Smart Connected Digital Factories: Unleashing the Power of Industry 4.0 and the Industrial Internet

Michael P. Papazoglou
Executive Director - ERISS
Tilburg University, The Netherlands
email: mikep@uvt.nl,
http://www.eriss.org
AGENDA

• An Introduction to Industry 4.0
• Smart Connected Factories
• Big Data & Analytics in Smart Connected Factories
• Closing Remarks
An Introduction to Industry 4.0
The 4th Industrial Revolution

**First Industrial Revolution**
Based on the introduction of mechanical production equipment driven by water and steam power

**Second Industrial Revolution**
Based on mass production achieved by division of labor concept and the use of electrical energy

**Third Industrial Revolution**
Based on the use of electronics and IT to further automate production

**Fourth Industrial Revolution**
Based on the use of cyber-physical systems

- First mechanical loom, 1784
- First conveyor belt, Cincinnati slaughterhouse, 1870
- First programmable logic controller (PLC) Modicon 084, 1969

Siemens AG 2015
What is Industry 4.0?

- Industry 4.0 is a new level of organisation and control over the entire value chain of the life cycle of products. It is geared towards increasingly individualised customer requirements.

- This cycle begins at the product idea, covers the order placement and extends through to development and manufacturing, all the way to the product delivery for the end customer.

- It is based on the digitisation of the entire production environment:
  - availability of all relevant information in real time by connecting all instances involved in the value chain.
  - ability to derive the optimal value-added flow at any time from the data.
  - connection of **people**, **things**, **services** and **systems** to create dynamic, optimised value-added connections within and across companies.

  - These can be optimised according to different criteria, e.g., costs, availability & consumption of resources.
The Road to the 4th Industrial Revolution

Digitized manufacturing takes adaptability to the next level

**Conventional manufacturing**
- Mass production
- Large quantities
- Small margins
- Sequential value chain
- Long turnaround time
- Low flexibility

**Digitized manufacturing**
- Custom production
- Small quantities, short run
- High margins
- Changing collaborative partnerships
- Short turnaround time
- Highly flexible and adaptive

Source: GPS Consulting
The 4th Industrial Revolution: The Big Picture

**Aware**

Smart Products are equipped with sensor technology giving access to condition information regarding the product and its environment.

**Connected**

Smart Products are equipped with a M2M communication device that enables interaction and data exchange with other cyber-physical systems.

**Intelligent**

Smart Products are equipped with computing power that enables autonomous decision-making and self-learning processes based on defined algorithms.

**Responsive**

Smart Products are equipped with control technology that enables autonomous product adoption based on internal or external commands.

Source: Capgemini Consulting
Industry 4.0 Smart Factory

Cyber-physical components carrying all necessary processing information are triggered by the order.

Customer order

What is your price for this operation?

OK Station 3!

Cutting station 1

Cutting station 2

Cutting station 3

Cyber-physical shop floor

Further processing

M2M communication, information flow

Material flow

CPPS = CYBER-PHYSICAL PRODUCTION SYSTEM

M2M = MACHINE-TO-MACHINE

Source: Capgemini. Consulting
The Future of Manufacturing with Industry 4.0

Source: Siemens AG, 2016
1. Digitisation of all physical assets and processes

2. Integration of vertical and horizontal value chains

3. Control and visibility:
   - As products move from ideation and development to end of life, the wealth of data produced at every stage of the manufacturing lifecycle can create a product’s “digital thread,” which denotes the aggregated, product-specific data stream that combines information from a variety of systems and sources.

4. Actionable insights:
   - The convergence of the IoT, processes and analytics is generating a new world of big data, which is enabling new capabilities such as tailored customer offerings, predictive solutions, streamlining production processes and adapt to changes.

5. Human-centred automation:
   - Improve user experience so that information is presented in the context of manufacturing tasks performed, leading to better decision-making and new possibilities for improvement.
Industry 4.0 Enabling Technologies

Industry 4.0 is Big Science!!

Source: PWC, 2016 Global Industry 4.0 Survey
Cloud-centred manufacturing, extends the concept of virtualisation to a shared diversified collection of manufacturing resources e.g., machine tools & factories, offers those resources – in the form of SaaS model - and deploys them at scale to form production lines in response to customer demand.

- manufacturing service providers can engage in new, flexible arrangements leading to better utilisation of manufacturing capabilities & provide heightened levels of quality and value

“Edge analytics” greatly reduces the amount of raw data that must be stored on servers, either on premises or in the cloud, and reduces the amount of network traffic being generated.

- Collecting and analysing data close to the endpoints means that action can take place locally in real or near-real time.
Smart Connected Factories
En route to Smart Manufacturing Networks

Horizontal integration through value networks

Vertical integration and networked manufacturing systems

End-to-end digital integration of engineering across the entire value chain

Manage the people, culture and leadership transformation ('People 2.0')

Agile Value Chain

Goods flow

Financial flow

Information flow

Source: Capgemini Consulting 2015
**The Digital Twin:**
Connecting The Physical & Digital Worlds

**Digital Twin:**

A digital representation of a physical product or process to enable testing before physical implementation.

Enables manufacturers to overlay the virtual, digital product on top of any physical product at any stage of production on the factory floor and analyse its behaviour.

- Manufacturers can have a complete digital footprint of the entire manufacturing process spanning product, production, and performance.

Product designers and engineers can make informed choices about materials and processes using visualisation tools, e.g., 3D CAD/CAM tools, during the design stages of a digital product and immediately see the impact on a physical version of the product.

Manufacturing Operations Management

MANUFACTURING OPERATIONS MANAGEMENT
Business and Manufacturing Process View

LEVEL 4  Enterprise / Business Operations
- Production Demand & Supply
- Production & Production Definition
- Product & Production Capability
- Business & Production Performance

LEVEL 3  Manufacturing Operations Management
- Receiving & Shipping
- Production & Process Engineering & Optimization
- Production Performance Reporting & Analysis
- Detailed Production Planning & Scheduling
- Production Assets
- Plant/Equipment Maintenance
- Materials & Energy Purchasing & Inventory
- Production Execution, Tracking & Visualization
- Human Resource & Labor
- Quality Assurance

LEVELS 2,1,0  Industrial Automation
- Discrete
- Hybrid
- Batch
- Continuous

Source LNS Research, May 2013.
Factory Model: Connecting the Enterprise to the Shop-Floor

Enterprise Business Systems
(ERP, PLM, Supply Chain Management)

Enterprise

Manufacturing Ops

Work Requirements
Work Scheduling
Resource Management
Work Dispatching
Work Execution
Personnel, Equipment, Materials

Automate Business Processes

Work Responses
Product Analysis (QA)
Historical Data Management
Process Analysis
Production Analysis

Automate Mfg Events & Ops

ISA-95 Model for MES

Plant Processes & Equipment

Process Control Systems
(Continuous, Batch, Discrete)
Sensing and instrumentation

Automate Equipment Ops

KEY CHALLENGES

Disconnect between Enterprise & Shop-floor Applications

Disconnect between PLM & Manufacturing

Limited point-to-point connections between Business IT & Factory Automation

Lack of visibility into plant/enterprise ops to help eliminate bottlenecks

Unable to identify work order performance related to on-time completions & quality
From Smart Factory to Agile Value Chains

- **Service-oriented Business Architecture**
- **Business functions as self-contained/independent services** (internal and external)
- Cross-company, flexible process flow
- Process instances (products/orders) as self-organized ‘agents’
- Standardized or **common interfaces/protocols**
- A common 'data lake' as platform for analytics functions (Big Data)
- **Supply-Chain-Control tower** providing extended supply chain transparency
**From Smart Data to Smart Manufacturing Networks**

Smart sensors help merge disparate data into streams of actionable info. & allow assets to be monitored and optimized from anywhere in real-time. Smart machines are able to monitor key components & environmental conditions with minimal human intervention. A smart factory can self-optimize performance across a broader network of assets, self-adapt to & learn from new conditions, & autonomously run entire production processes. Integrating a permanent or temporal coalition of production systems of geographically dispersed smart factories, suppliers & customers to better achieve joint production objectives.

**Customer Advantage**
- Better Customised Products
- Better Performance
- Lower Costs
- Saving Energy
- Reduce Risks
- New Business Models

---

**"Smart data to Smart Manufacturing Networks"**

<table>
<thead>
<tr>
<th>Data</th>
<th>Data analytics</th>
<th>MfG Intelligence</th>
<th>MfG Innovation</th>
<th>Value Generation</th>
</tr>
</thead>
</table>

**Domain know-how + Device know-how (IoT) + Analytics know-how = Smart Data**

---

**Smart Sensors**

**Smart Machines**

**Smart Factory**

**Connected Factories**

**Data from Products, Systems, Sensors, Processes...**

---

**"Smart data to Smart Manufacturing Networks"**

**Domain know-how + Device know-how (IoT) + Analytics know-how = Smart Data**

---

**Customer Advantage**
- Better Customised Products
- Better Performance
- Lower Costs
- Saving Energy
- Reduce Risks
- New Business Models
Vertical integration of production activities within smart factories from product design and development and the various shop floor applications, devices, IoT, robot and equipment is necessary to enable production.

Source: PWC 2016
Horizontal integration is combined with vertical integration to offer the prospect of coordination of orders, materials flow and production data, with all geographically dispersed entities, e.g., customers, distributors and channel partners, materials and sub-product suppliers, contract manufacturers, and technology solution providers, to achieve end-to-end, holistic integration through the entire value chain.
Big Data & Analytics in Smart Connected Factories
Resources, Processes & Data are Behind it All!

Understanding the Hourglass --

<---- Suppliers, Partners, Machines, Components, Materials, Devices, Humans, …

<---- Production processes

<---- Production, Distribution, Sales, x*, data
Production Plant Data

Data sources include:

- **External data sources**: e.g., user groups, social media, focus groups, or surveys to build customer data.
- **Internal data sources**: for data capture and analysis (e.g., an integrated ERP system provides data on products, processes, & people at all levels & departments in organization).
- **M2M interaction**: Smart sensors can collect data directly from machines and equipment. Built-in, low-cost sensors can detect a wide range of attributes, including location, weight, temperature, vibration, flow rate, humidity, and balance.

The above figures reflect the data generated from just one of many production lines that produce a particular consumer packaged products.

*Source: GE Intelligent Platforms.*
Industry 4.0 Data Loop

Source: General Electric
Smarter Analytics: Improved Resource & Process Performance

How can I perform in depth root cause failure analysis on my process and equipment?

How can I optimize my maintenance plan?

How can I detect warranty issues sooner?

What is the life expectancy of an asset’s component or part?

How can I predict an impending equipment failure and the cause?

How do I achieve optimal equipment efficiency and availability?

How can I create highest quality products?

How can I reduce process variability?

How can I ensure supply is aligned with demand?
Smarter Analytics Lead to Systems of Insight

Source Forrester Research, July 2015.
In Closing ...
Concluding Remarks: What is so Different about Smart Manufacturing?

- Transitions from “owning & operating” dedicated assets (including people, expertise & equipment) to sourcing & orchestrating shared resources & services on a global scale.
- Customers pushing demands.
- Flexible production of smaller customized production volumes.
- More knowledge/information driven, optimized & automated.
### Strategic R&D Opportunities for IoE

<table>
<thead>
<tr>
<th><strong>Science &amp; Engineering Foundations</strong></th>
<th><strong>Robust Effective Construction of Systems &amp; Infrastructure</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Devise cost effective system, design, analysis &amp; development</td>
</tr>
<tr>
<td></td>
<td>• Create domain-specific architectures &amp; frameworks</td>
</tr>
<tr>
<td></td>
<td>• Enable more natural, more seamless human-IoE interactions</td>
</tr>
<tr>
<td></td>
<td>• Offer assumption-based options, analytics &amp; improved decision-making.</td>
</tr>
<tr>
<td></td>
<td>• Synthesize &amp; evolve complex, dynamic systems with predictable behaviour</td>
</tr>
<tr>
<td></td>
<td>• Anticipate emergent behaviours arising from interactions.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Systems Engineering</strong></th>
<th><strong>Improved Performance &amp; Quality Assurance of Computational &amp; Physical Systems</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Create methods for system-level evaluation, verification, &amp; validation of IoE</td>
</tr>
<tr>
<td></td>
<td>• Develop IoE-based metrics (e.g., security, privacy, safety, resilience, adaptability, flexibility, reusability)</td>
</tr>
<tr>
<td></td>
<td>• Consider roles of humans &amp; improve understanding of human knowledge &amp; behaviour</td>
</tr>
<tr>
<td></td>
<td>• Incorporate uncertainty &amp; risk management into reasoning &amp; decision-making</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Applied Development and Deployment</strong></th>
<th><strong>Effective and Reliable System Integration and Interoperability Mechanisms</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Create universal definitions for representing ultra-large heterogeneous systems</td>
</tr>
<tr>
<td></td>
<td>• Build an inter-connected and interoperable shared development infrastructure</td>
</tr>
<tr>
<td></td>
<td>• Provide advanced abstraction mechanisms to manage complexity of IoE programming, evolution, monitoring &amp; mgt that span the digital &amp; physical divide</td>
</tr>
<tr>
<td></td>
<td>• Develop flexible IoE design methods based on Agile &amp; DevOps</td>
</tr>
</tbody>
</table>
Shift from Traditional to Smart Factories

- New business models through the convergence of IT & production