Control, Automation & Digitalization: An Industrialist’s Perspective

Peter Terwiesch, President Industrial Automation, ABB Ltd
## Introducing ABB

### What (Offering)

<table>
<thead>
<tr>
<th>Pioneering technology</th>
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</thead>
<tbody>
<tr>
<td>Products 58%</td>
</tr>
<tr>
<td>Systems 24%</td>
</tr>
<tr>
<td>Services &amp; software 18%</td>
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</tbody>
</table>

### For whom (Customers)

<p>| |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Utilities</td>
</tr>
<tr>
<td>~35% of revenue</td>
</tr>
<tr>
<td>Industry</td>
</tr>
<tr>
<td>~40% of revenue</td>
</tr>
<tr>
<td>Transport &amp; Infrastructure</td>
</tr>
<tr>
<td>~25% of revenue</td>
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### Where (Geographies)

<p>| |</p>
<table>
<thead>
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<tbody>
<tr>
<td>Asia, Middle East, Africa 38%</td>
</tr>
<tr>
<td>Americas 29%</td>
</tr>
<tr>
<td>Europe 33%</td>
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</table>

<p>| |</p>
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<tbody>
<tr>
<td>~$34 bn revenue</td>
</tr>
<tr>
<td>~100 countries</td>
</tr>
<tr>
<td>~132,000 employees</td>
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</tbody>
</table>
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
Model predictive control: advancing the frontiers

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

Number of signals

Isolated

Connected

Collaborative

Autonomous

Breadth of domain
New sensors and algorithms enable transition towards autonomous systems

- **Descriptive Analytics:**
  On equipment level: Enable to **detect** and resolve problems

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

- **Predictive Analytics:**
  On system level and across: enable to **solve** problems

- **Prescriptive Analytics**

- **Autonomous Systems**

**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.

Operations
- Control
  - Sense
  - Act

Assets
- Asset analytics
  - Sensing
  - Service

Steady state control
- Normal operation
  - Start, transients, stop

Adapted operation through plant lifecycle
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)

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

Enablers often from govt labs (1980s), IT enterprise level (1990s) and consumer mobile (2000+)
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
Digitalization enables new ways of working

Intelligent Projects™ to cut cost, schedule and risk

Cloud engineering

Digital marshalling

Standardization

Automated data management

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™

- Plan
- Build

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

Collaborative Operations™

- Operate
- Optimize

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

- e.g., CAD
- e.g., Modelica
- e.g., Process graphics in 800xA
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

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

Results
“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

**Analytic and Visualization**
- Analytics and visualization
- Simulation

**Operations and Technical Support**
- Operations and technical support

**Predictive Maintenance**
- Condition monitoring
- Asset health
- Predictive maintenance

**Optimization**
- Emission monitoring
- Energy optimization
- Performance optimization
- Alarm management

**Cyber and Safety**
- Cyber security
- Safety management

**Control**
- Control centers

**Customer Value:** Safety, productivity, energy efficiency

Customer assets:
- e.g. rigs, mills, vessels

ABB Ability™
Collaborative Operations™ Center

©ABB
Collaborative Operations™
Customer examples from process industries

<table>
<thead>
<tr>
<th>Aker BP (oil &amp; gas)</th>
<th>Leading Indian cement manufacturer</th>
<th>Metsä Fibre (pulp &amp; paper)</th>
<th>Genting (marine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full scope of electrical, instrumentation, automation and telecom to enable digital transformation of value chain</td>
<td>Enterprise-wide digital service partner for energy efficiency and reliability enhancement</td>
<td>Range of digital services for condition monitoring of critical equipment for newest Pulp &amp; Paper plant</td>
<td>Propulsion, electric power plant, automation, software and digital services for five new cruise ships</td>
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Underground mining
Automation keeps people out of harm’s way and enables more continuous production

Production cycle

Where automation can help

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

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

Feed-forward control, e.g. regulate milling or flotation operations based on ore characteristics

Feed-back control, e.g. required quantities and qualities
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

<table>
<thead>
<tr>
<th>Efficient at every level</th>
<th>Reliable and available</th>
<th>Integrated ecosystem</th>
<th>Flexible and agile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower fixed costs and uncompromised quality and safety.</td>
<td>Proactive, actionable intelligence that reduces incidents and speeds recovery.</td>
<td>Seamless collaboration across the value chain to better respond to customer needs.</td>
<td>Automation processes which can quickly and efficiently adapt in real-time to new situations.</td>
</tr>
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Flexibility, Collaboration & Digitalization
From robot programming to teaching and learning
Ongoing paradigm shift in the accessibility, installation and commissioning of robots

Yesterday: **programming**

![Robot programming](image)

```plaintext
//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]];```

Today: **teaching**

![Teaching](image)

Tomorrow: **learning**

![Learning](image)
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.
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

<table>
<thead>
<tr>
<th>Safety</th>
<th>Easy to Install</th>
<th>Easy to Program</th>
<th>Simplification</th>
</tr>
</thead>
</table>
| Shared tasks and workspaces  
No need for barriers or separation zones | Lightweight, portable robot  
Up and running in minutes, not hours | Via intuitive devices or by lead through  
No previous experience required | 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.
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”

Human:
- Systems designed by experts
  - + Intuition
  - + Creativity
  - + Expertise
  - – Computation

Artificial:
- Knowledge learned from data
  - – Intuition
  - – Creativity
  - + Expertise
  - + Computation

Augmented:
- Experts supported by algorithms
- Amplifying human potential

1Webster referring to intelligence
AI is seen as finally taking off …
Could displace 10M jobs within 10 years (more than during the Great Depression)$^1$

“The next 10,000 startups = take x & add AI”$^2$
– David Kelly, founder of Wired
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**

ABB Ability™

Lumada

Ecostruxure

Predix

Mindsphere
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

Today

Source: Fortune, March, 2016
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?
Towards autonomous operations

Level of solution integration

- Single-loop PID control and other traditional methods
- Asset condition monitoring
- Nonlinear model-predictive control, predictive asset maintenance
- Real-time process optimization, Advanced analytics and visualization
- Integrated optimization across IT & OT domains
- Perceive, understand, solve: Artificial intelligence et al

Customer value

- Keep operations running
- Asset optimization
- Process optimization
- Operations optimization
- Business optimization
- Customer value

Level of digitalization

- Isolated Operations
- Connected Operations
- Collaborative Operations
- Autonomous Operations

August 22, 2018
Towards autonomous operations: Let’s build a bridge into this future

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