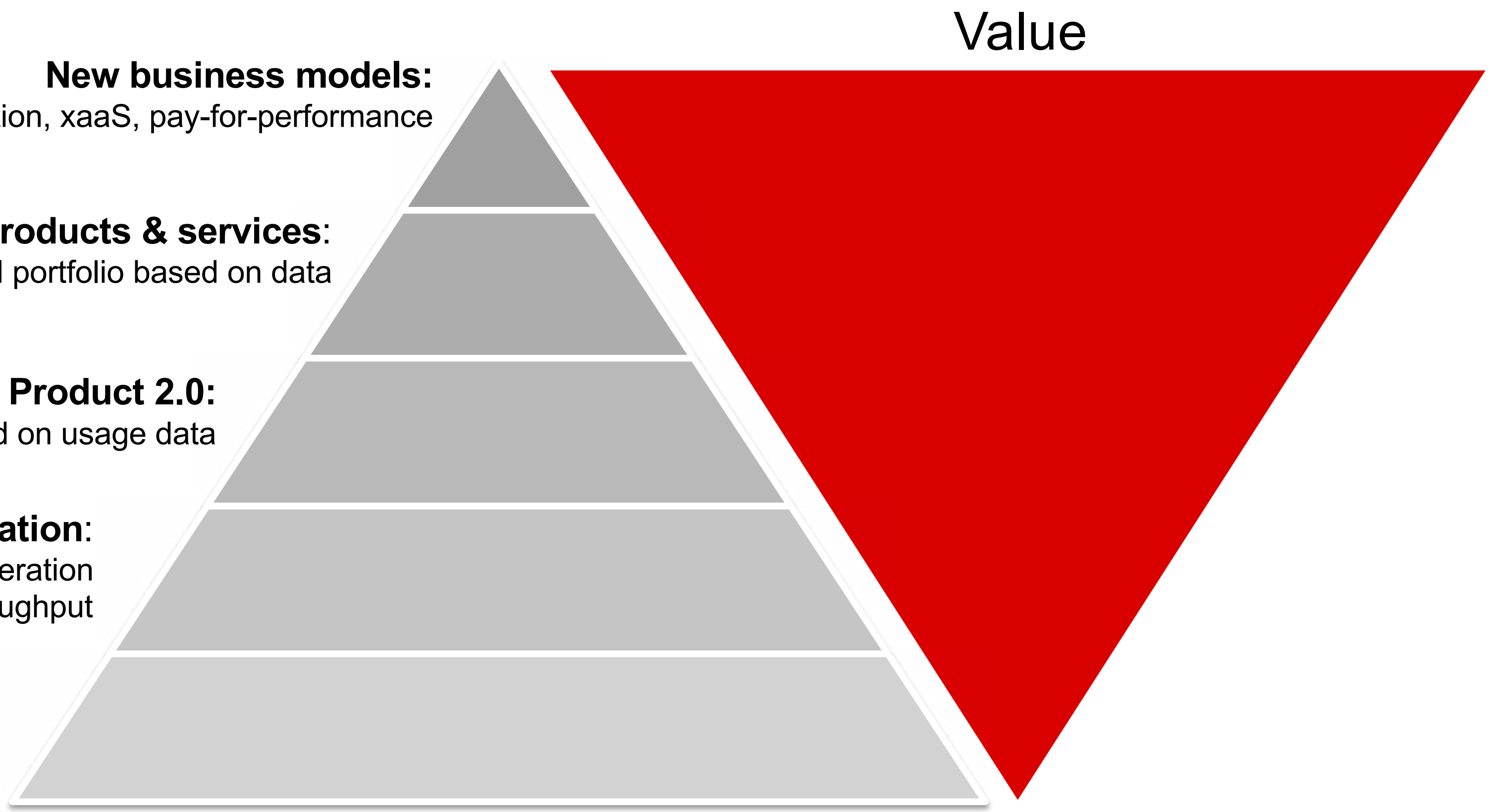
New business models:
Subscription, xaaS, pay-for-performance

Adjacent products & services:
Expanded portfolio based on data

Product 2.0:
Improved products based on usage data

Optimization:
Single mode of operation
→ energy / reliability / throughput

Monitoring:
Time-based
→ condition-based maintenance



A point in case: asset utilization in other industries

Connecting supply to demand for under-utilized assets

Yesterday

Cars are parked 95% of the time

Source: Fortune, March, 2016

Today

Critical reflection: questions and challenges to be addressed

Vast amounts of data and more ubiquitous sensing & compute

- Enable closing of entirely new loops,
  both classical feedback control loops and beyond
- Not all data is information-rich,
  e.g., challenges of closed-loop system identification?
- With more data, black-box models and correlations
  are easily done and gain share relative to first-principles
  models ➔ how to establish causality and reasoning/proving?

Cyber security is foundational to digitalization

Business models

- We got paid for HW in the past, now for a HW/SW mix
- Shifting towards XaaS
- Open dialogue on data ownership rather than platform lock-in

Humans remain in charge & accountable

- Need legal & ethical frameworks for increased autonomy

Need to **further develop Artificial intelligence**

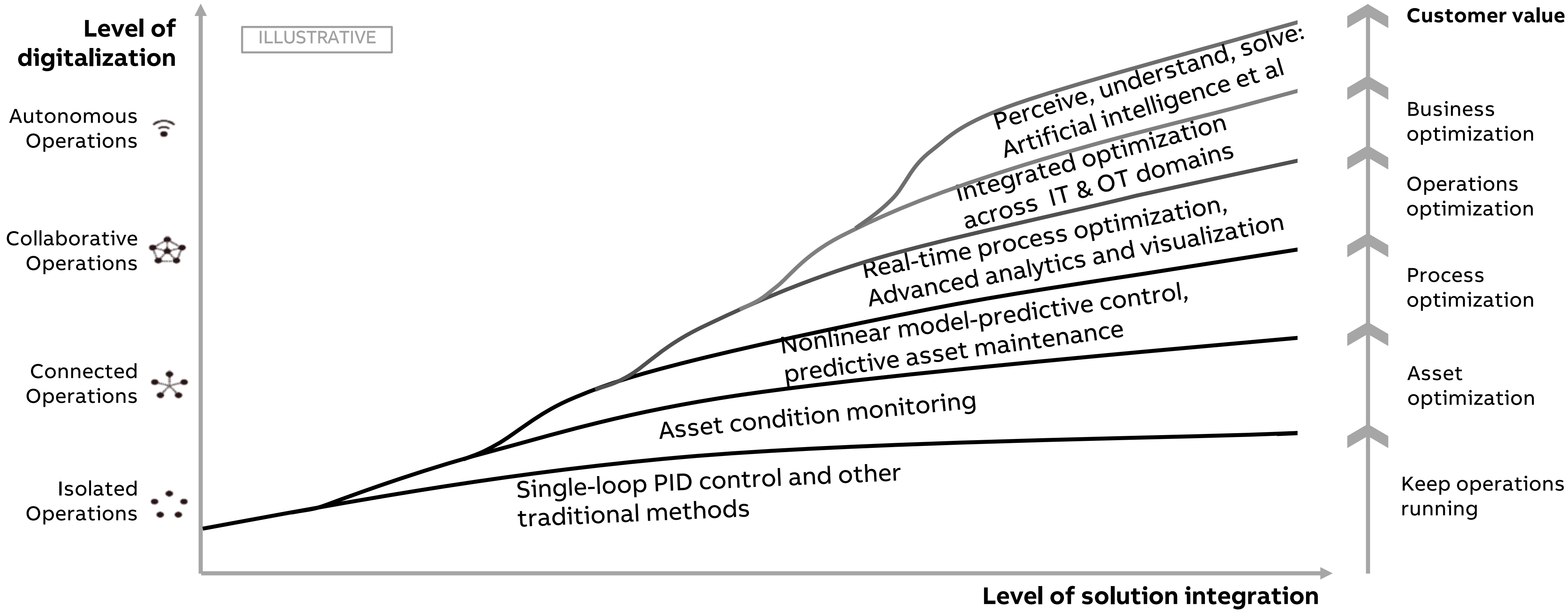
- Currently narrow AI, e.g., good at image/pattern recognition
  ➔ develop broader, more general-purpose AI
- Currently better at interpolation, somewhat opaque
  ➔ improve extrapolation/dealing with new situations

Architecture evolves, mix of **innovation vs standardization**

- As many hardware constraints fade away,
  what replaces the traditional "automation pyramid"?
- What to put on-prem vs cloud?
- How to reconcile fast-changing consumer IT
  vs industrial investment-grade tech cycles?

ABB

Towards autonomous operations



Towards autonomous operations: Let's build a bridge into this future

See also: www.mx3d.com, using ABB robots.