Architectures, Technologies, Algorithms

Industry 4.0

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Outline

- Introduction
- Architectures
- Technologies
- Algorithms
- Applications

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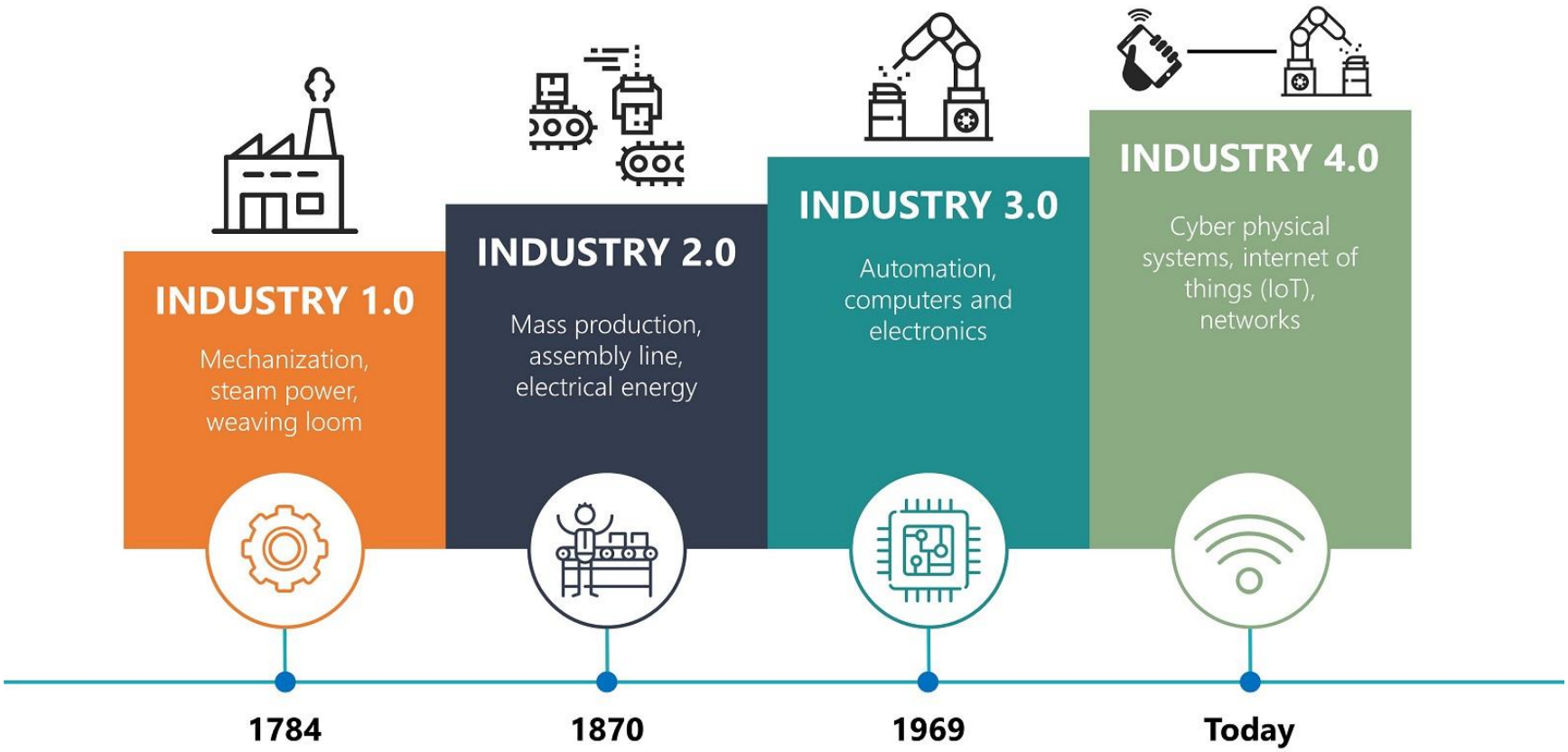
The AUDI smart factory

https://www.youtube.com/watch?v=qCgRSJZiloE

The 4 industrial revolutions

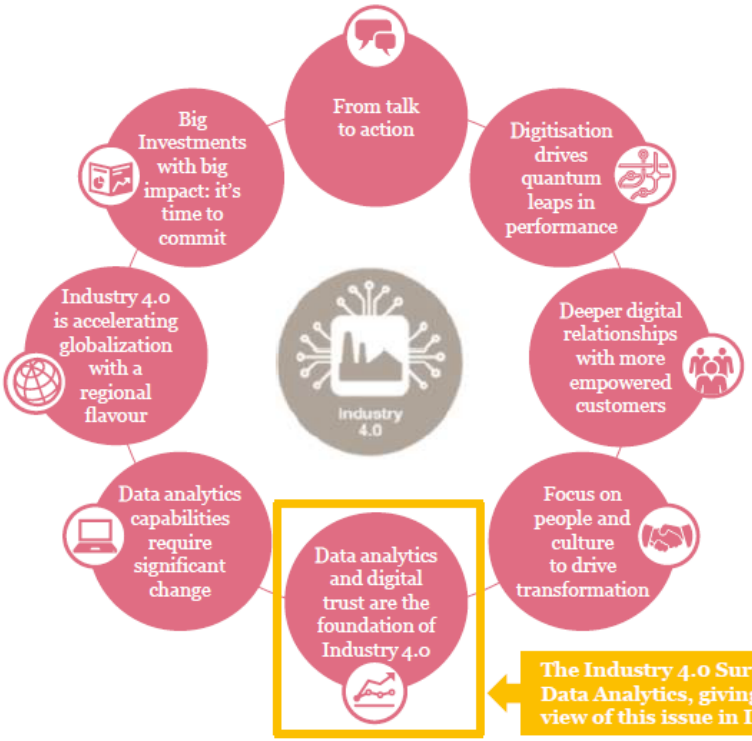


Today's factories are not efficient

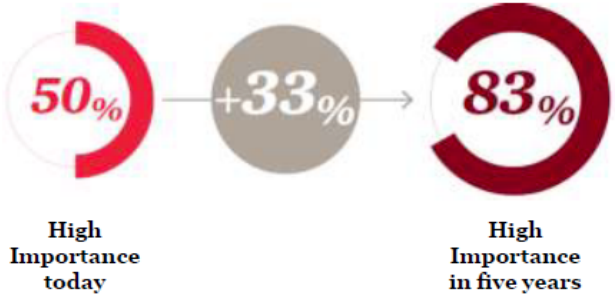
- If there is one decisive metric in the manufacturing environment, it is the OEE (Overall Equipment Effectiveness).
  - It measures how effectively a manufacturing operation is utilized compared to how effective it could be.
  - Average OEEs run at 60-70%. Today's world class OEEs are around 85%.
  - That means that even the most effective factories today lose 15% of time on non-value-adding tasks like machine changeovers, stoppages, maintenance, and production of faulty products.
  - The monetary equivalent to a one percentage point increase in OEE is gigantic for every company.

PwC survey (1/2)

The survey highlighted the importance of Data Analytics in our clients' decision-making processes over the next five years

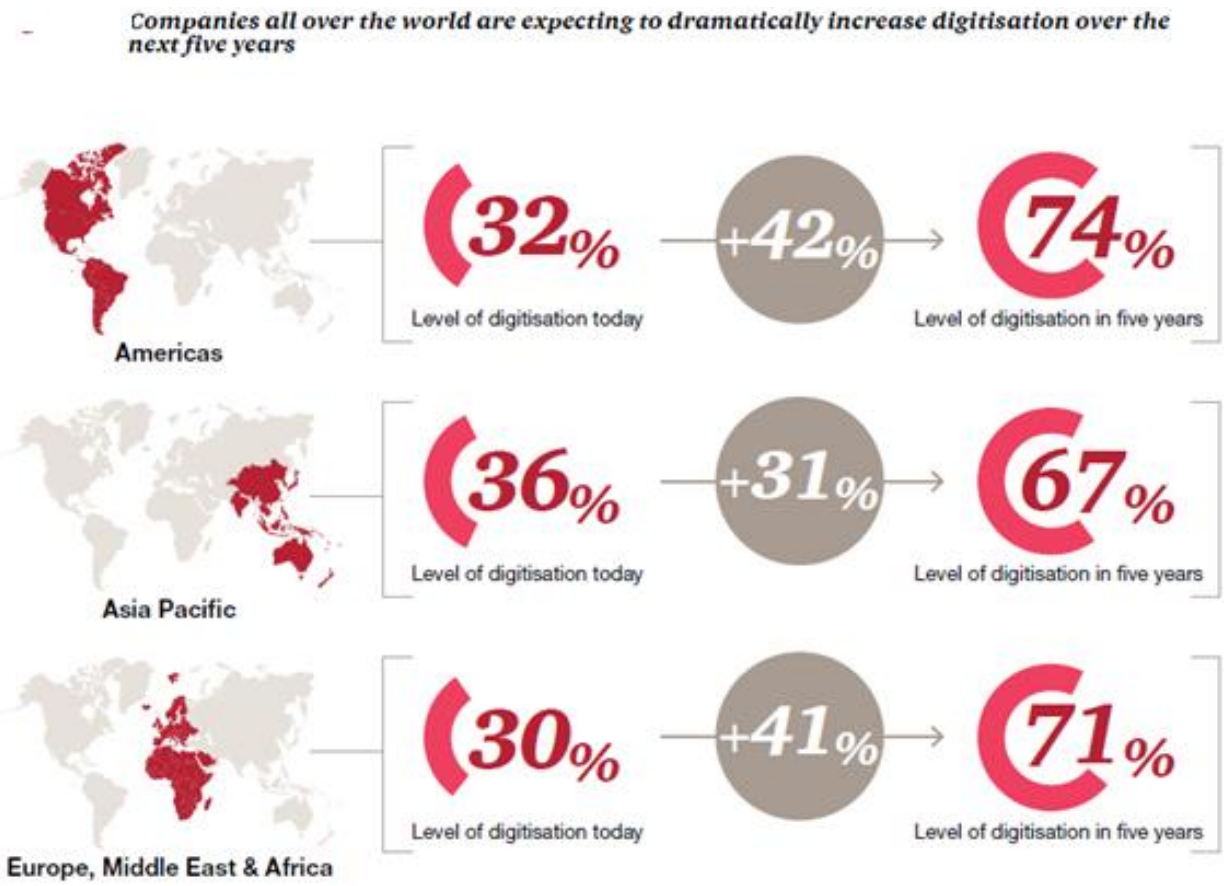


- **83%** of respondents expect data analytics will have a significant influence on their decision-making processes in five years' time
- **33%** of respondents expect this change to happen in the next five years

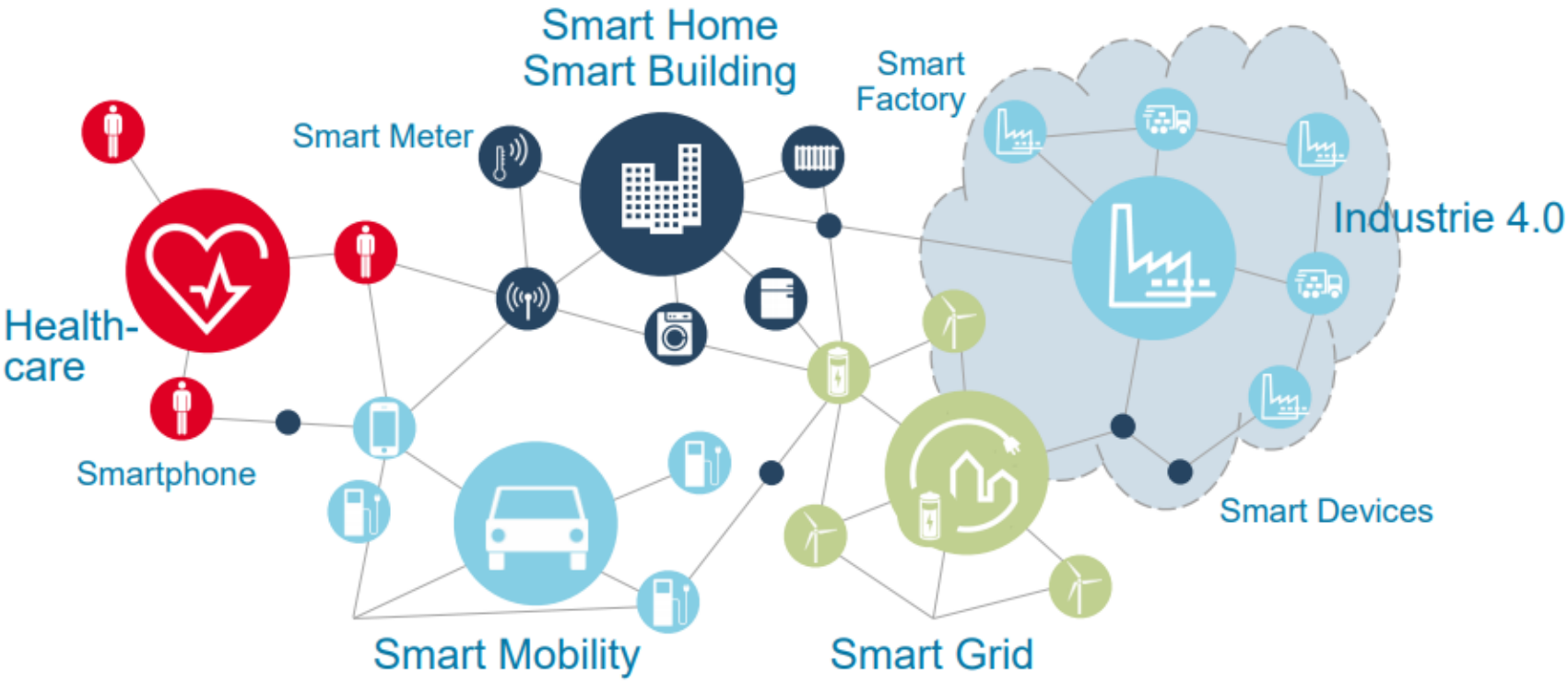


The Industry 4.0 Survey had a focus on Data Analytics, giving us a bird's eye view of this issue in Industry

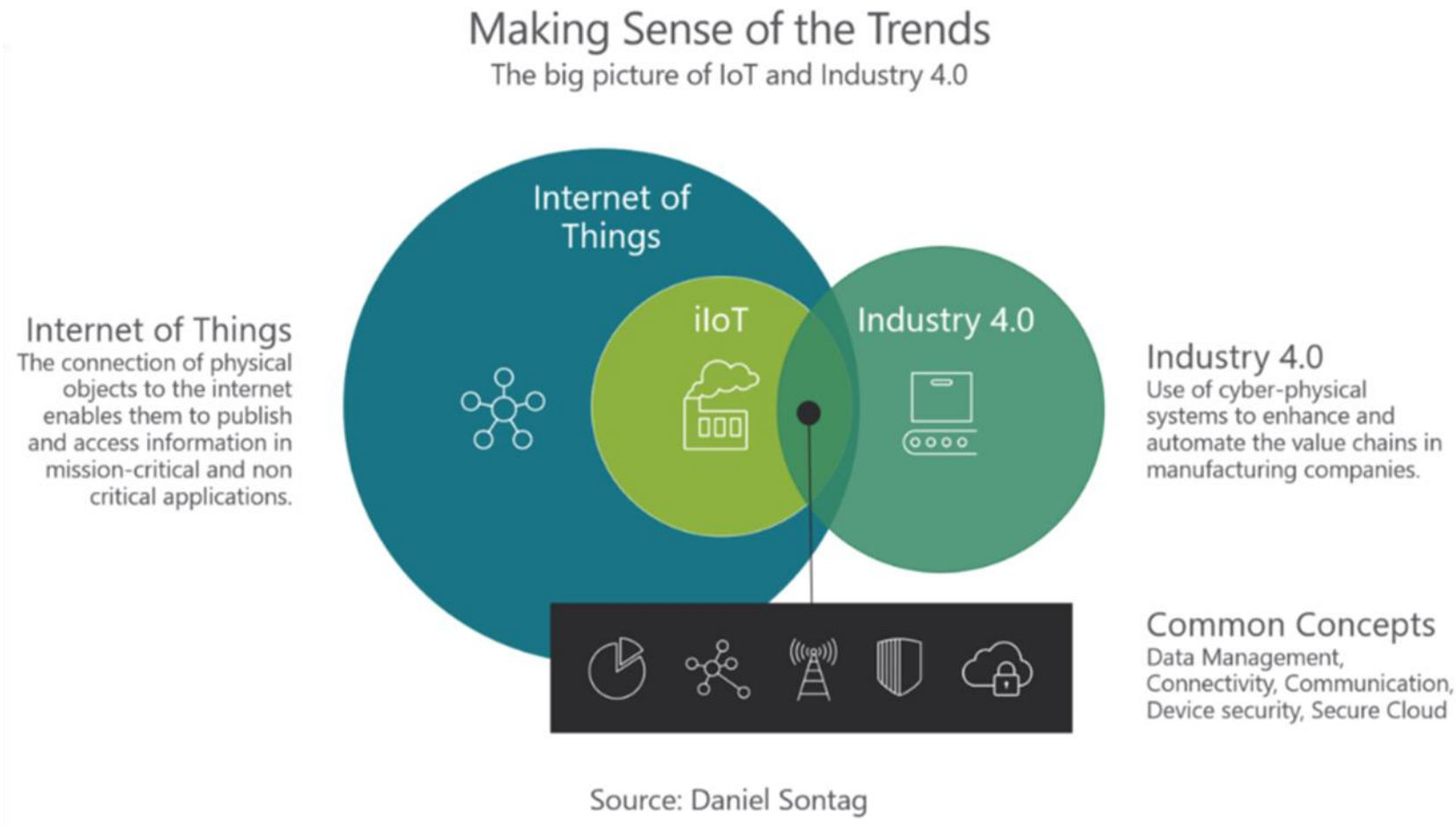
PwC survey (2/2)



Internet of Things (IoT)



Industry 4.0 and Internet of Things



The future of Industrial IoT

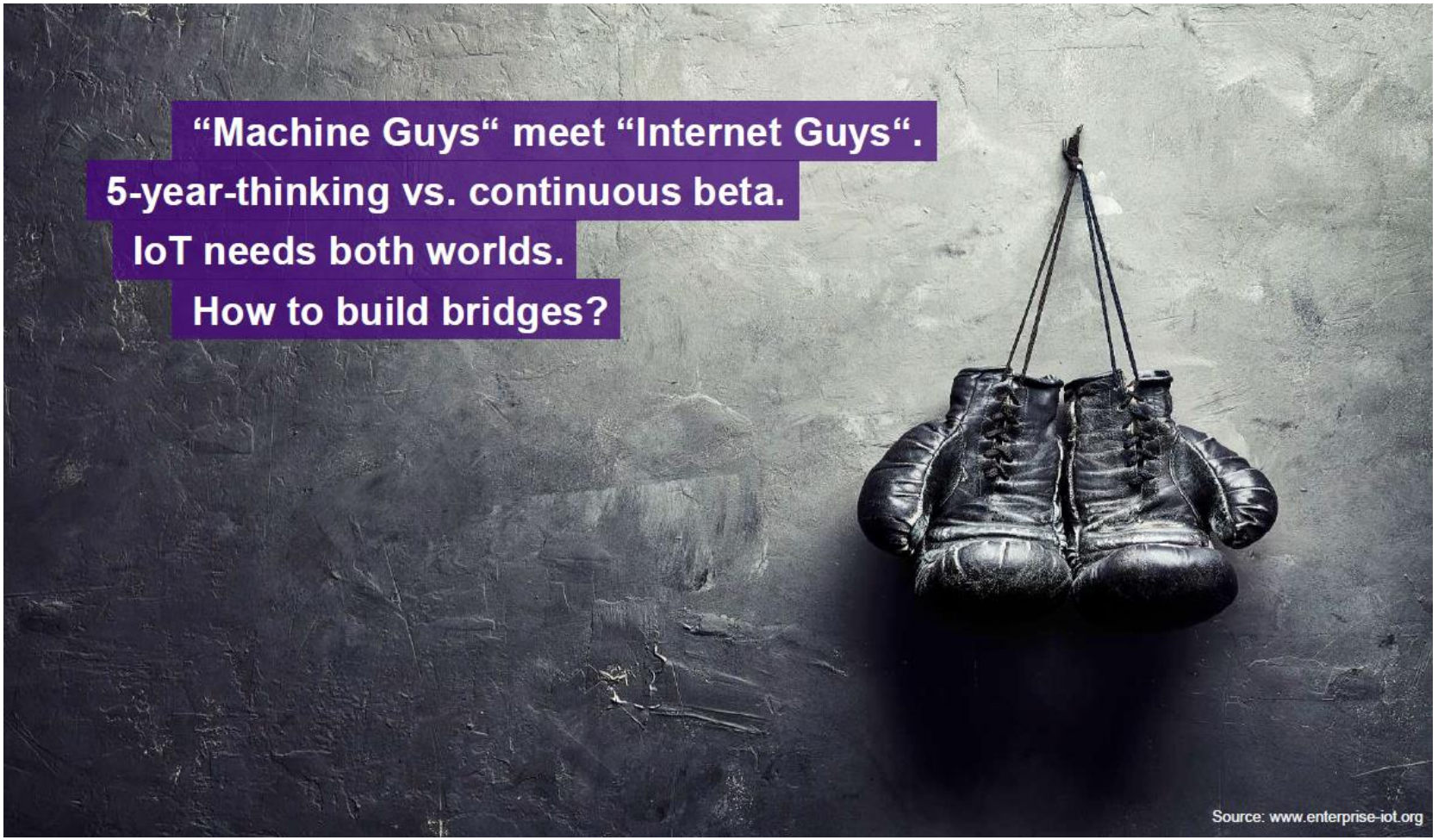
- Many market researchers such as Gartner, Cisco and PwC consider the **industrial IoT** as the IoT concept with the **highest overall potential**.
- However, **it has not gathered yet the interest** that smart homes or wearables have gathered, due to the **high investments** required and the **long periods of implementation** needed.
- **The 2/3 of IoT benefits will deal with Industry** and the 1/3 with consumer benefits.

Industry 4.0: Revolution or Evolution?

- *"The electric light did not come from the continuous improvement of the candle."*

- *"Technological innovation is continuous and the concept of a "revolution" is based on a lack of knowledge of the details."*

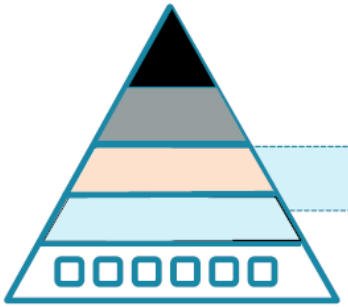
Clash of two worlds



Revolution or Evolution? – The answer

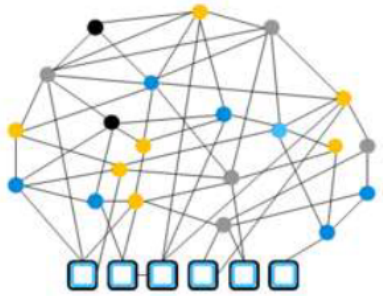
Evolution or Revolution ?

Revolution on Business Level



Automation Pyramid

Interoperability/Standards
IT-Security/Industrial Data Space®
Dependability and Latency
Machine Learning/Data Analytics
Human-Machine Collaboration



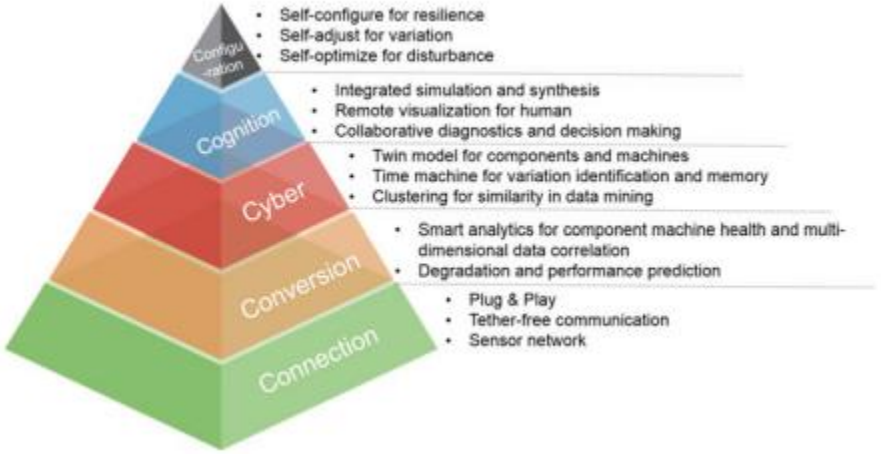
Service Network

Evolution on Technological Level

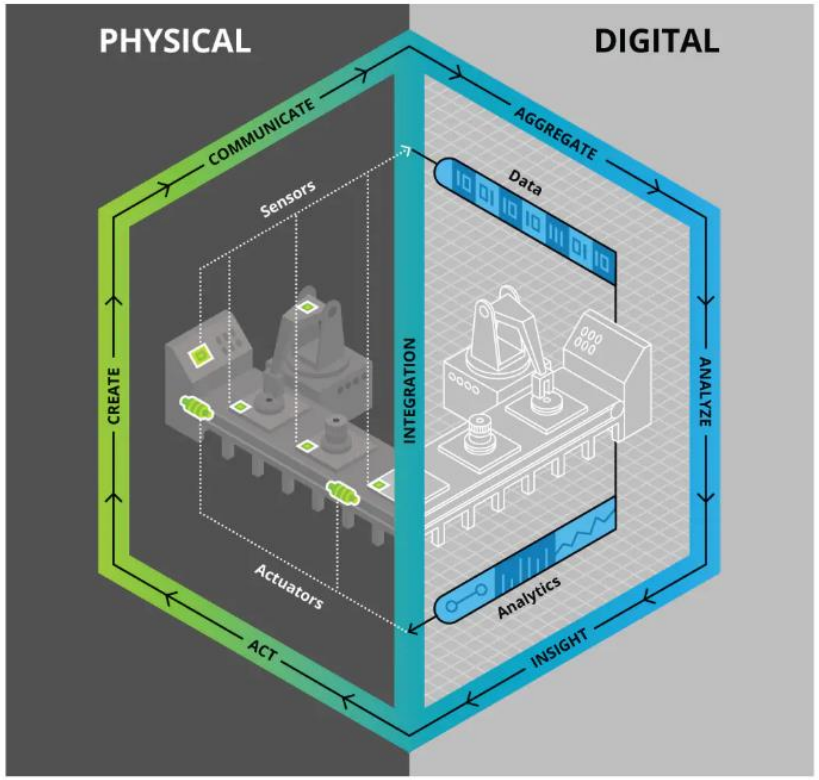
Industry 4.0 pillars

Cyber Physical System (CPS)

- CPS systems require seamless integration between computational models and physical components.
- Each physical component and machine will have a Digital Twin model in the cyber space composed of data generated from sensor networks and manual inputs.
- A CPS can be constructed by following the "5C" architecture, which serves as a guideline for the development of CPS for industrial applications

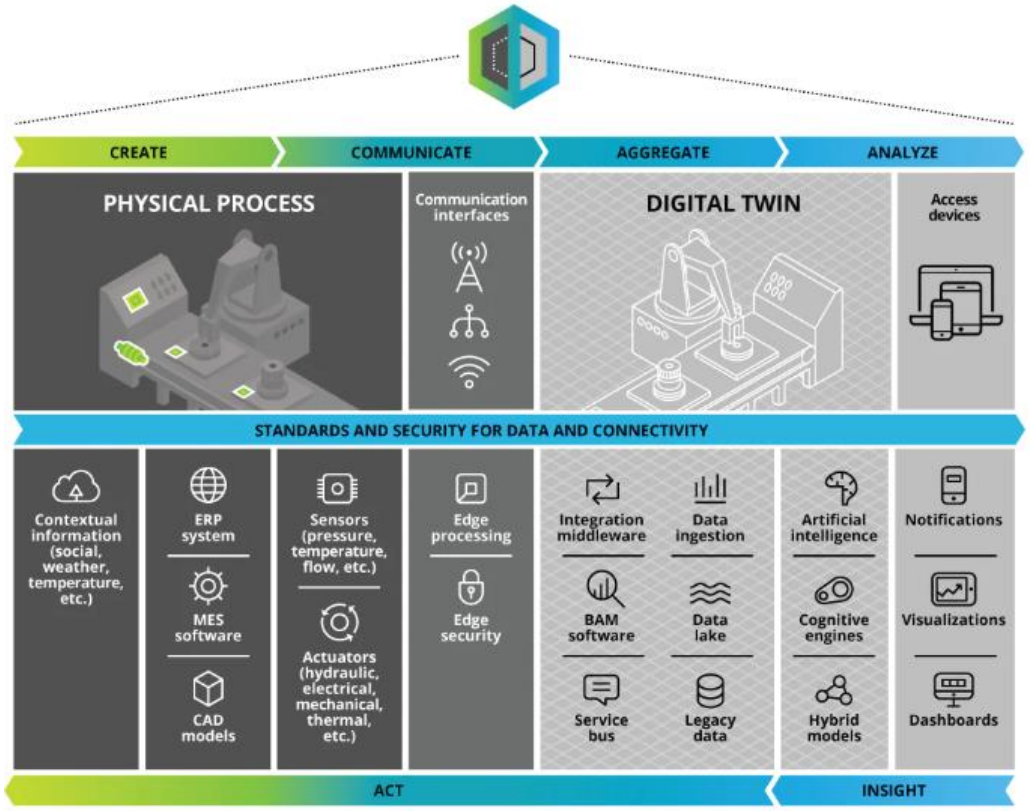


Digital twin



Source: Deloitte University Press.

Deloitte University Press | dupress.deloitte.com



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Reference Architectural Model for Industry 4.0 (RAMI 4.0)

Platform Industrie 4.0

Platform Industrie 4.0

PLATTFORM INDUSTRIE 4.0

Working groups
Main topics

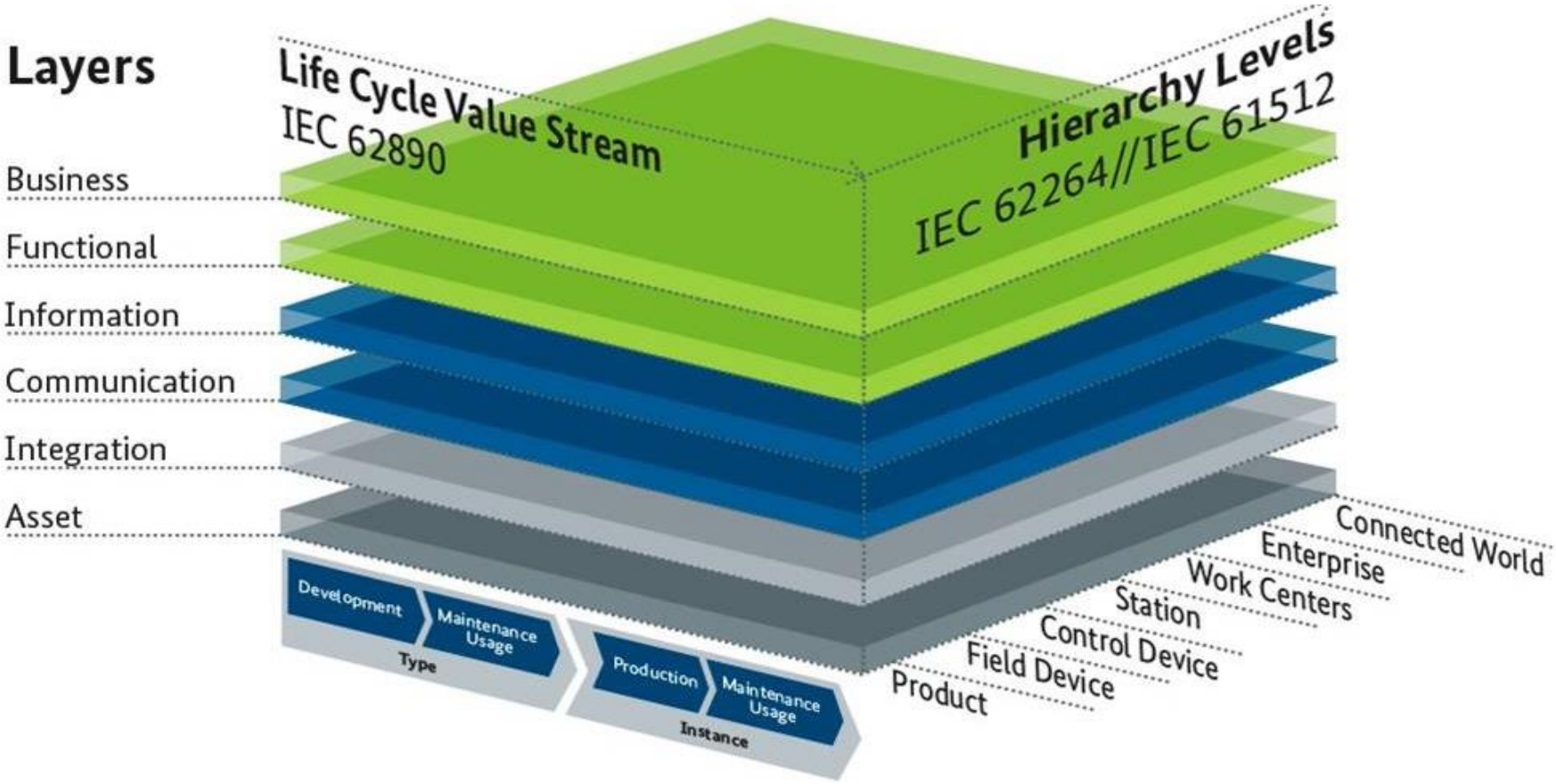
WG1	WG2	WG3
Reference Architectures, Standards and Norms **Chair:** Kai Garrels, *ABB STOTZ-KONTAKT GmbH*	**Technology and Application Scenarios** **Chair:** Johannes Kalhoff, *Phoenix Contact*	**Security of Networked Systems** **Chair:** Michael Jochem, *Robert Bosch GmbH*
Legal Framework **Chair:** Dr. Hans-Jürgen Schlinkert, *ThyssenKrupp*	**Work, Education and Training** **Chair:** Martin Kamp, *IG Metall*	**Digital Business Models for Industrie 4.0** **Chair:** Prof. Dr. Svenja Falk, *accenture*

WG4 WG5 WG6

https://www.plattform-i40.de/

Industry partners involved

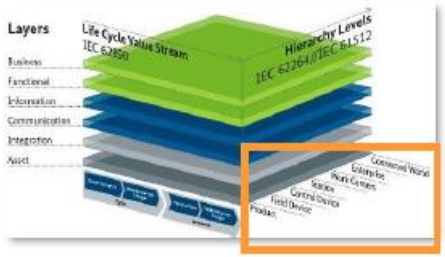
RAMI 4.0

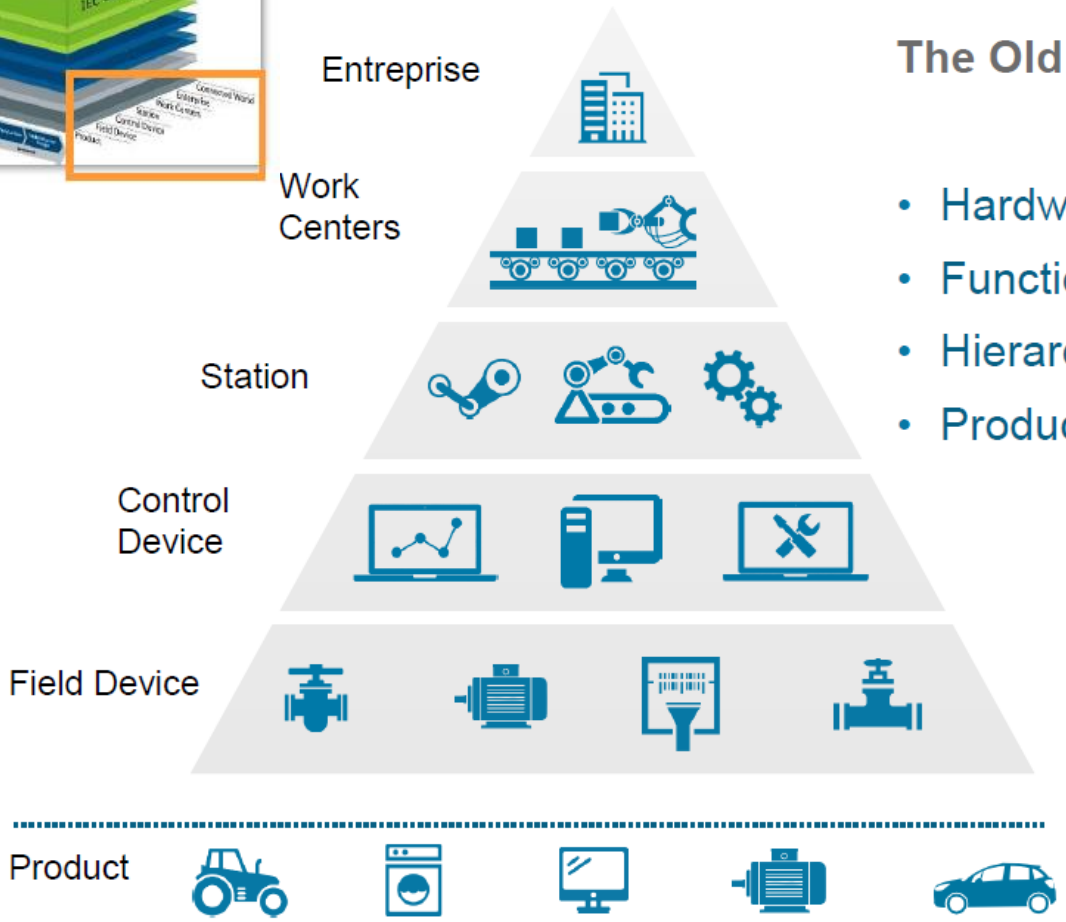

Layers
Business
Functional
Information
Communication
Integration
Asset
Life Cycle Value Stream
IEC 62890
Hierarchy Levels
IEC 62264//IEC 61512
Connected World
Enterprise
Work Centers
Station
Control Device
Field Device
Product
Development
Maintenance Usage
Type
Production
Maintenance Usage
Instance

RAMI 4.0

- RAMI 4.0 is a **three-dimensional map** showing how to approach the issue of Industrie 4.0 in a structured manner.
- RAMI 4.0 ensures that all participants involved in Industrie 4.0 discussions **understand each other**.
- RAMI 4.0 is a **SERVICE-ORIENTED ARCHITECTURE**.
- RAMI 4.0 **combines all elements and IT components** in a layer and life cycle model.
- RAMI 4.0 **breaks down complex processes** into easy-to-grasp packages, including data privacy and IT security.

Axis 1 – Hierarchy: The Factory

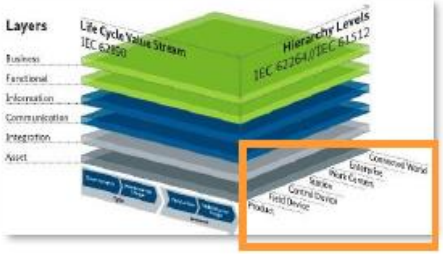




The Old World: Industrie 3.0

- Hardware-based structure
- Functions are bound to hardware
- Hierarchy-based communication
- Product is isolated

Axis 1 – Hierarchy: The Factory



The New World: Industrie 4.0

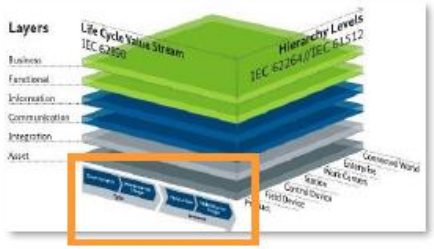
- Flexible systems and machines
- Functions are distributed throughout the network
- Participants interact across hierarchy levels
- Communication among all participants
- Product is part of the network

Connected World

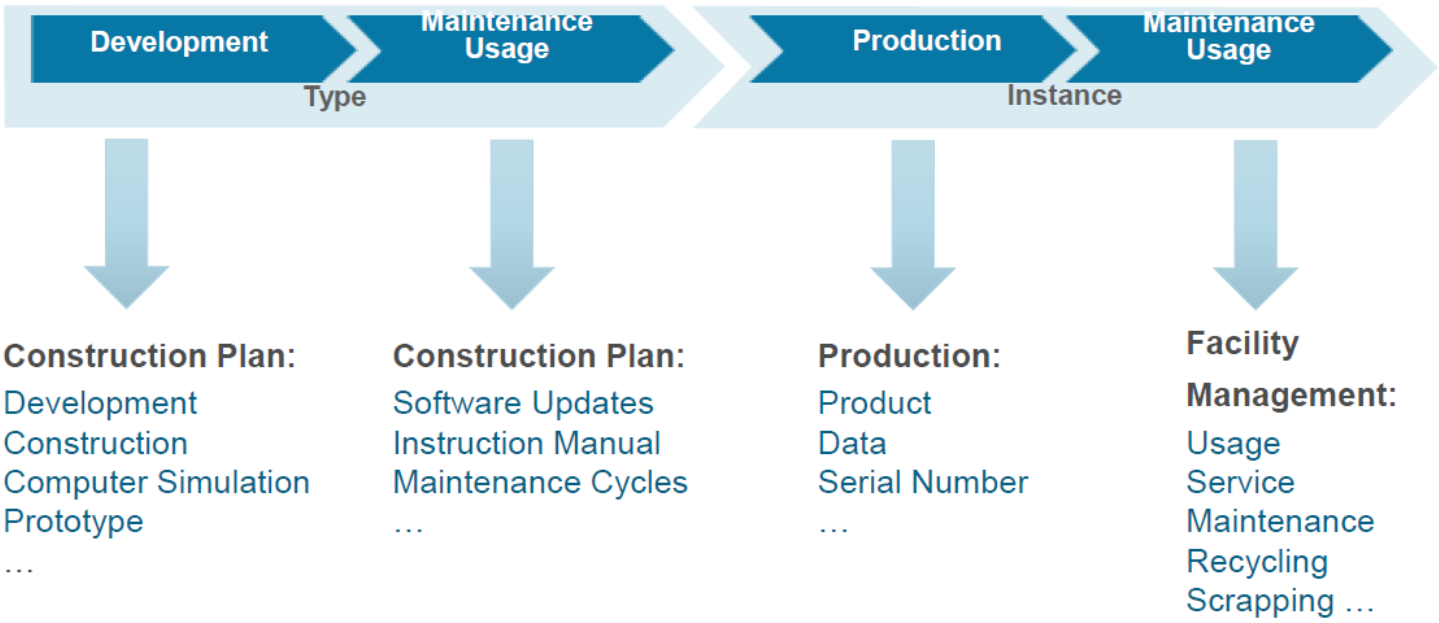
Smart Factory

Smart Products

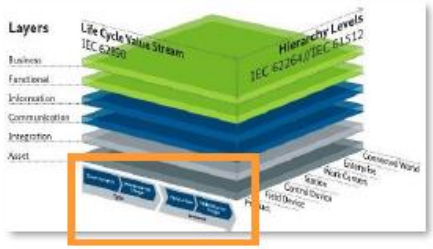
Axis 2 – Product Life Cycle

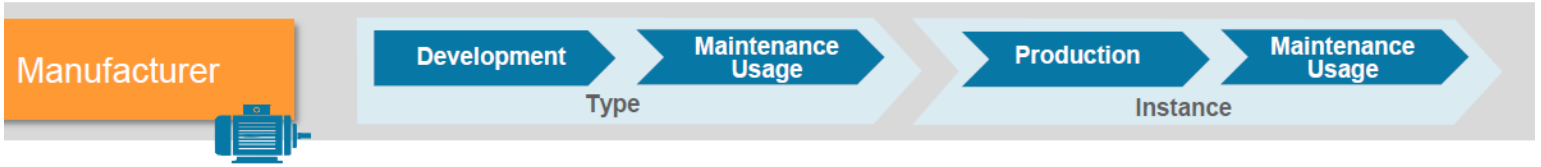


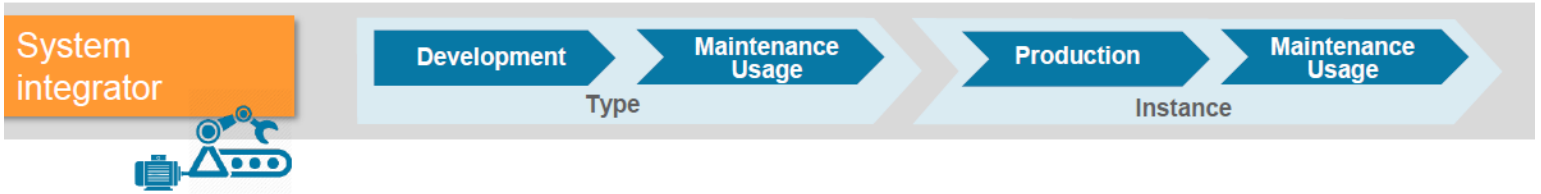
The Product: From the First Idea to the Scrapyard

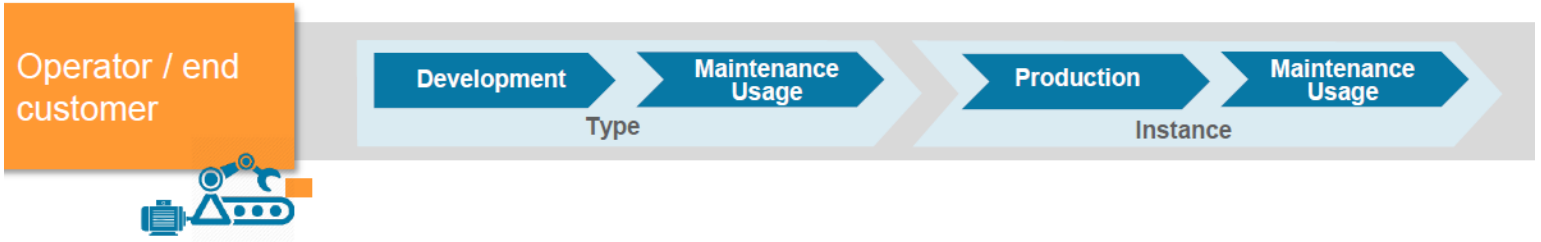


Axis 2 – Examples









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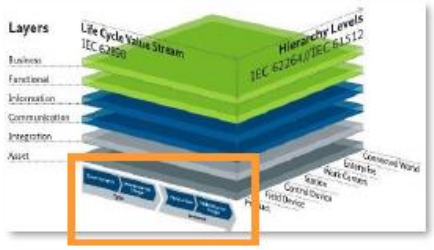

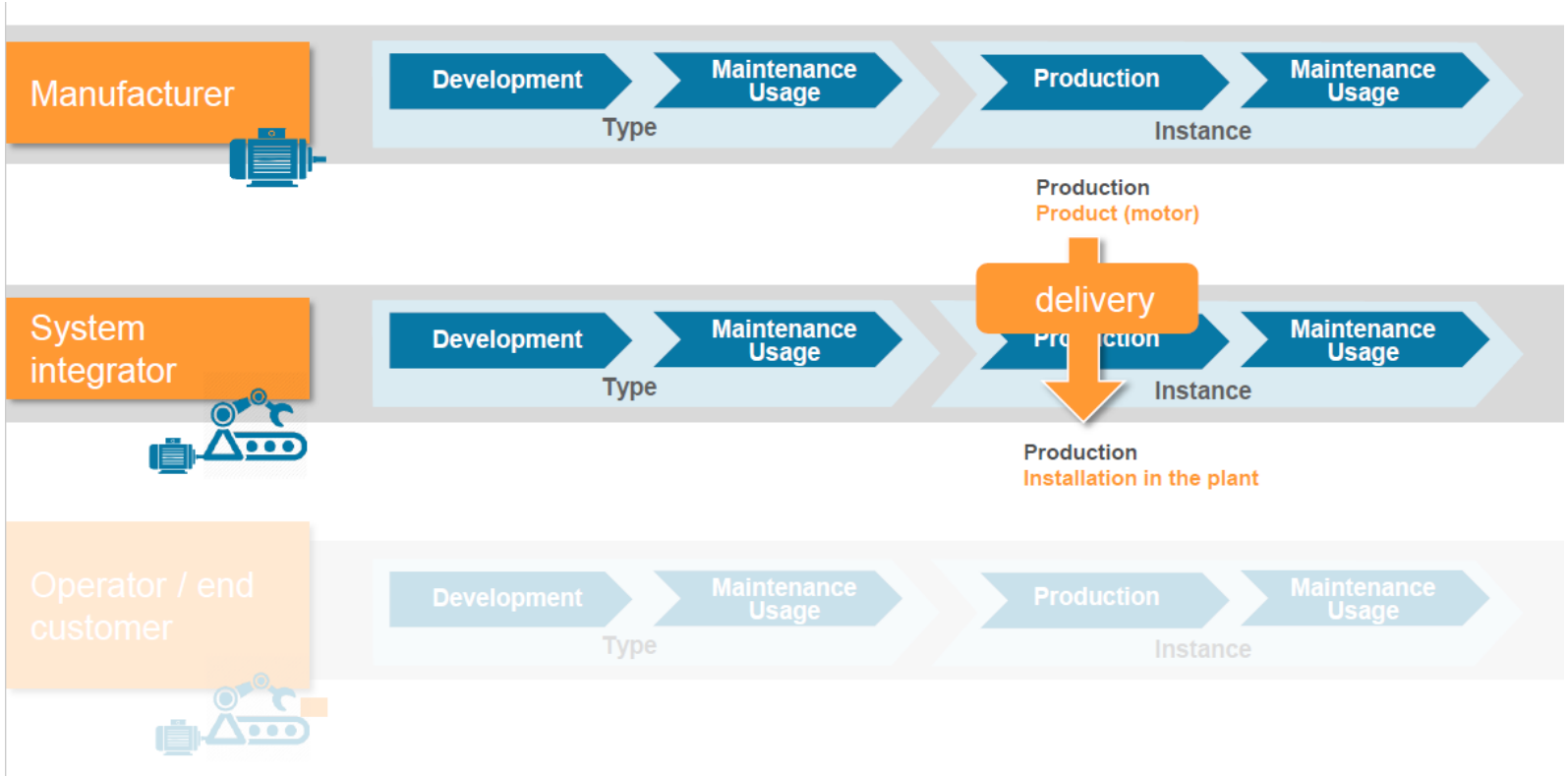

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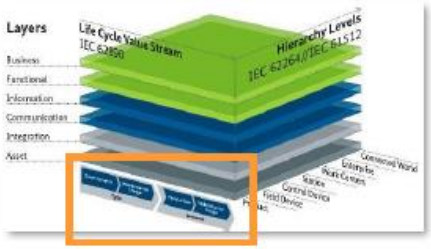

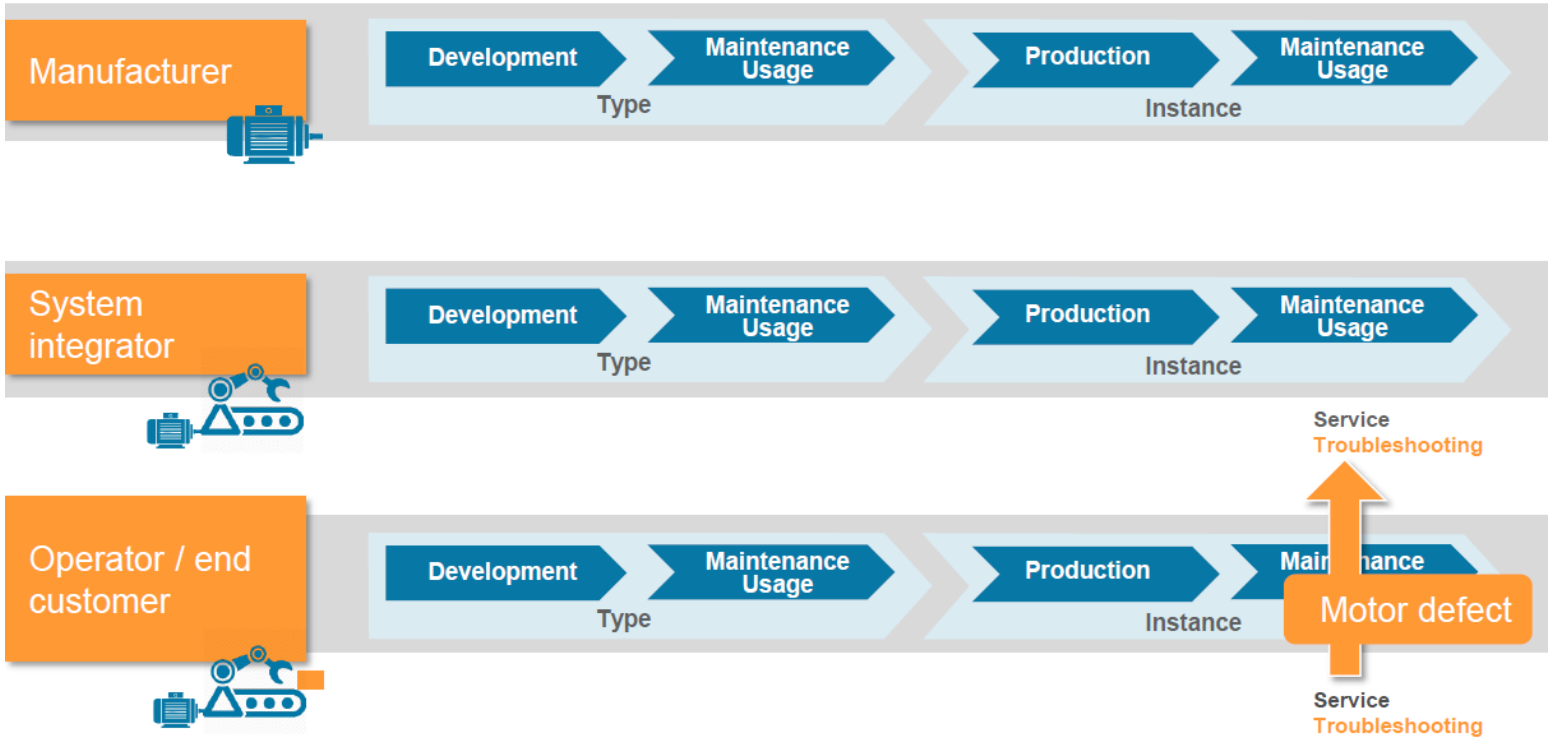

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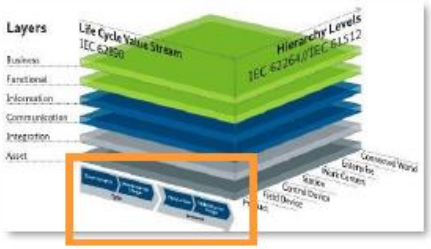

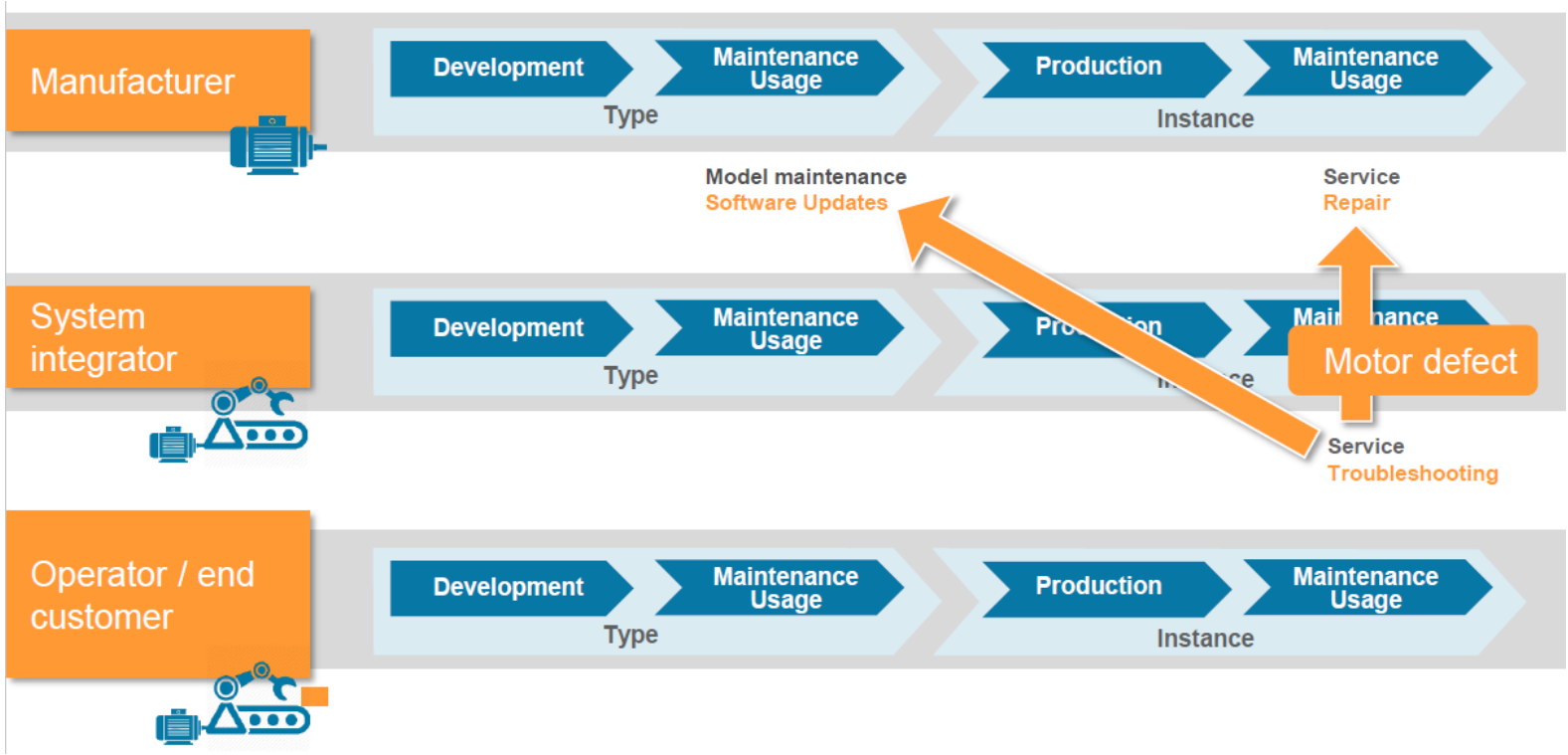

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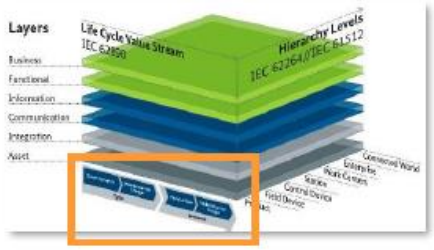

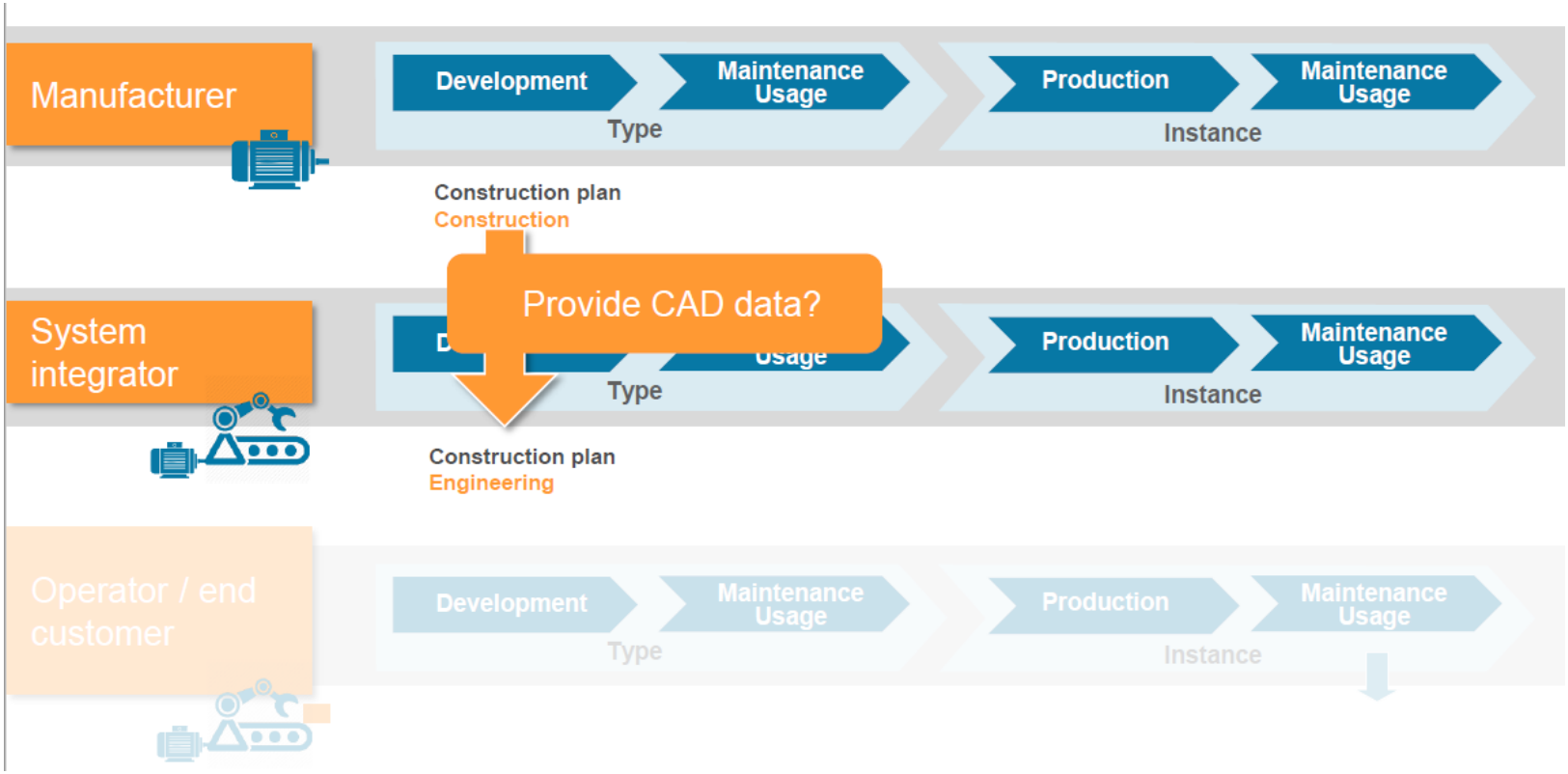

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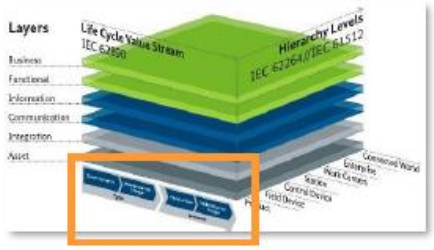

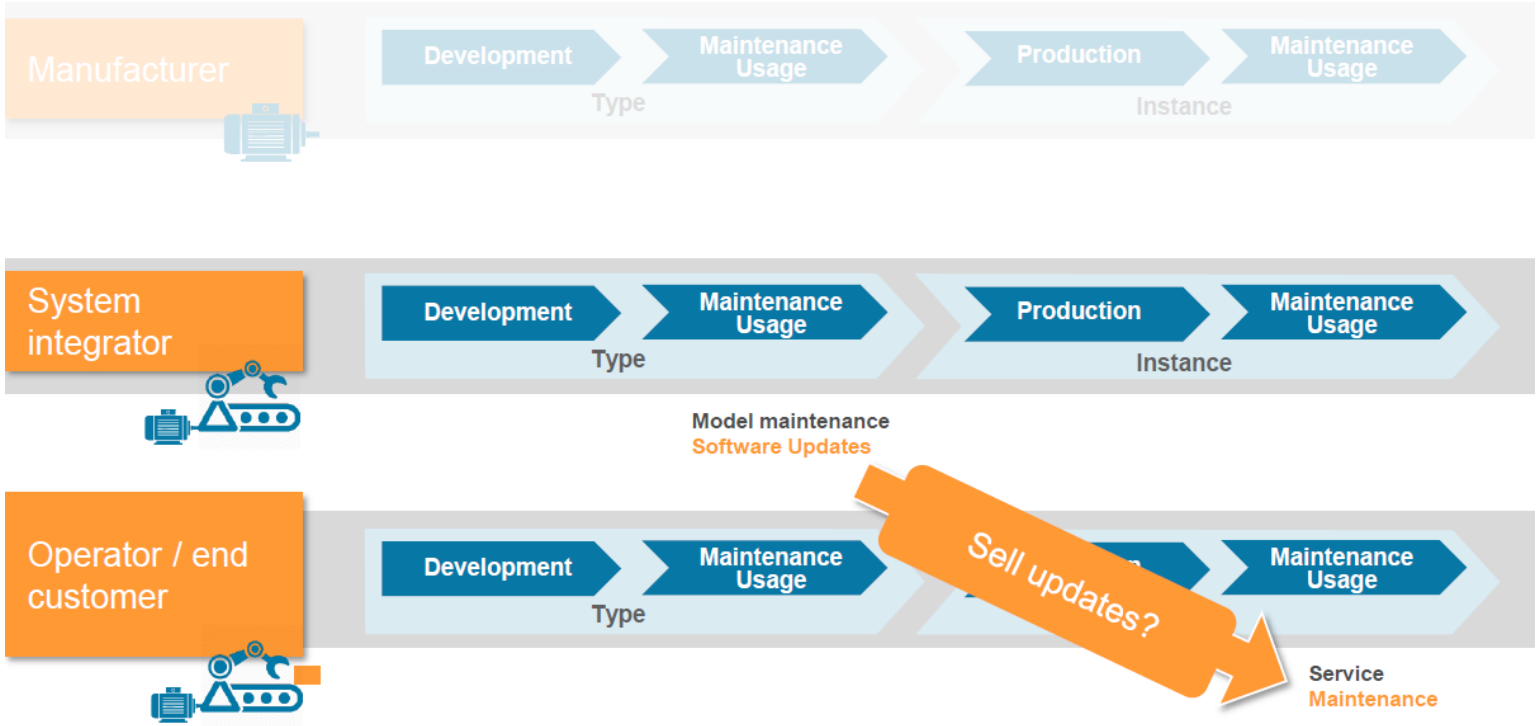

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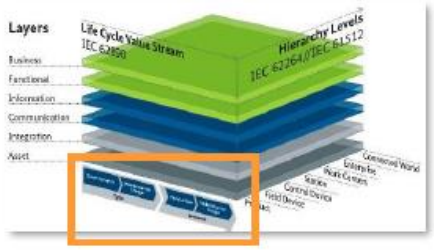

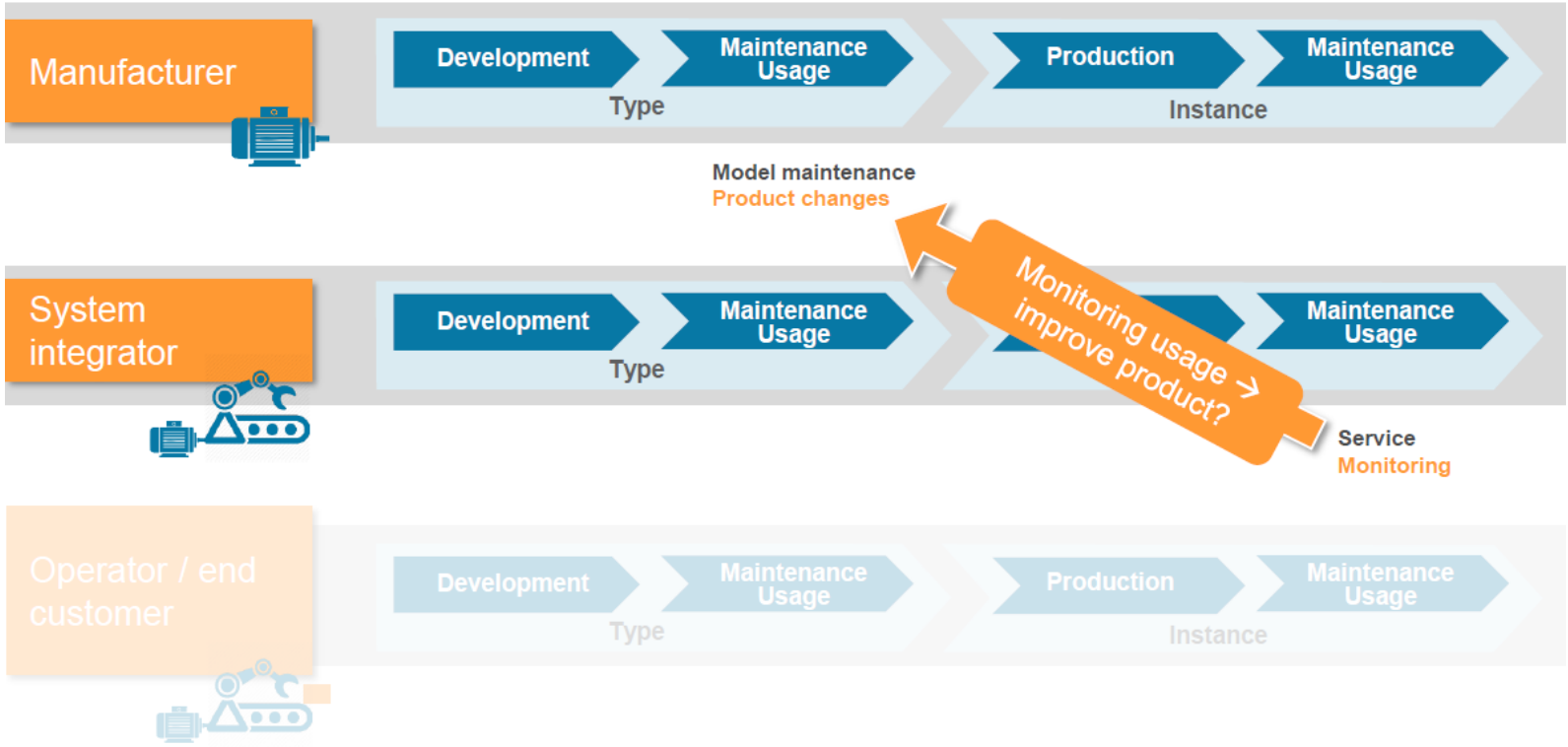

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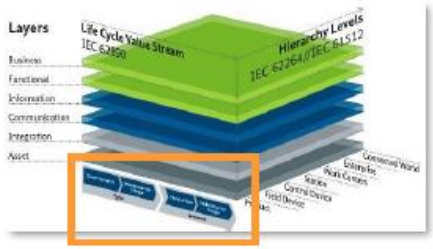

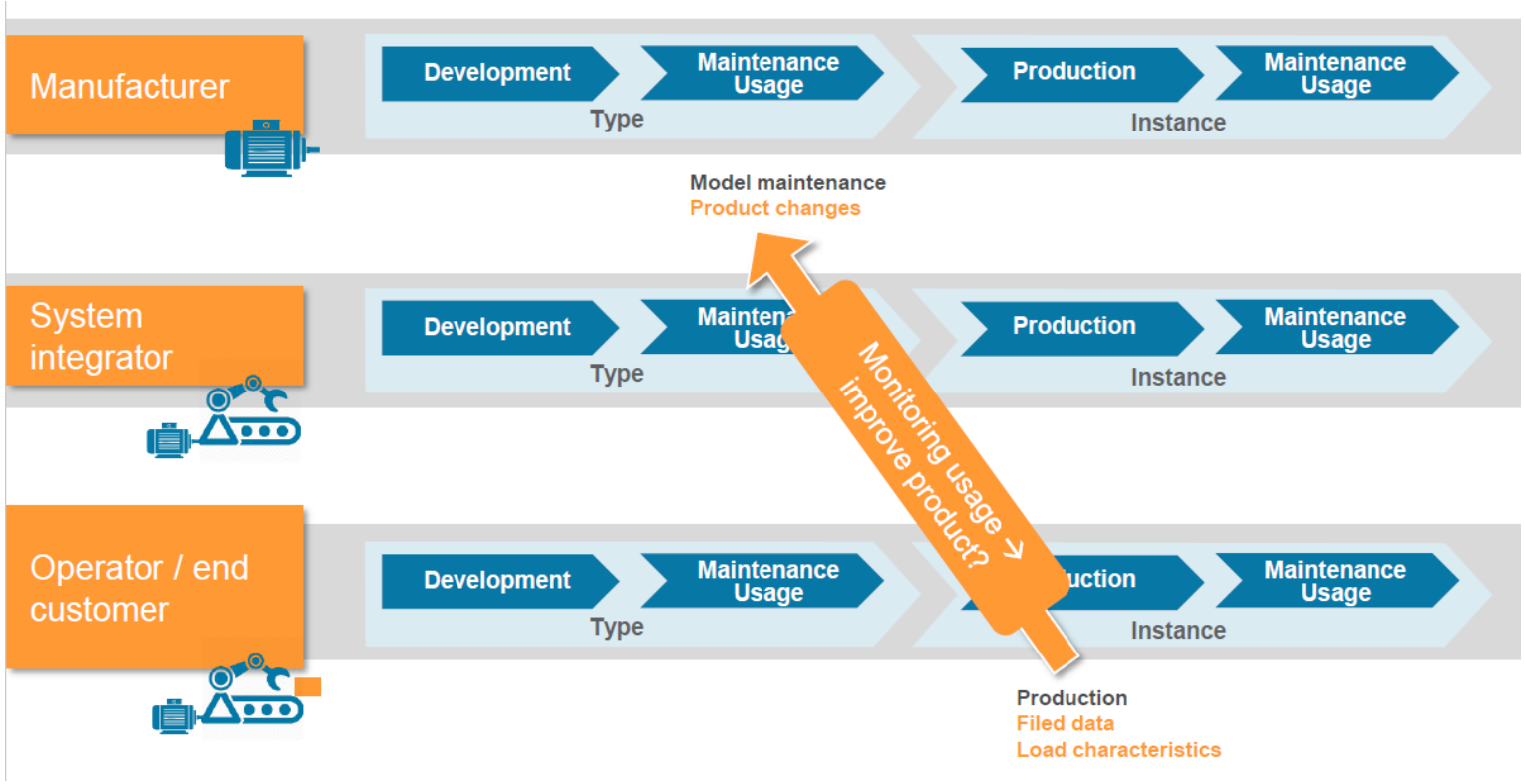

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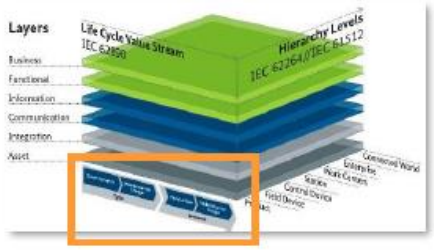

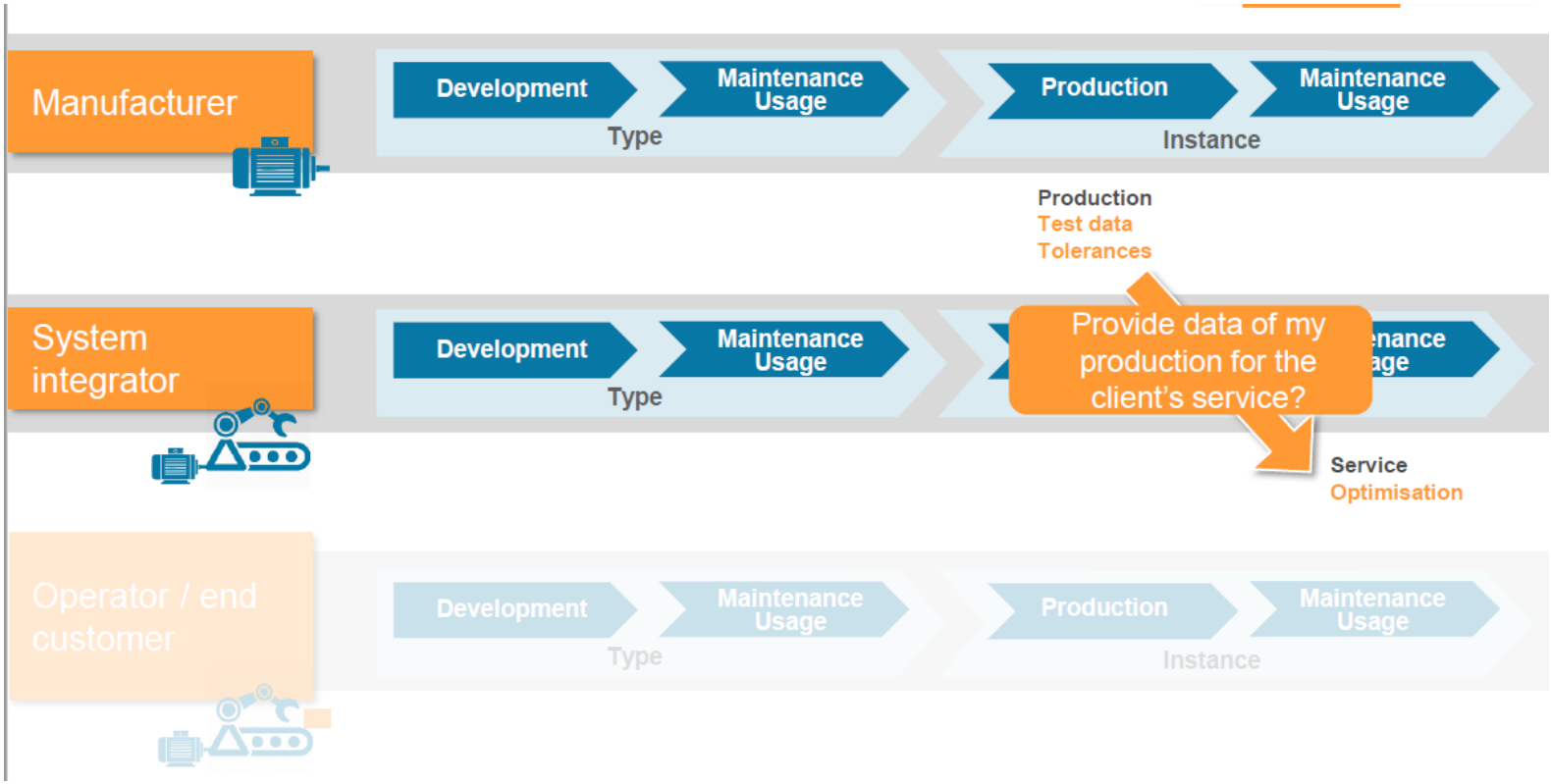

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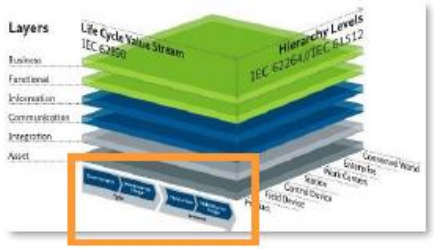
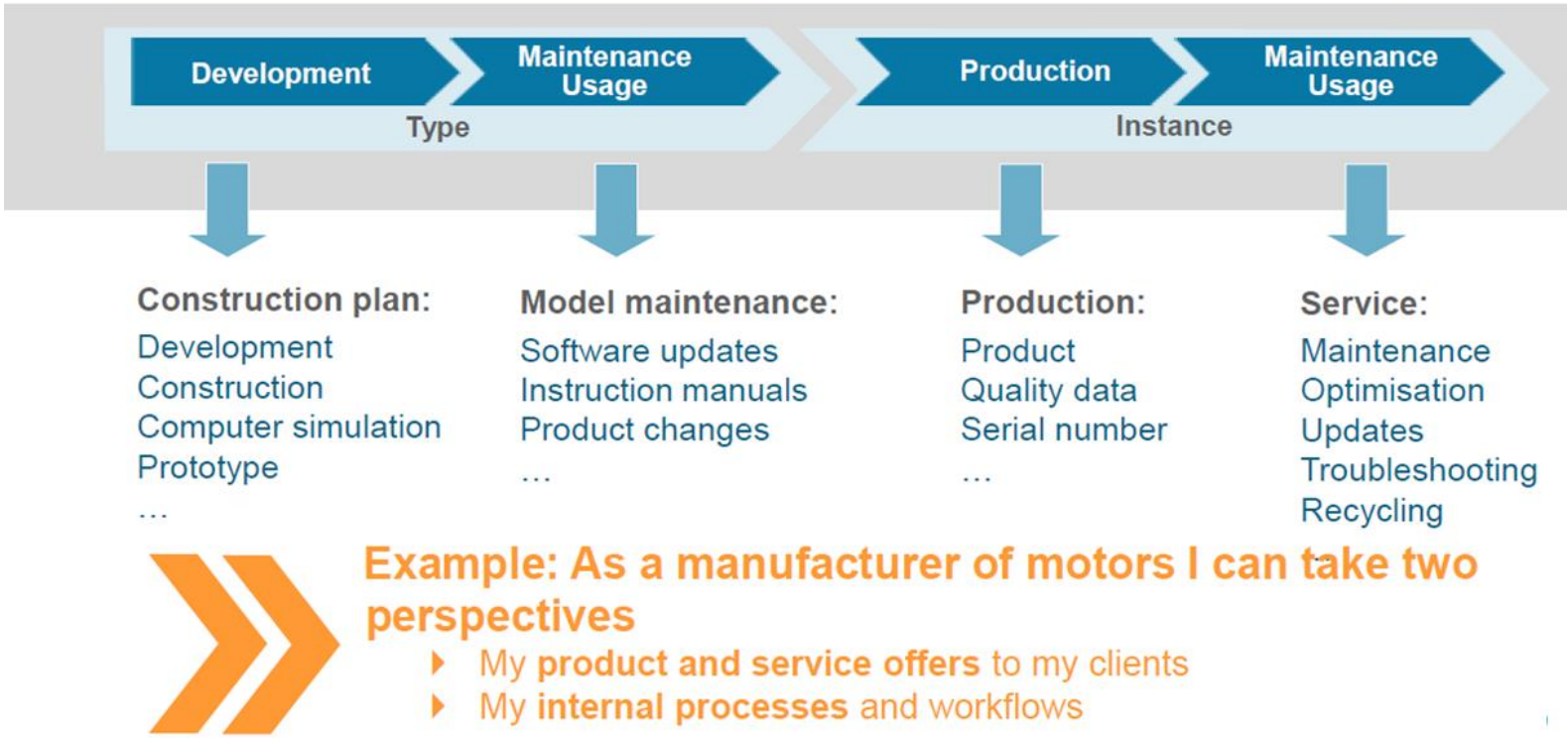
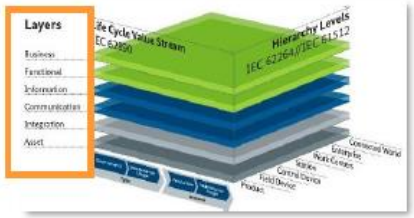




Axis 3 – Architecture



Business — Organisation and Business Processes

Functional — Functions of the Asset

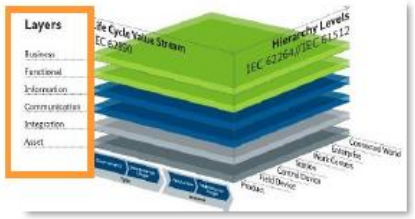
Information — Necessary Data

Communication — Access to Information

Integration — Transition from Real to Digital World

Asset — Physical Things in the Real World

Axis 3 – Architecture



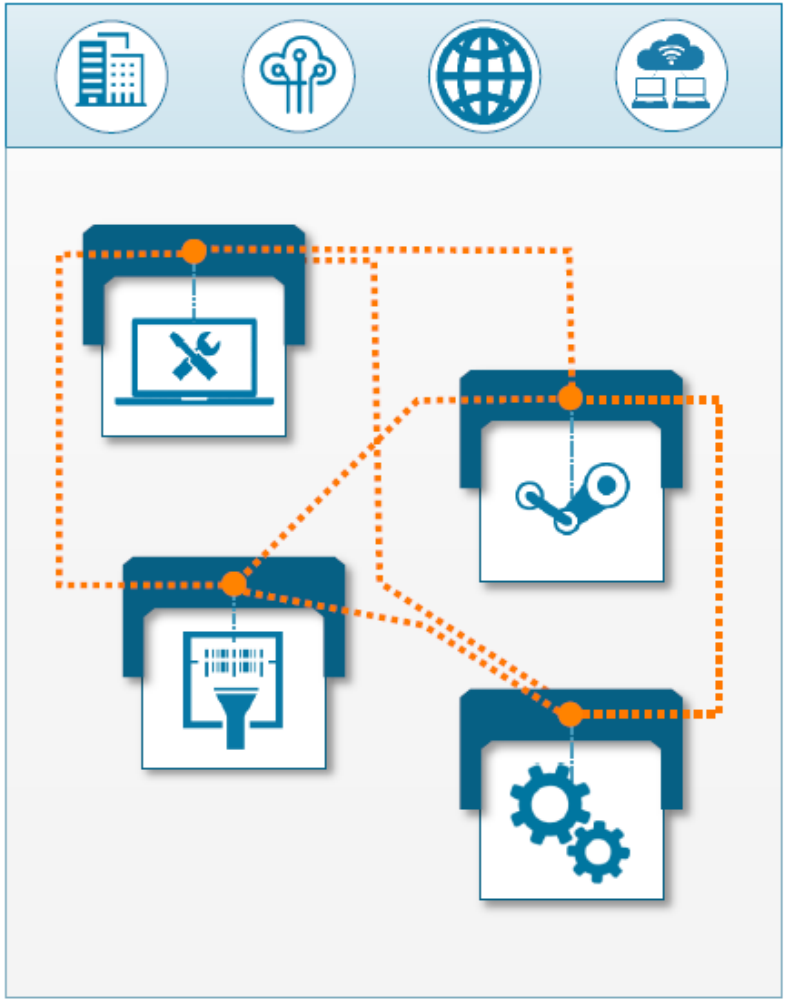
Basic questions about the business idea

Business	Organisation and business processes	What is the customer willing to pay for?
Functions	Functions of the asset	What is my product supposed to do?
Information	Necessary data	What data does my product have to provide?
Communication	Access to information	How do I or my customer access the data?
Integration	Integration of assets into the world of i	Which parts of my product are digitally available in the network?
Asset	"Things" in the physical world	How do I integrate my product with the process to move it in the real world?

Asset Administration Shell

Platform Industrie 4.0

Who provides interpretation?



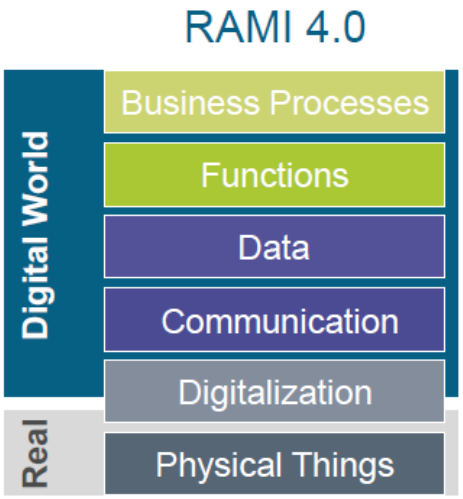
- The Administration Shell…
  - … is the interface connecting I4.0 to the physical Thing
  - … stores all data and information about the asset
  - … serves as the network's standardized communication interface
  - … is also able to integrate passive assets

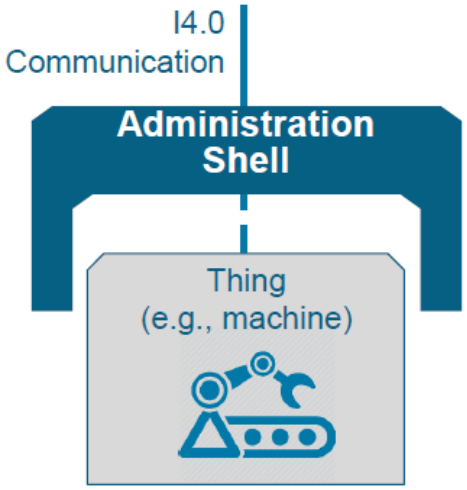
The Roles and Responsibilities of the Administration Shell

- Each physical thing has its own administration shell.
- Several assets can form a thematic unit with a common administration shell.

The Industrie 4.0 Component

- Each object needs its own administration shell that allows its integration into Industrie 4.0.





- The connection takes place over the I4.0 communication
- The administration shell forms the digital part
- The Thing forms the real part

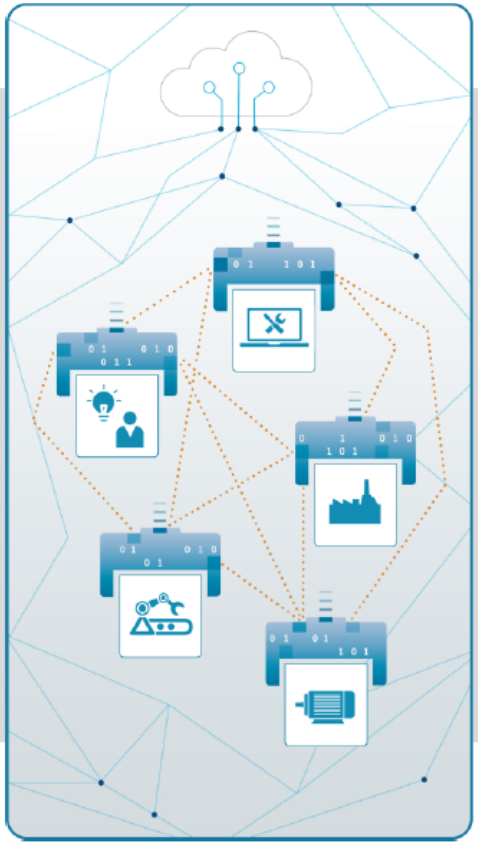
Administration Shell implements the Digital Twin

Digital Twin

Definition 1: Digital representation of a physical asset
Definition 2: Simulation model

The Administration Shell is the implementation of the Digital Twin for Industrie 4.0.

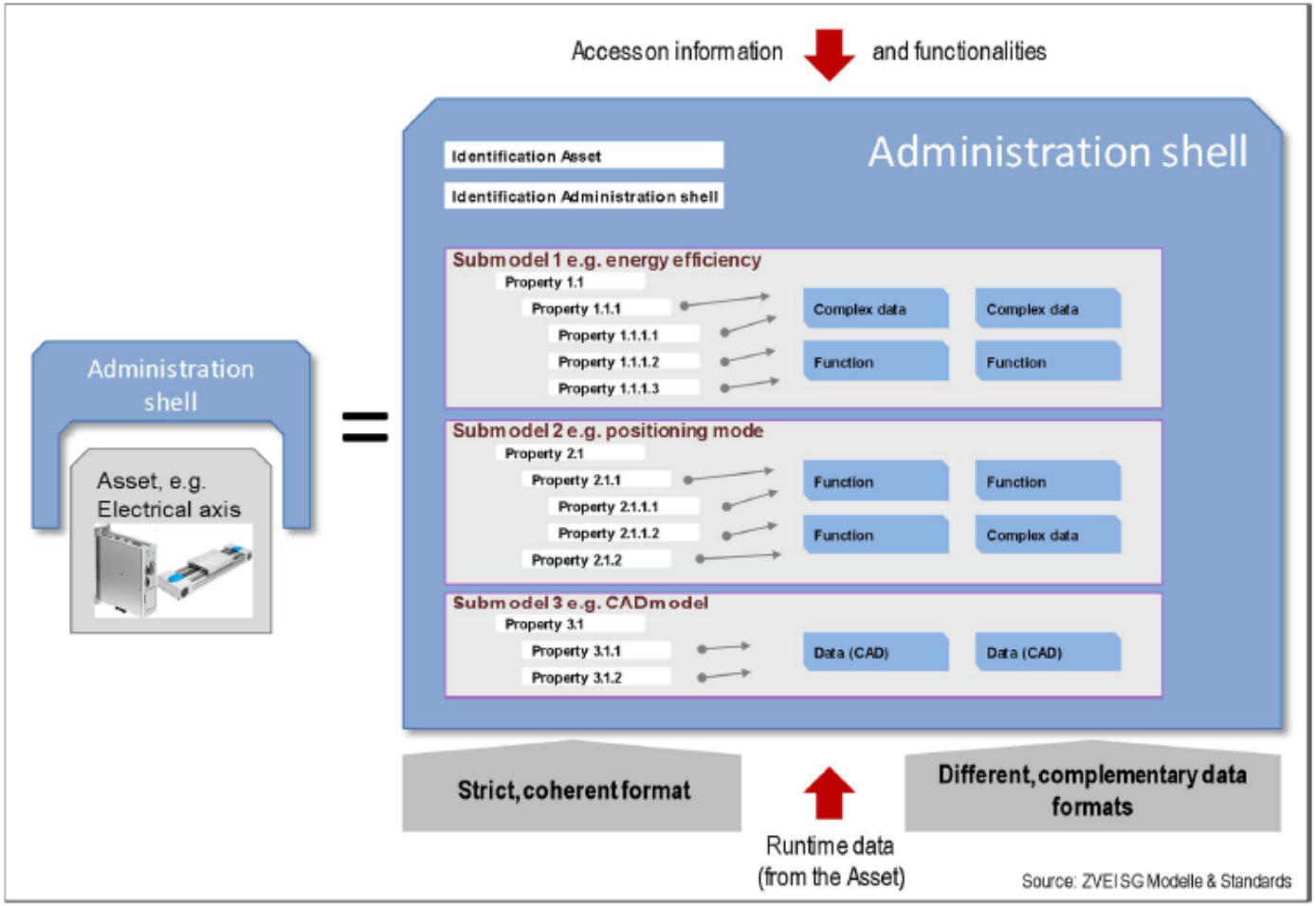
Administration Shell



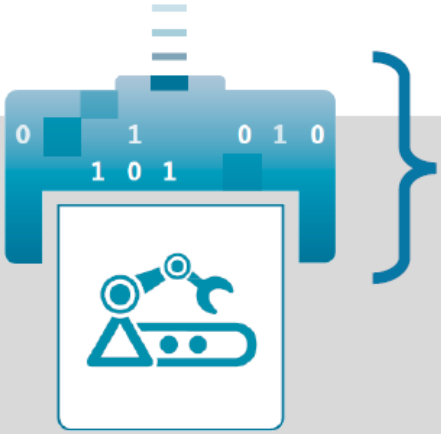
The Administration Shell…

- integrates the *asset into Industrie 4.0 communication*.
- is *addressable* in the network and *identifies the asset* unambiguously.
- provides a *controlled access to all information* of the asset.
- is the standardised and secure *communication interface*.
- can integrate *intelligent* and also *non-intelligent („passive“) assets* (without a communication interface), e.g. via bar codes or QR codes.

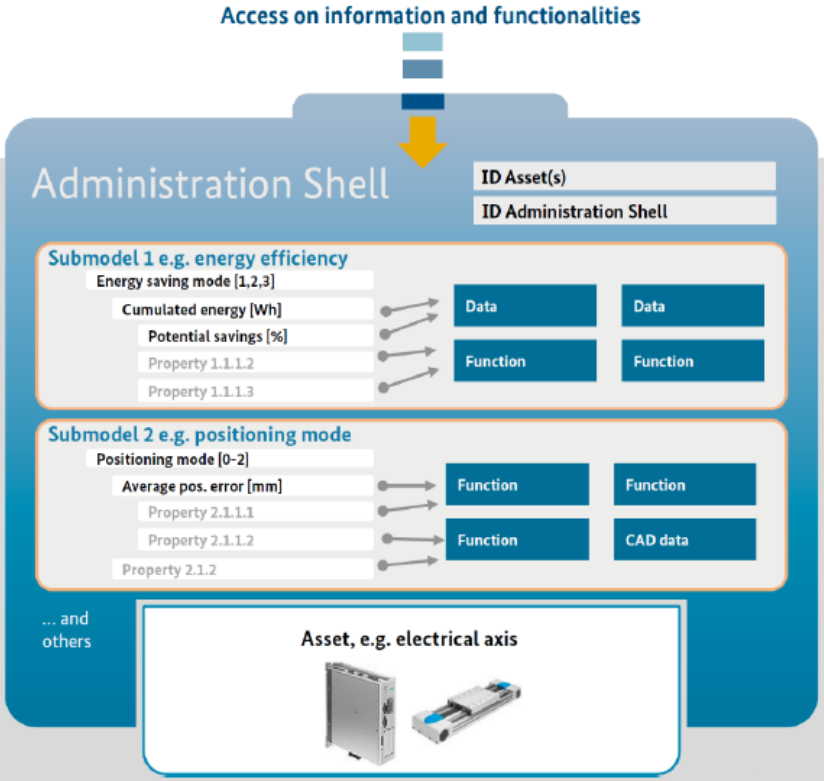
Basic structure



The generic structure of the meta information model

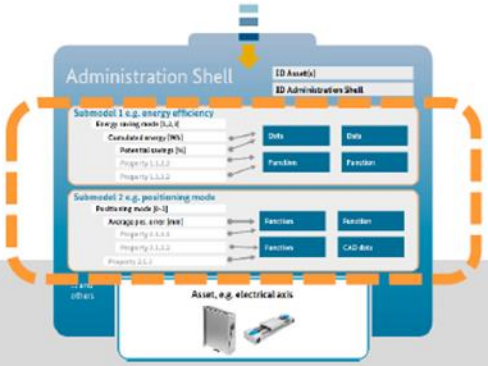


Administration Shell with its identifier (“Internet adress”) and submodel elements



Source: Plattform Industrie 4.0 illustration based on ZVEI SG Modelle & Standards

Submodels



Submodel **= aggregates information that belongs together**

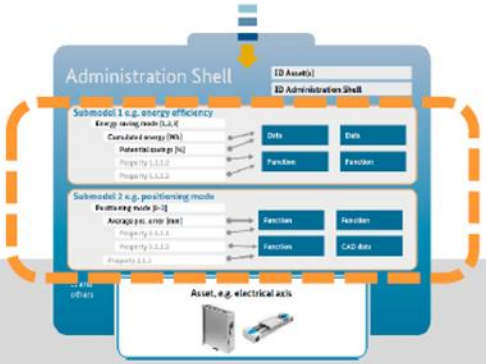
- *Submodels* combine different functional aspects of an Industrie 4.0 component
- *Basic submodels* (standardised): apply to many assets in the Industrie 4.0 world (e.g. catalogue data of products)
- *Free submodels*: agreed between partners in the value chain for a specific use case

Submodels should always be linked to a use case that creates value.

An Administration Shell may contain many submodels.

Aim: To develop one sub-model for each functional aspect.

Submodel elements / Properties



Submodels **contain submodel elements**

(Submodel elements include e.g. properties.)

- *Product properties* in terms of IEC61360-1 or ecl@ss
- *Process variables* and parameters, telemetry data
- *References* to external data sources or files
- *References* to other Administration Shells and their parts (submodels, properties), also from external partners in the value chain
- *Capabilities* of the asset, description of method calls
- *Sets* of properties, e.g. lists or arrays

Example

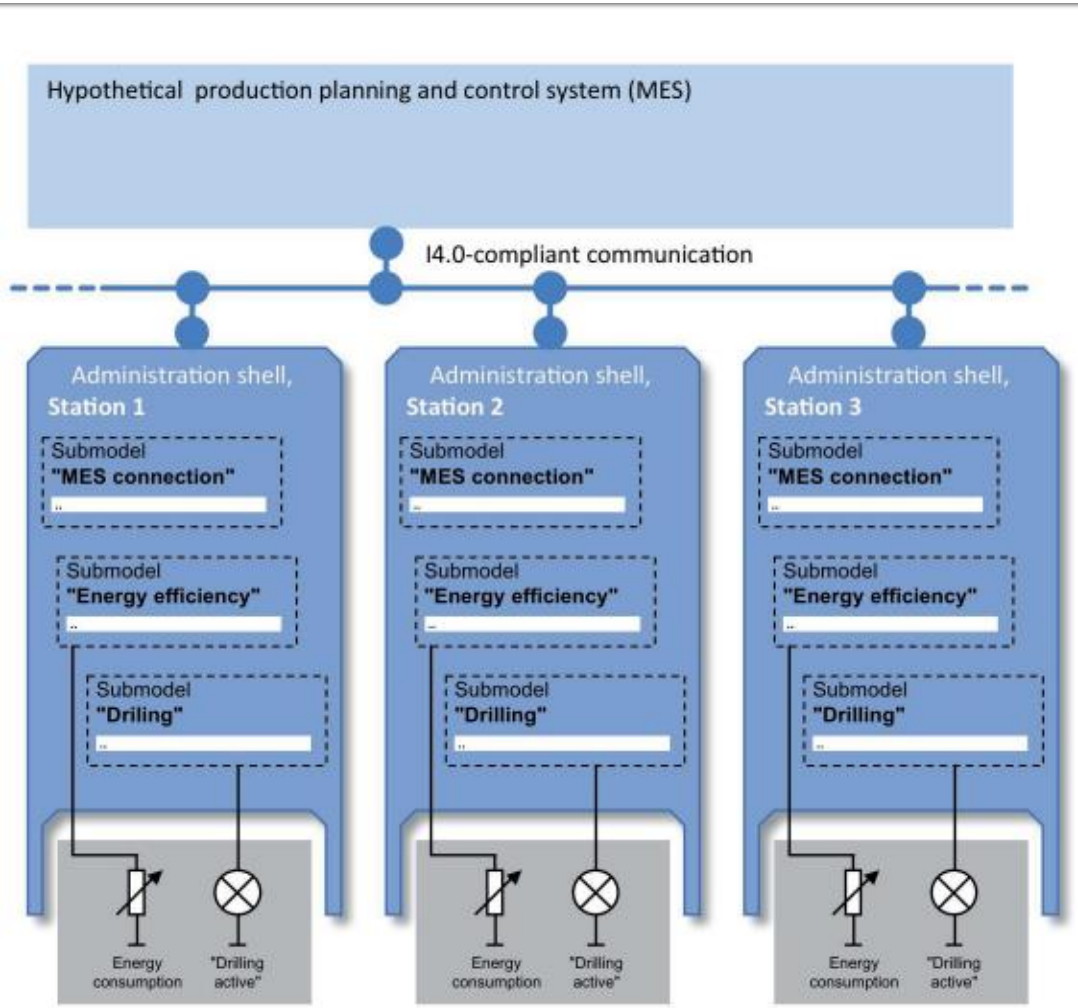
Submodel „energy efficiency“ contains e.g.

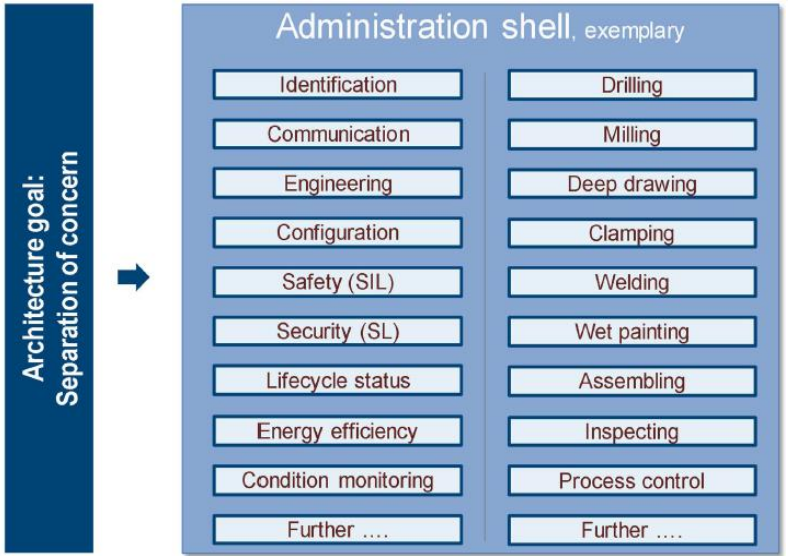
- Energy saving mode [1,2,3]
- Cumulated energy [Wh]
- Potential savings [%]

Submodel „positioning mode“ contains e.g.

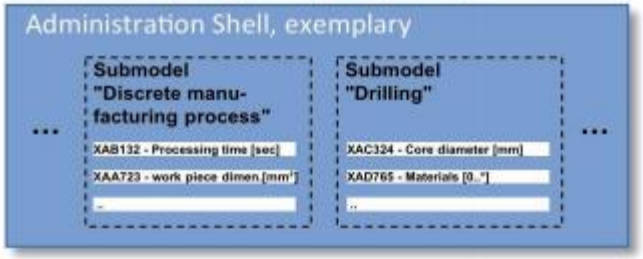
- Positioning mode [0-2]
- Average pos. error [mm]

Examples

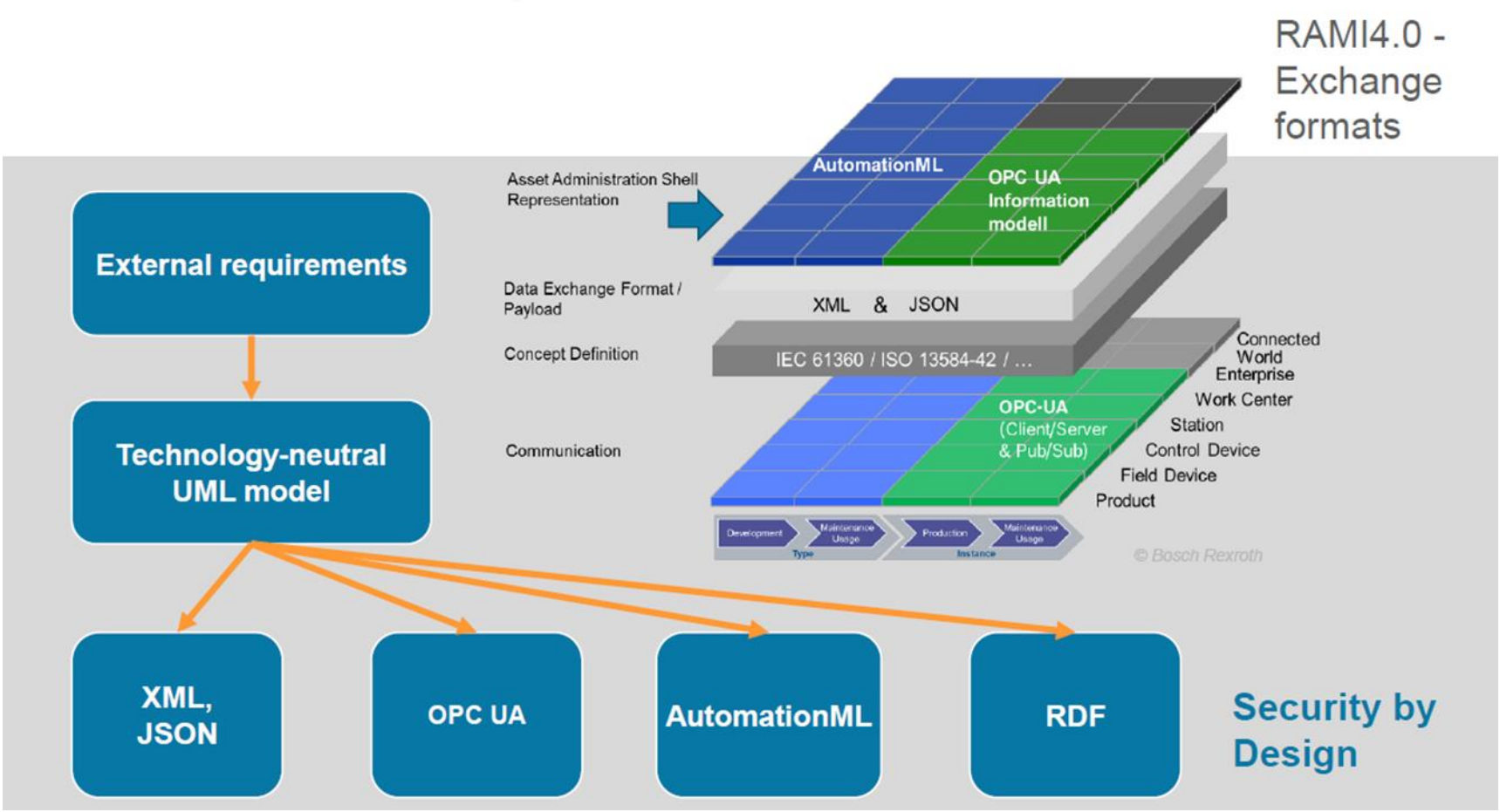




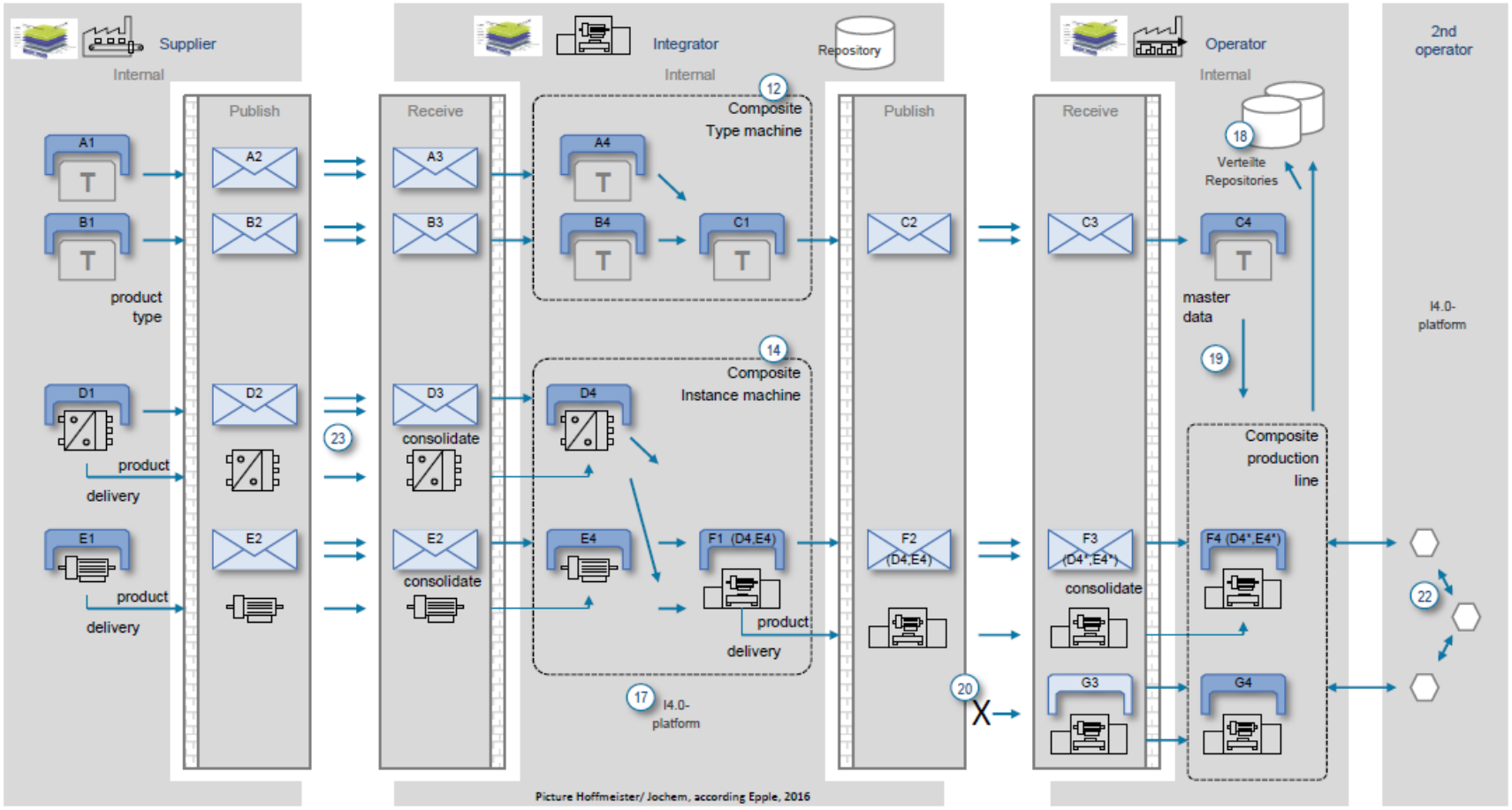
»Is a manufacturing process Drilling possible, having work piece dimension ≤ 500x300mm , a core diameter of ≤ 12mm , a material V2A steel , taking processing time ≤ 3sec ?«



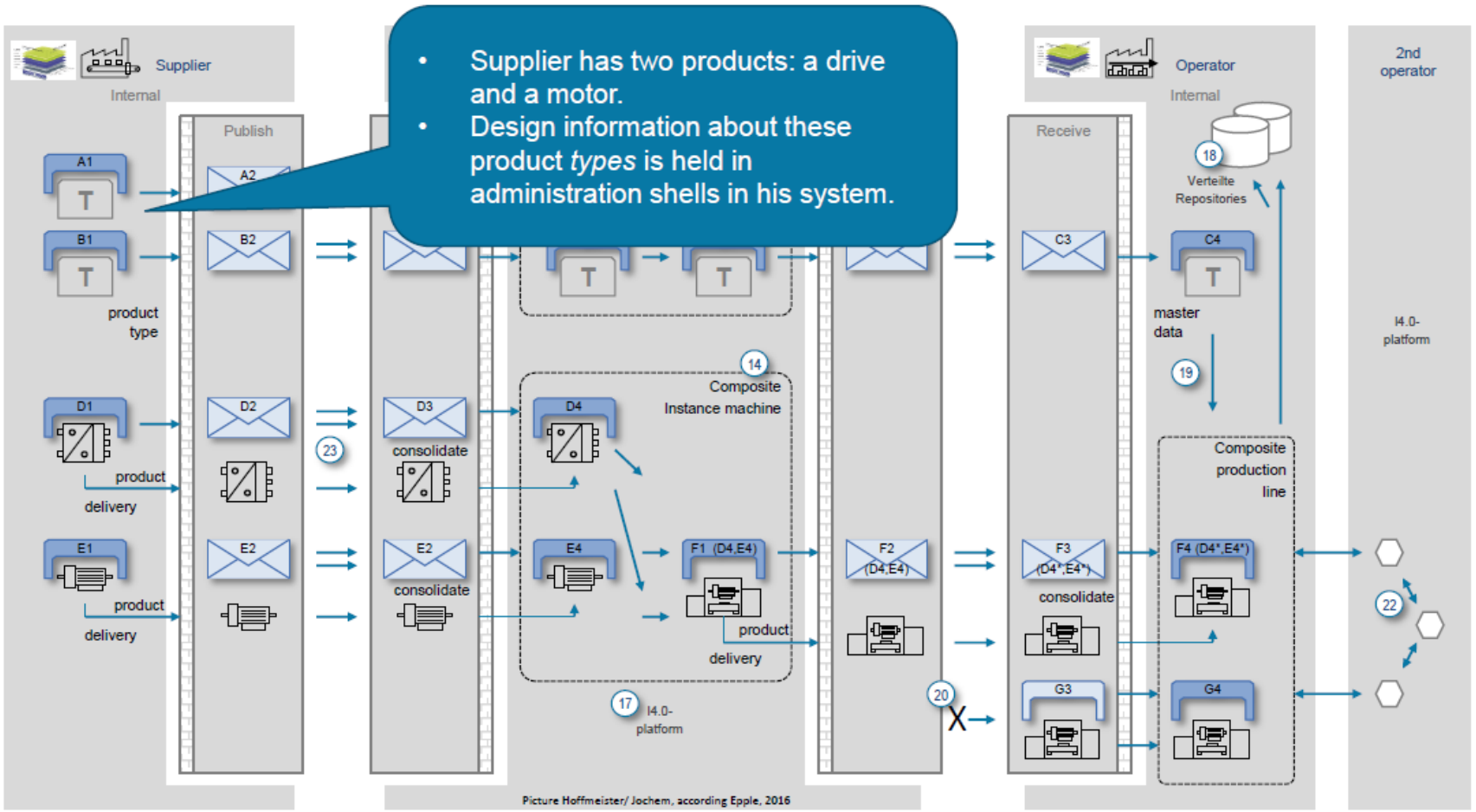
Overview of the Administration Shell



Leading picture for Use Cases: a three step value chain

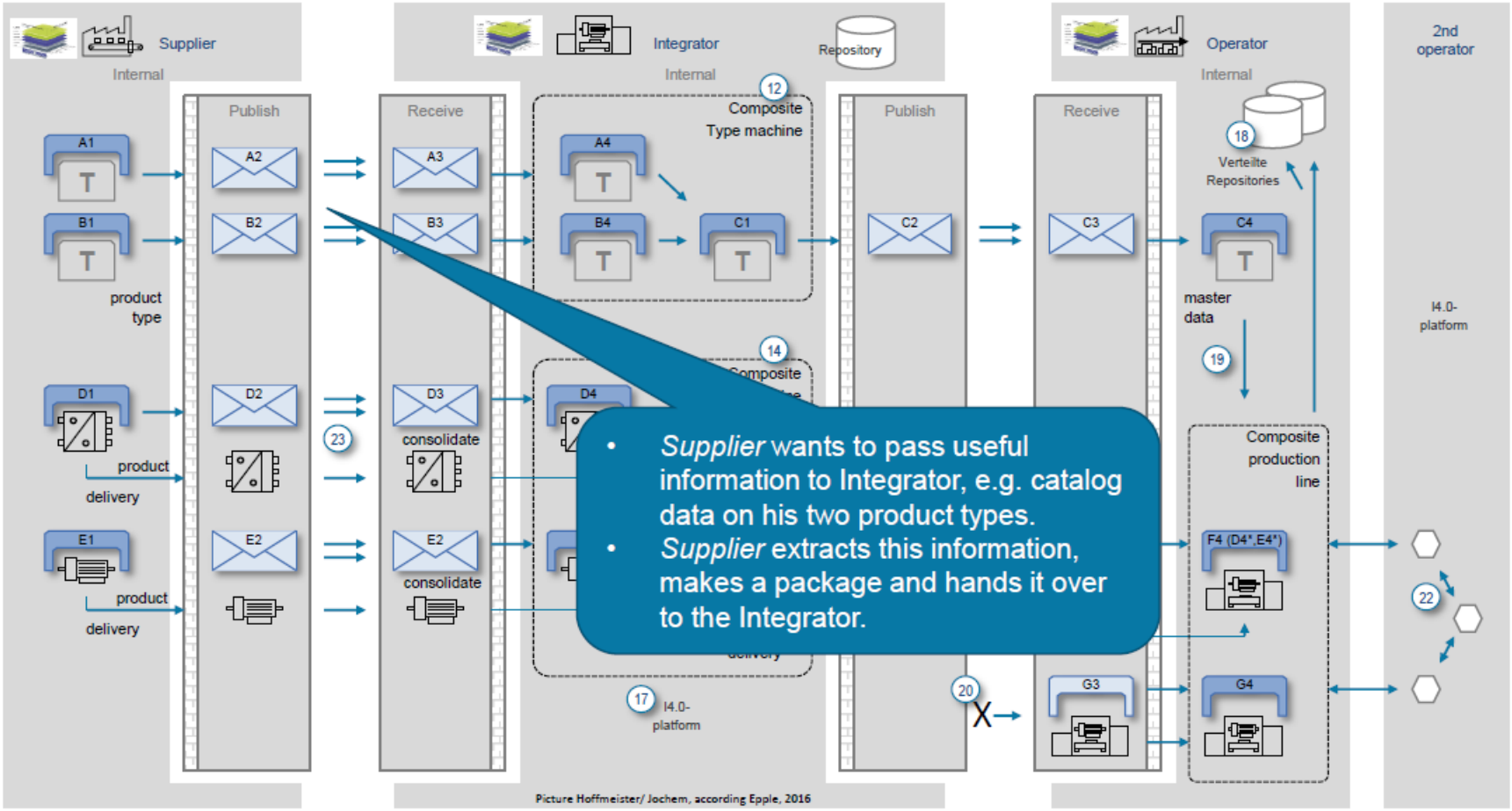


Use Case: Information about Products ("Types")



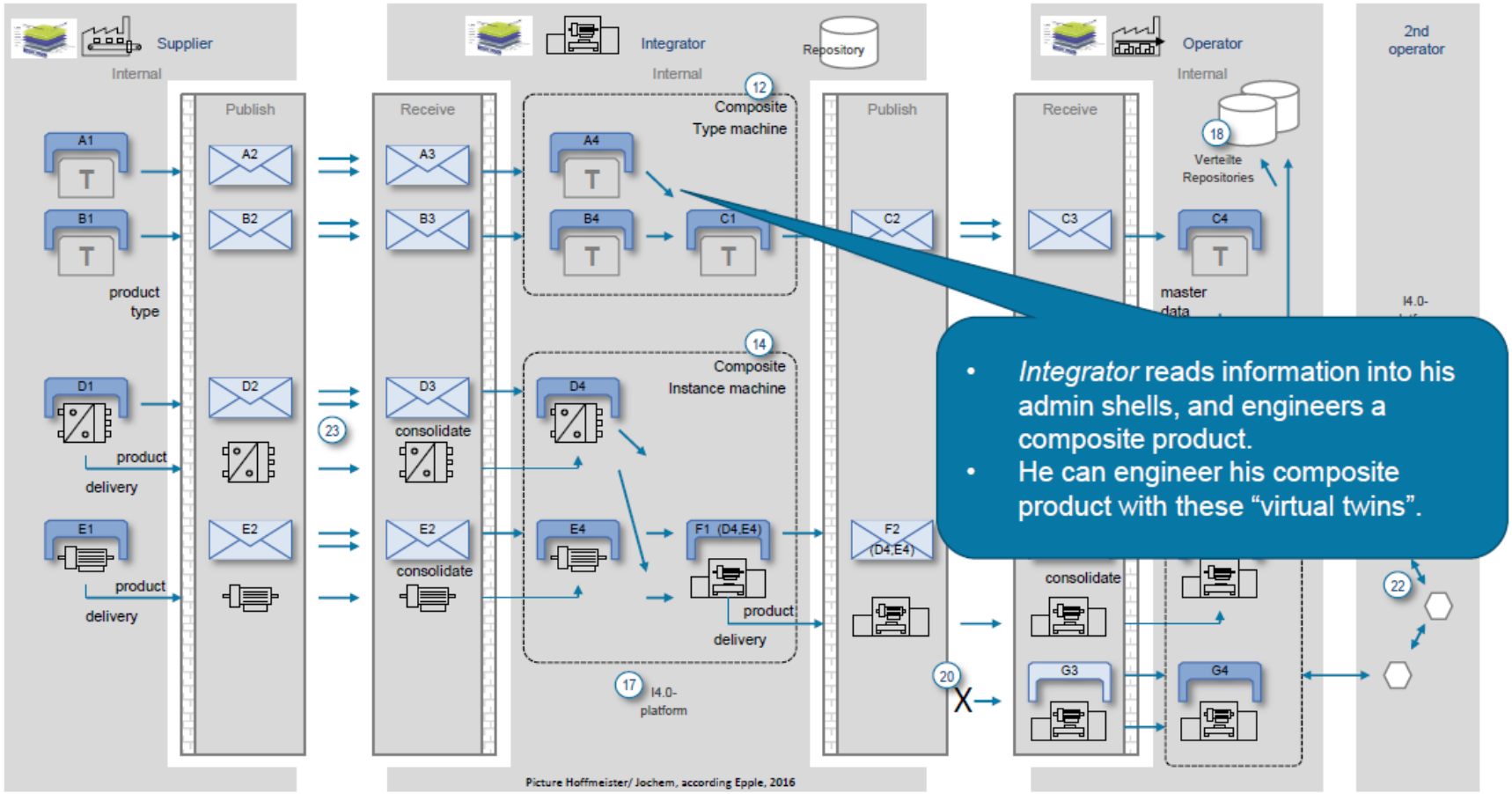
- Supplier has two products: a drive and a motor.
- Design information about these product *types* is held in administration shells in his system.

Use Case: Information about Products ("Types")



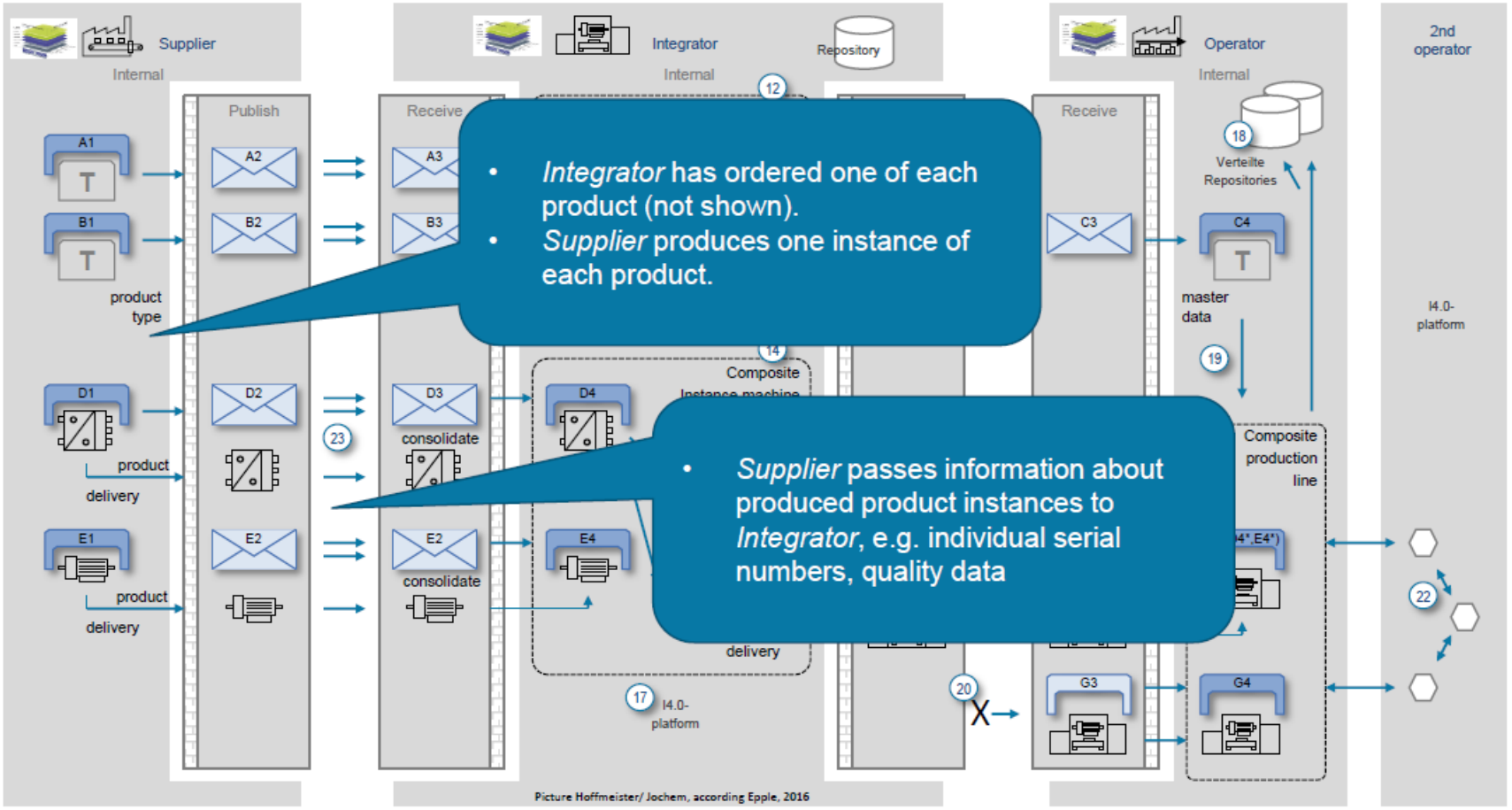
- *Supplier* wants to pass useful information to Integrator, e.g. catalog data on his two product types.
- *Supplier* extracts this information, makes a package and hands it over to the Integrator.

Use Case: Engineering with Product Types



- *Integrator* reads information into his admin shells, and engineers a composite product.
- He can engineer his composite product with these “virtual twins”.

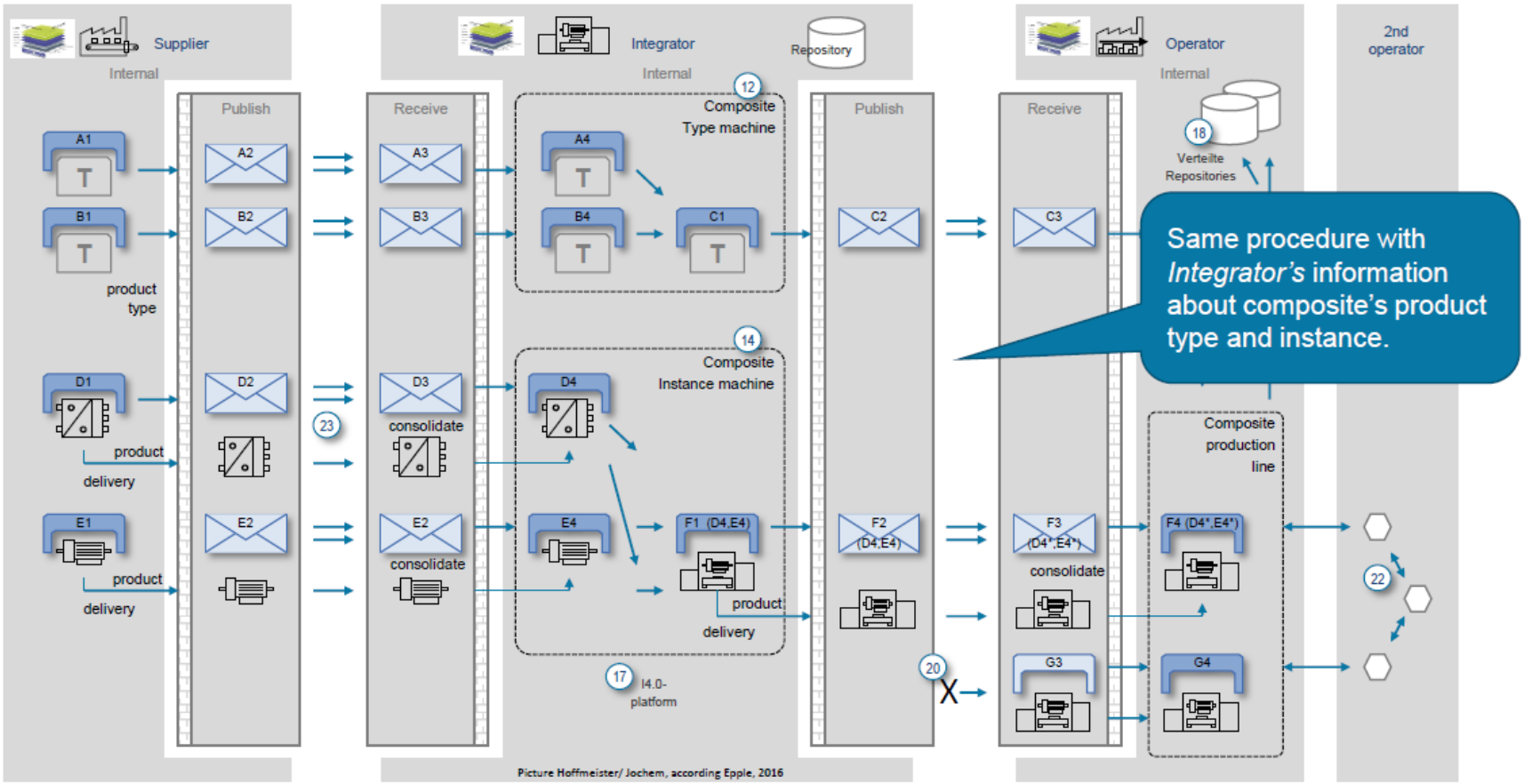
From Design to Reality: "Types" become "Instances"



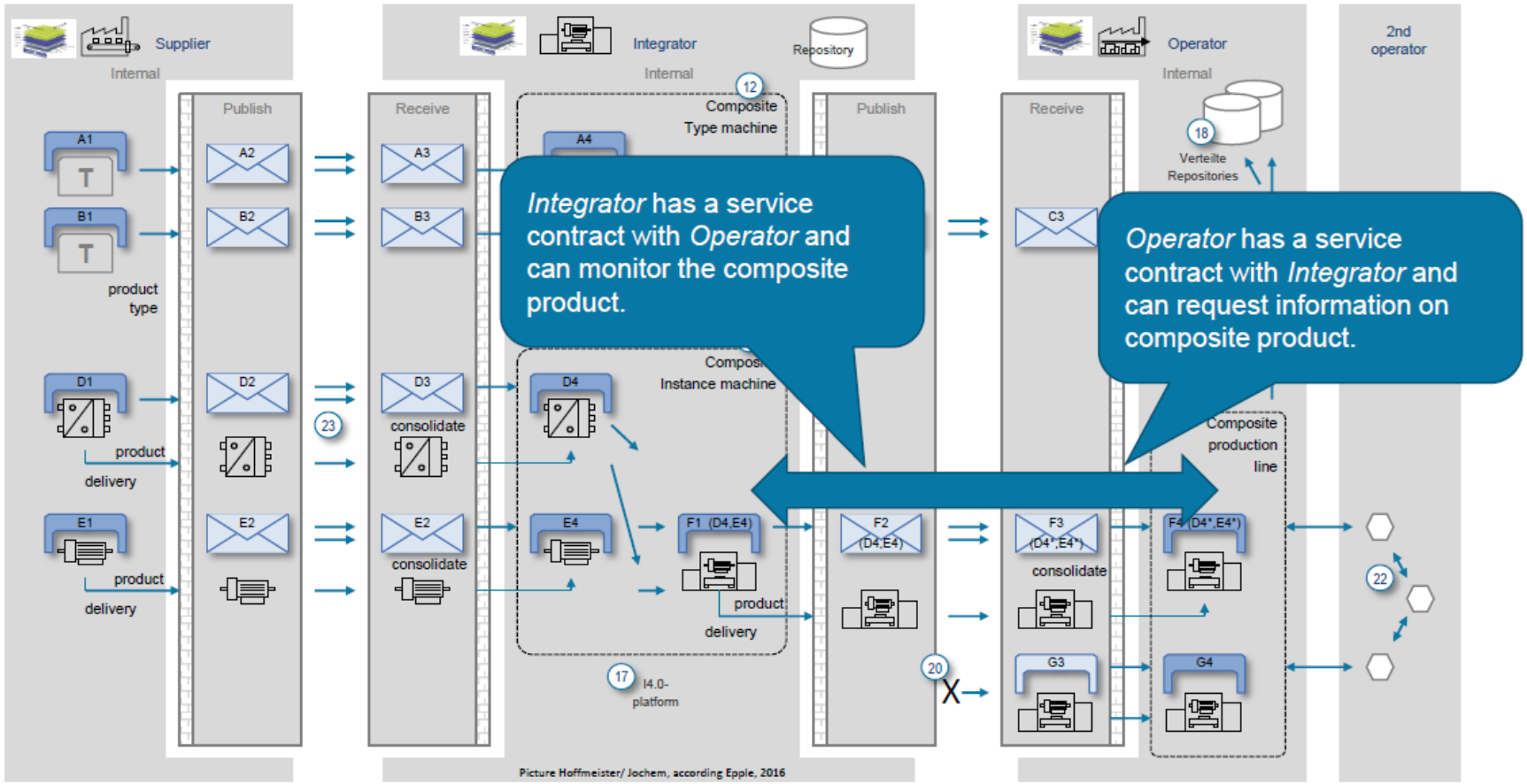
- *Integrator* has ordered one of each product (not shown).
- *Supplier* produces one instance of each product.

- *Supplier* passes information about produced product instances to *Integrator*, e.g. individual serial numbers, quality data

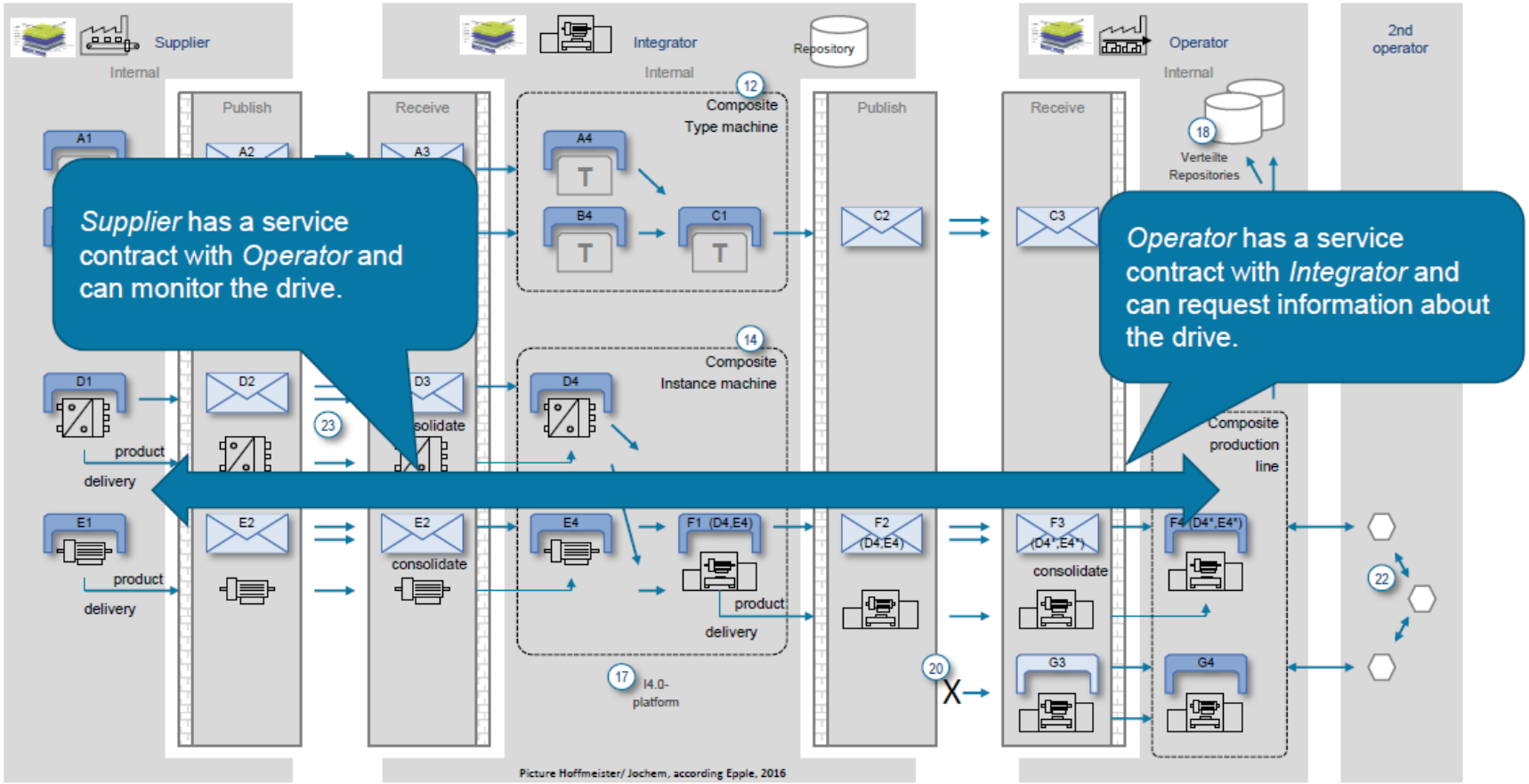
Leading picture for Use Cases: a three step value chain



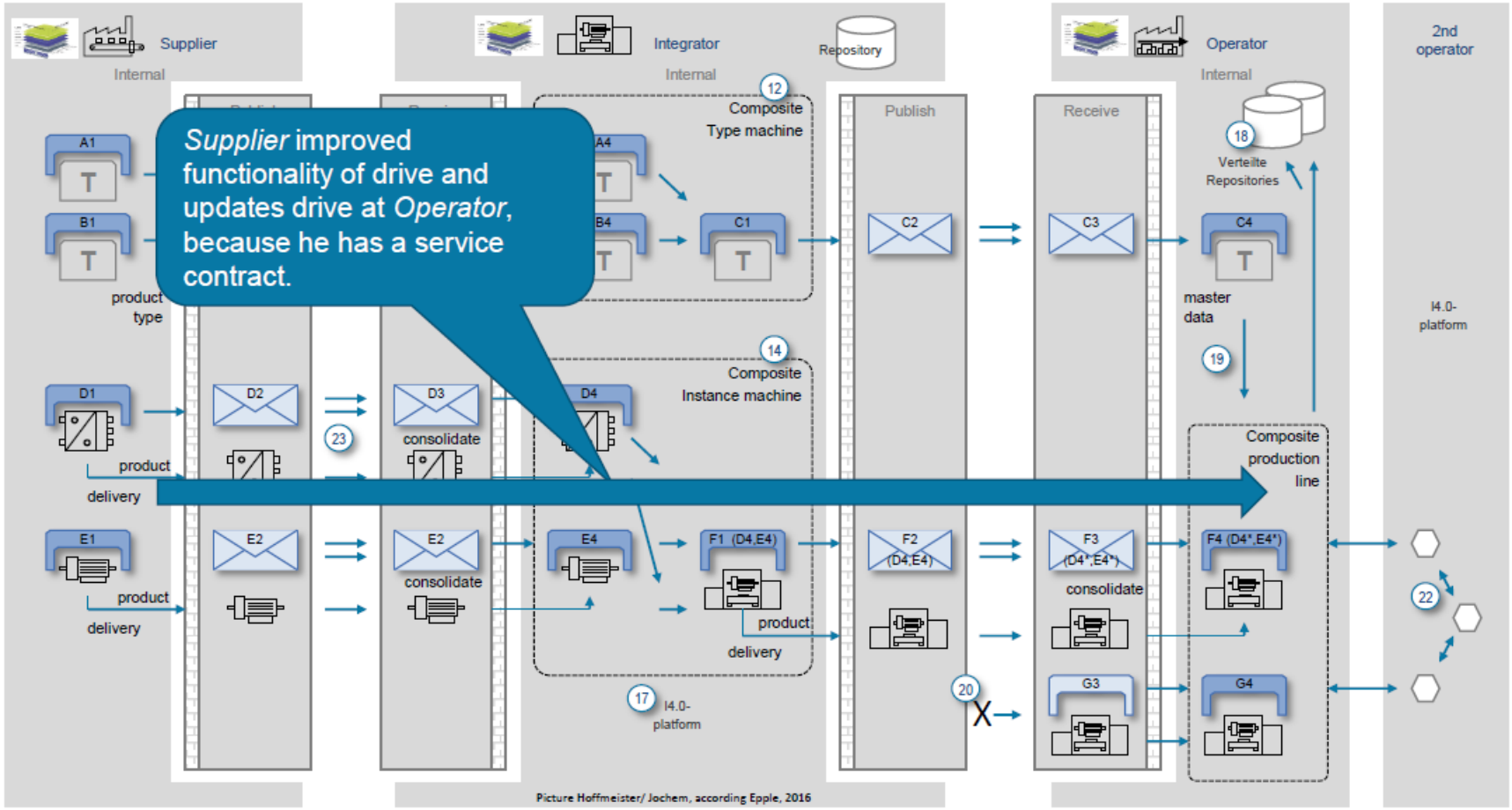
Use Case: Remote Monitoring & Asset Health



Use Case: Remote Monitoring & Asset Health

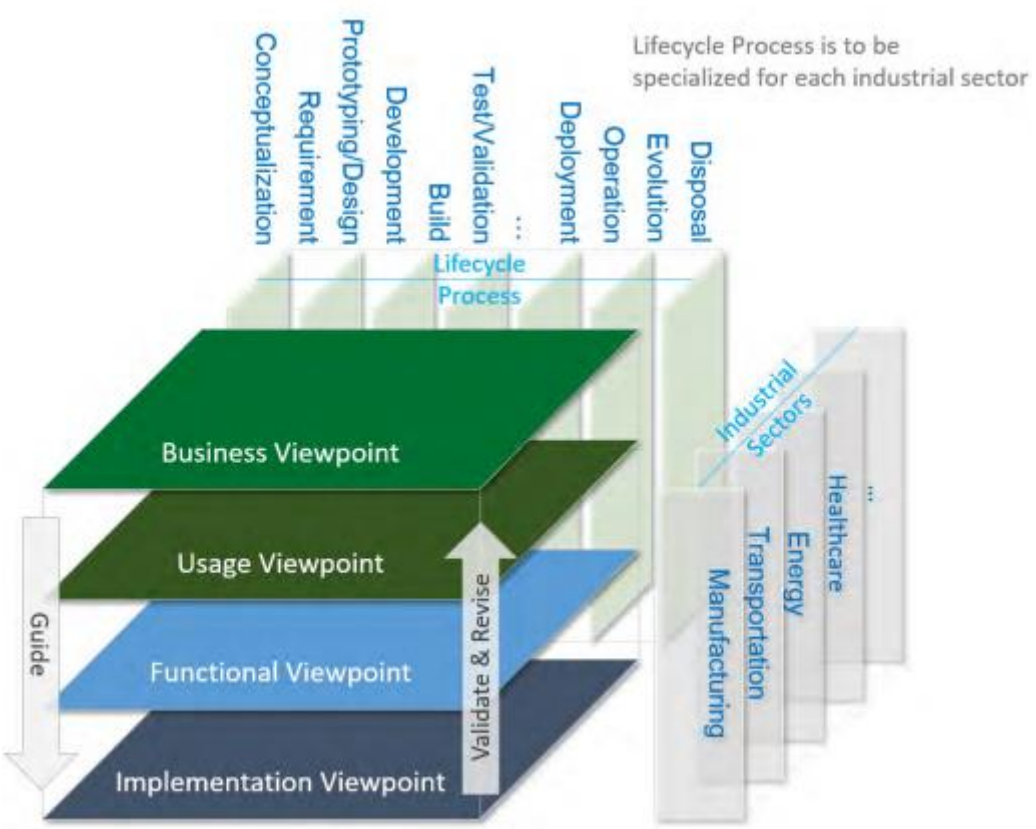


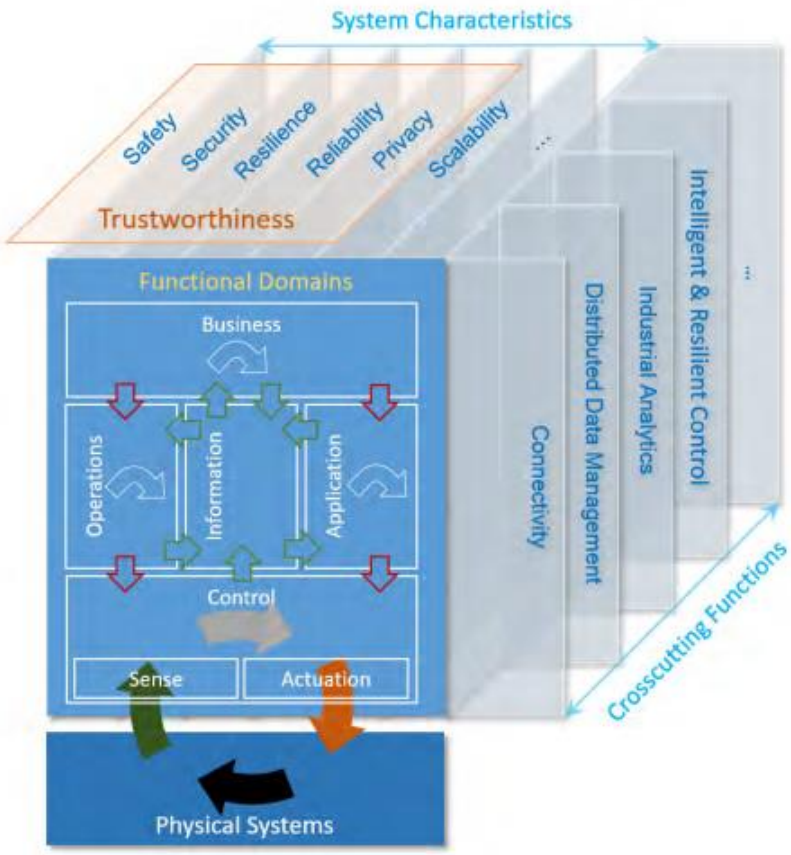
Use Case: Service Contracts



Other initiatives

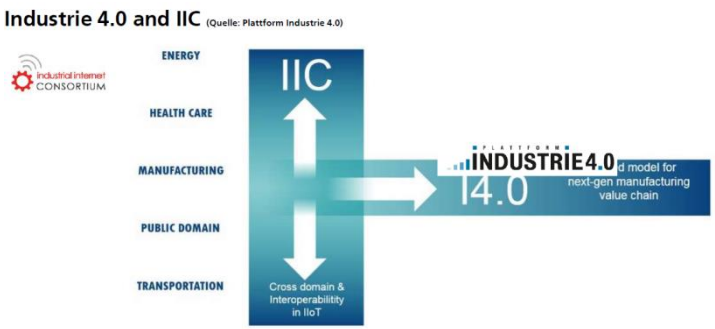
Industrial Internet Reference Architecture (IIRA)

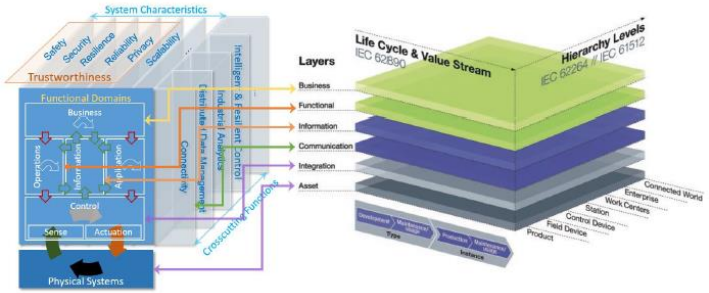


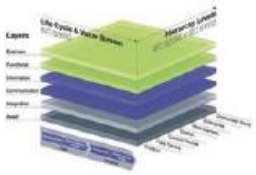


Industrial Internet Consortium (IIC) https://www.iiconsortium.org/

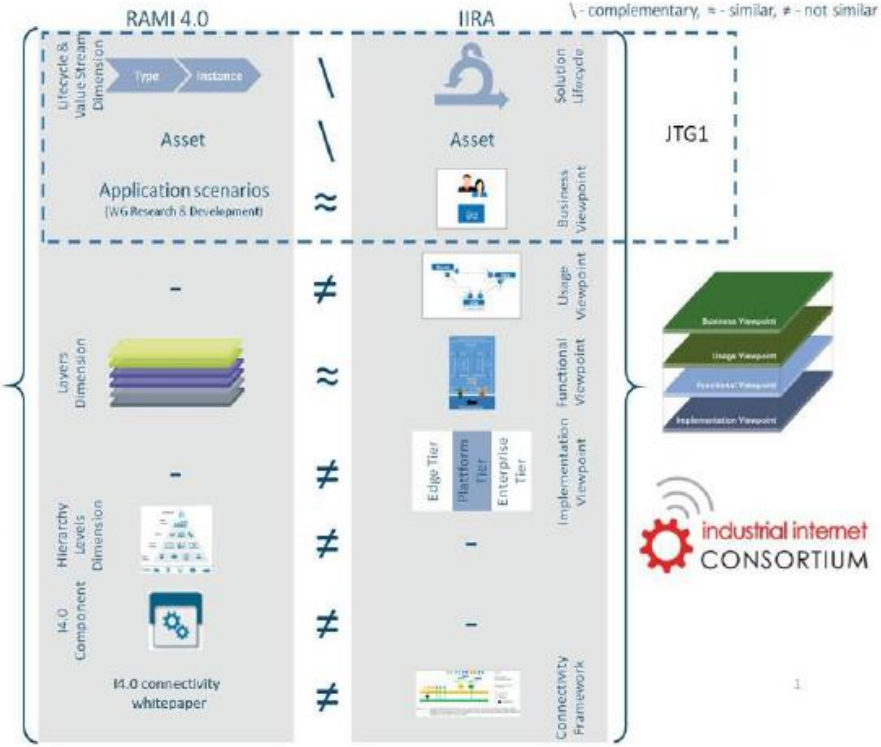
Mapping of IIRA and RAMI 4.0







INDUSTRIE 4.0



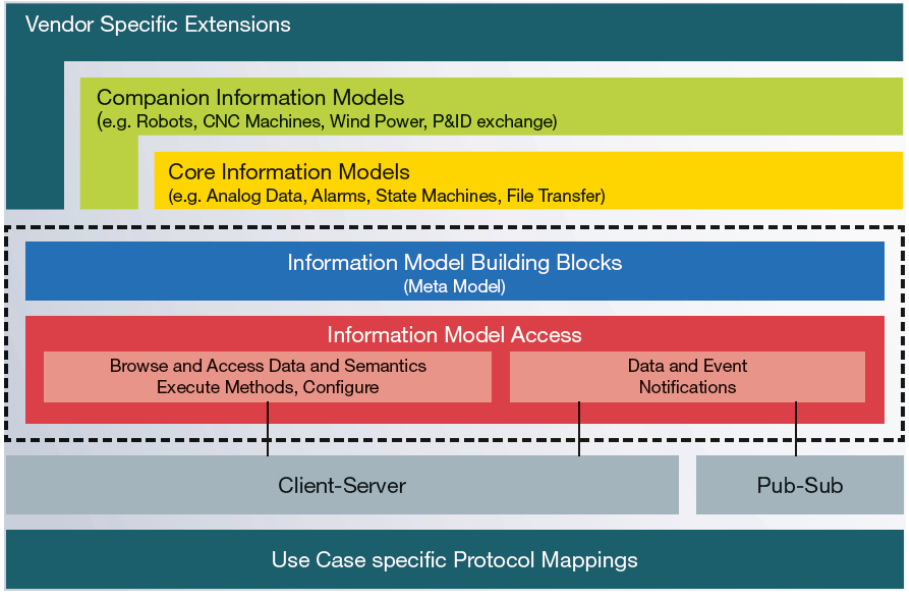
https://www.iiconsortium.org/pdf/JTG2_Whitepaper_final_20171205.pdf

OPC Unified Architecture (OPC UA)

- The OPC Unified Architecture (UA), released in 2008, is a **platform independent service-oriented architecture** that integrates all the functionality of the individual OPC Classic specifications into one extensible framework.

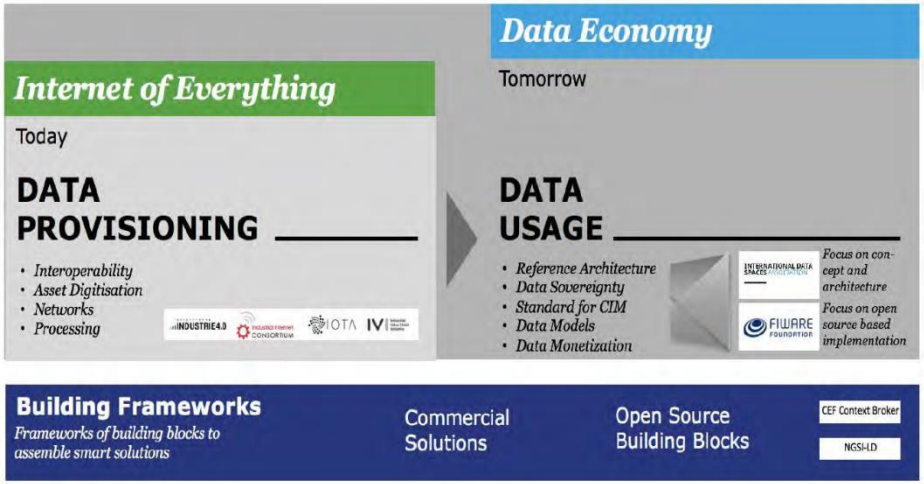
- This multi-layered approach accomplishes the original **design specification goals** of:

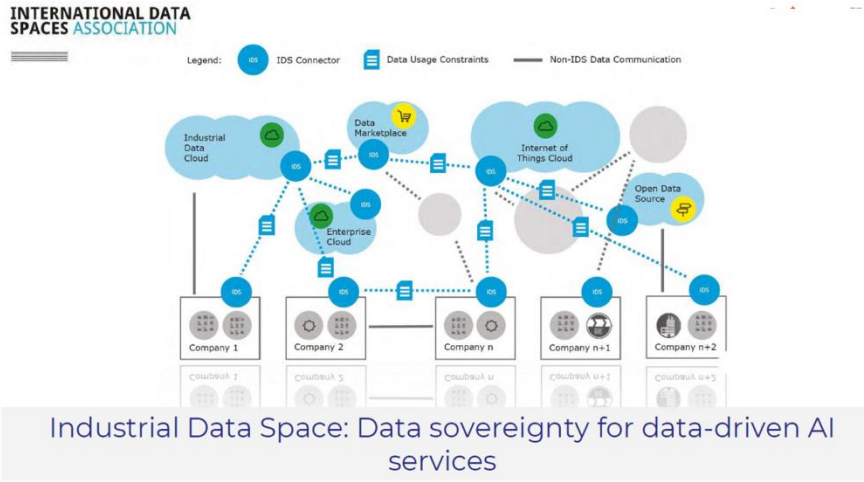
  - **Functional equivalence**: all COM OPC Classic specifications are mapped to UA
  - **Platform independence**: from an embedded micro-controller to cloud-based infrastructure
  - **Secure**: encryption, authentication, and auditing
  - **Extensible**: ability to add new features without affecting existing applications
  - **Comprehensive information modelling**: for defining complex information



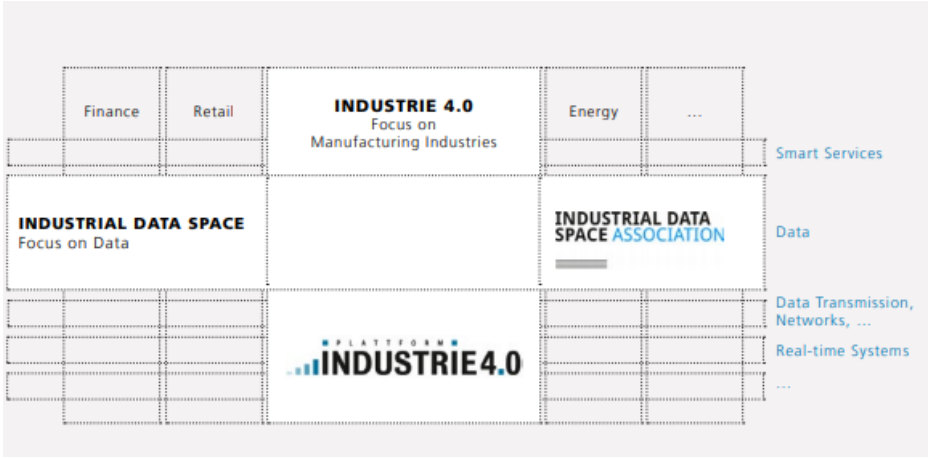
OPC Foundation https://opcfoundation.org/about/opc-technologies/opc-ua/

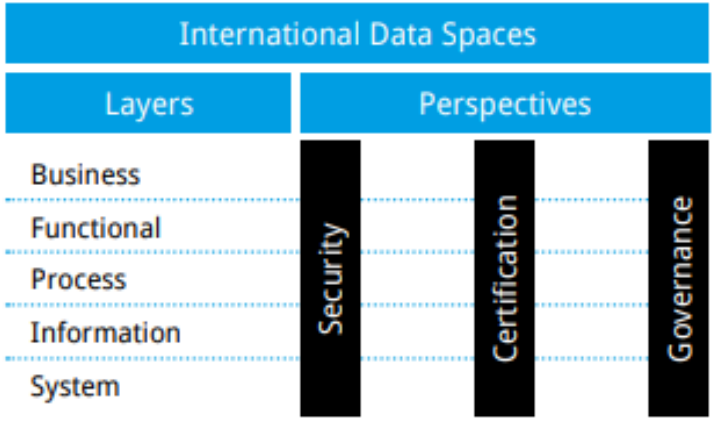
Industrial Data Space (IDS)





Industrial Data Space: Data sovereignty for data-driven AI services





International Data Spaces Association (IDSA) https://www.internationaldataspaces.org/

Outline

- Introduction
- Architectures
- Technologies
- Algorithms
- Applications

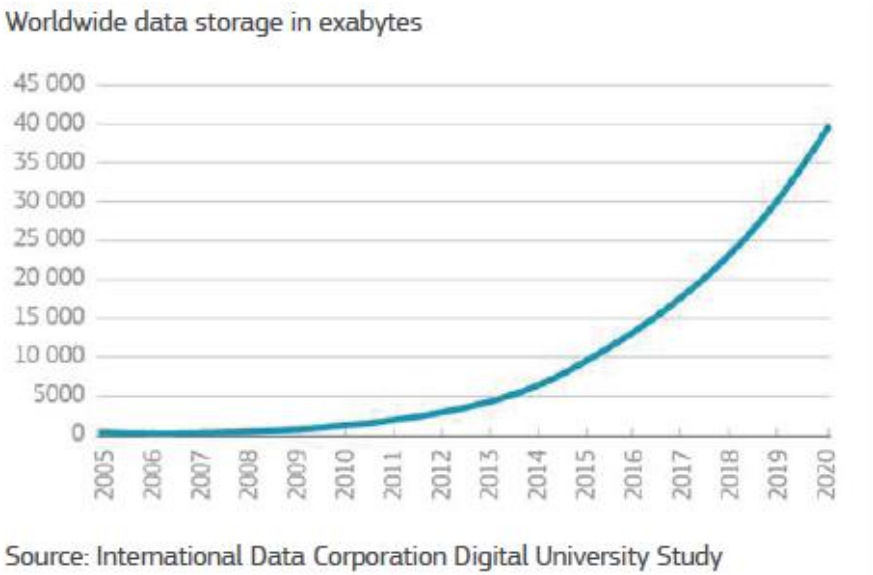
(Big) Data is the new oil

Emergence of Big Data

DATA AS THE NEW ECONOMIC ASSET

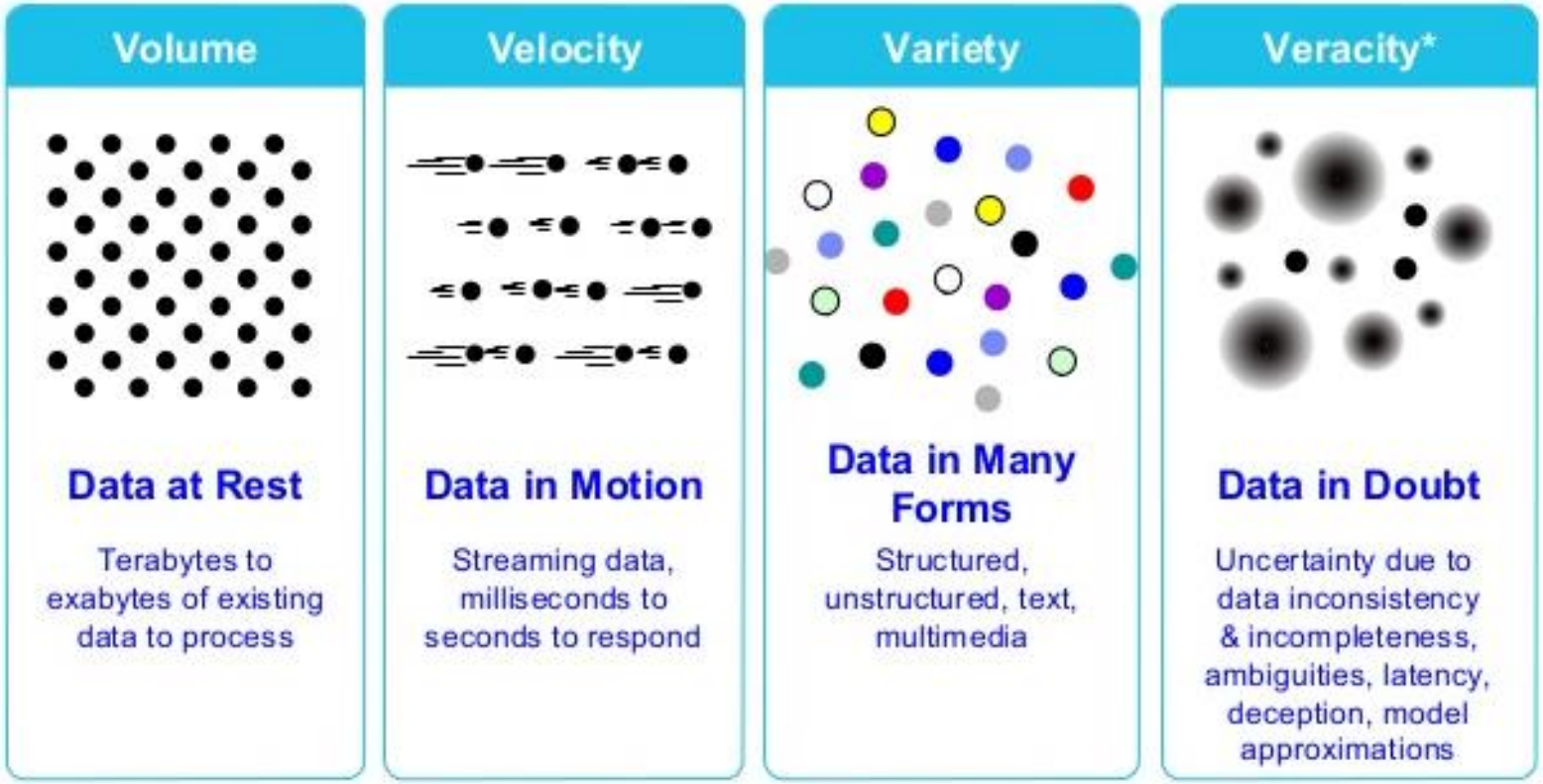
- Data is rapidly becoming the lifeblood of the global economy
- Gartner estimates there are currently about **4.9 billion connected devices** generating data
  - This is expected to reach 25 billion next years.

GLOBAL EXPLOSION OF DATA



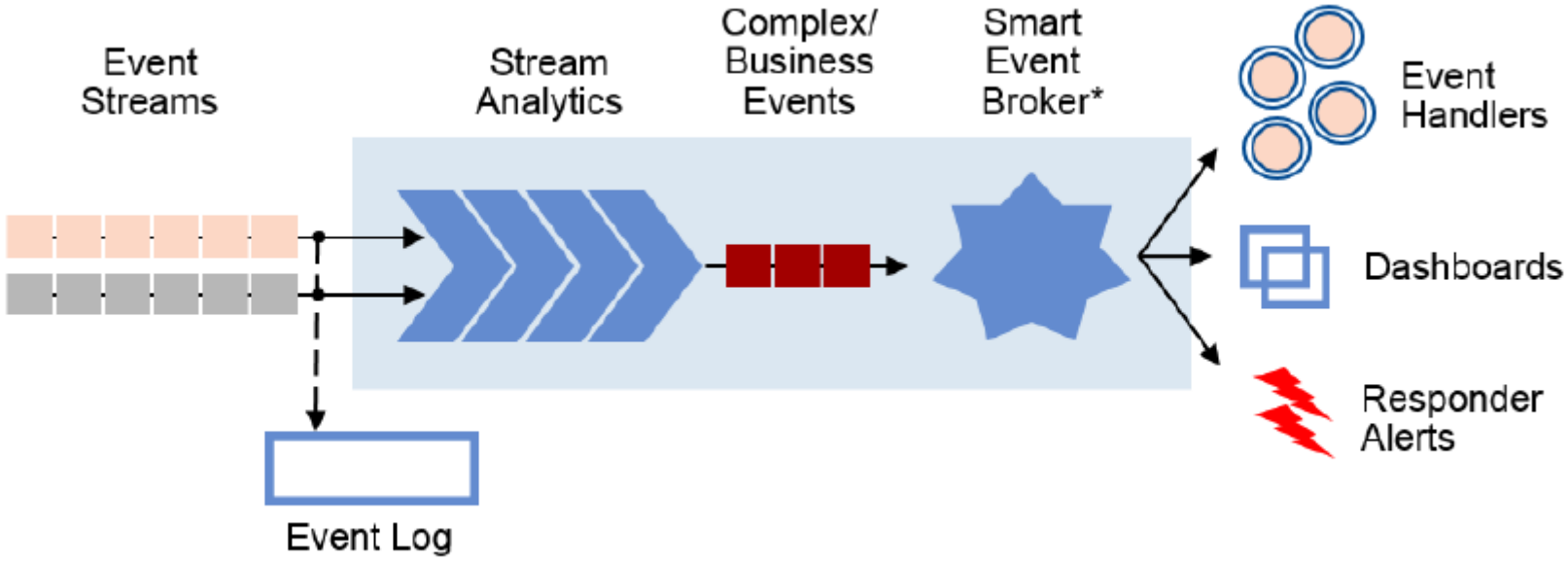
- The real value is no longer in the product, as such, but in the **opportunities** it can offer to users in terms of accessing information and experiences

The 4 Vs of Big Data



~~(Big) Data~~ Events is the new oil

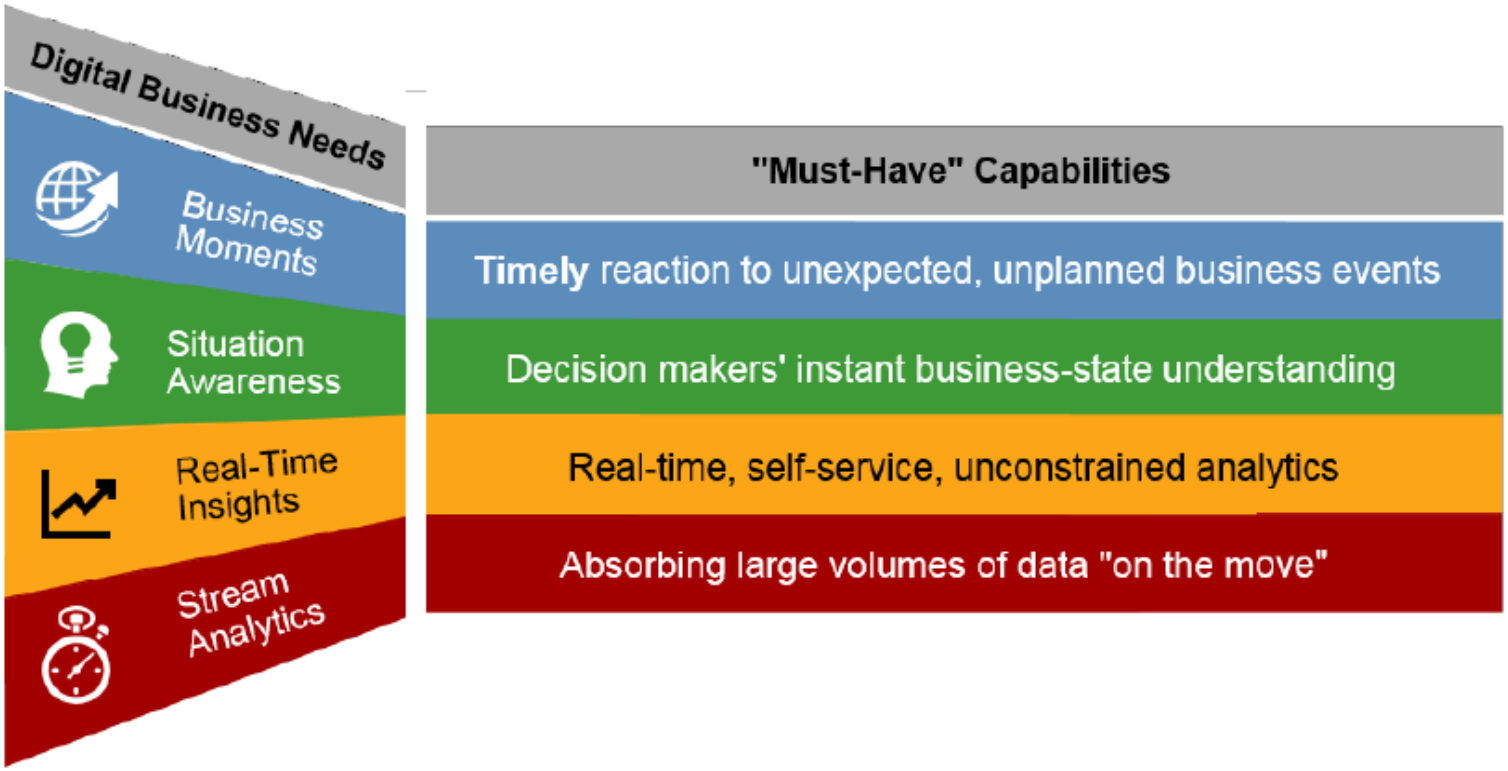
"Sense & Respond" Event-driven Architectures



* May include analytics, logging, integration, other mediation and routing of events to subscribers

“Data-in-motion” (Big data + Events) is the new oil

Data and event stream processing



Plethora of platforms

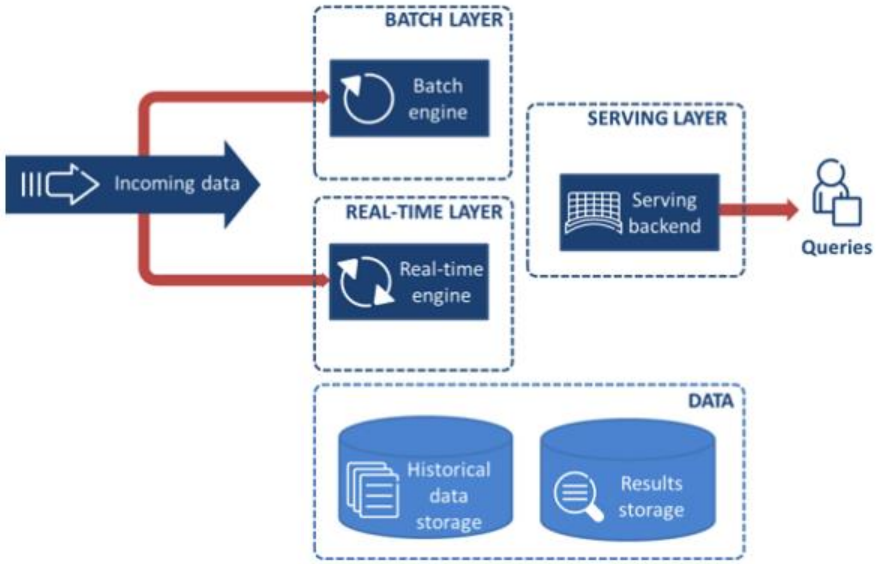
- Event processing
  - Esper (EsperTech)
  - Drools (Red Hat)
  - Apama (Software AG)
  - Business Events (Tibco)
  - IBM Streams …
- Stream Computing
  - Apache Storm
  - Apache Flink
  - Apache Spark Streaming
  - Apache Samza
  - Twitter Heron …
- Stream Data integration Platforms
  - Apache Kafka Streams
  - Apache Beam
  - Google Cloud Dataflow
  - Apache Gearpump
  - …

The Technology Landscape is flourishing

- More than 35 vendors in this market segment
- Trends
  - Open source
    - E.g. Confluent (Apache Kafka), data Artisans (Apache Flink), Databricks (Apache Spark Streaming), DataTorrent (Apache Apex) etc.
  - Hybrid products
    - E.g. FICO Data Management Integration Platform (DMIP), Hortonworks DataFlow, Impetus Technologies StreamAnalytix, Rapidminer Streams, and Salesforce Thunder leverage Apache Storm
  - Cloud-enablement
    - Amazon Kinesis Stream Analytics, Microsoft Azure Stream Analytics and Salesforce now offer similar services

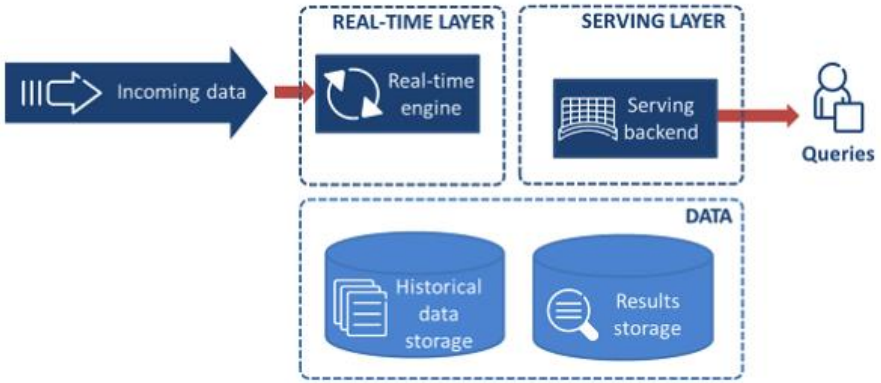
Lambda architecture

Lambda architecture



- Developed by Nathan Marz, creator of Apache Storm (2011)
- Used by Twitter and Spotify

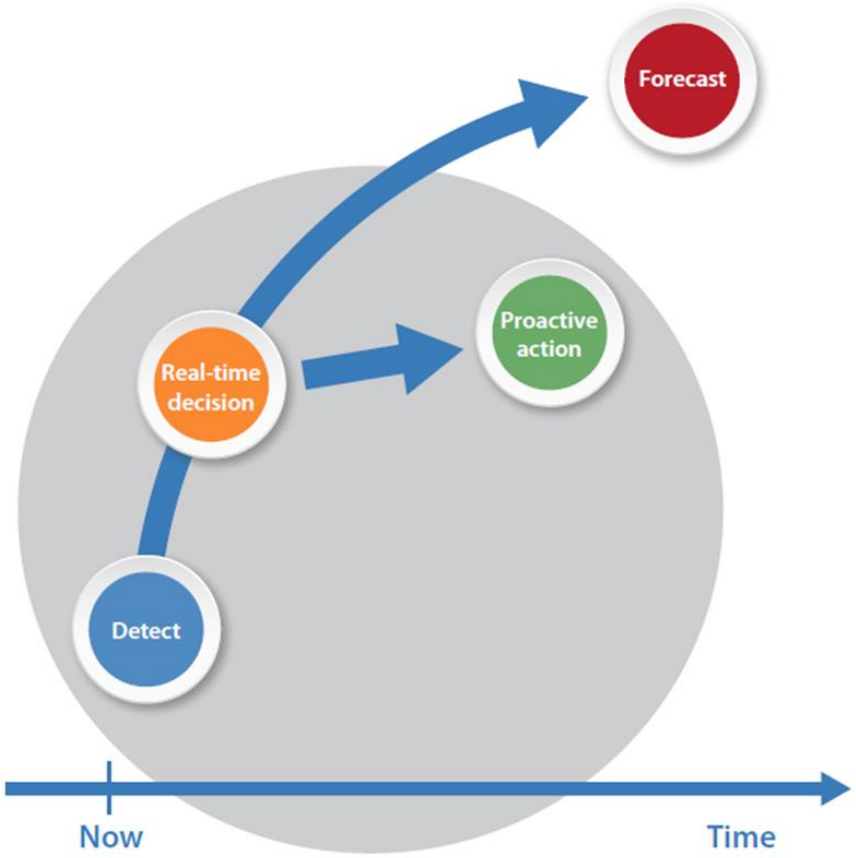
Kappa architecture

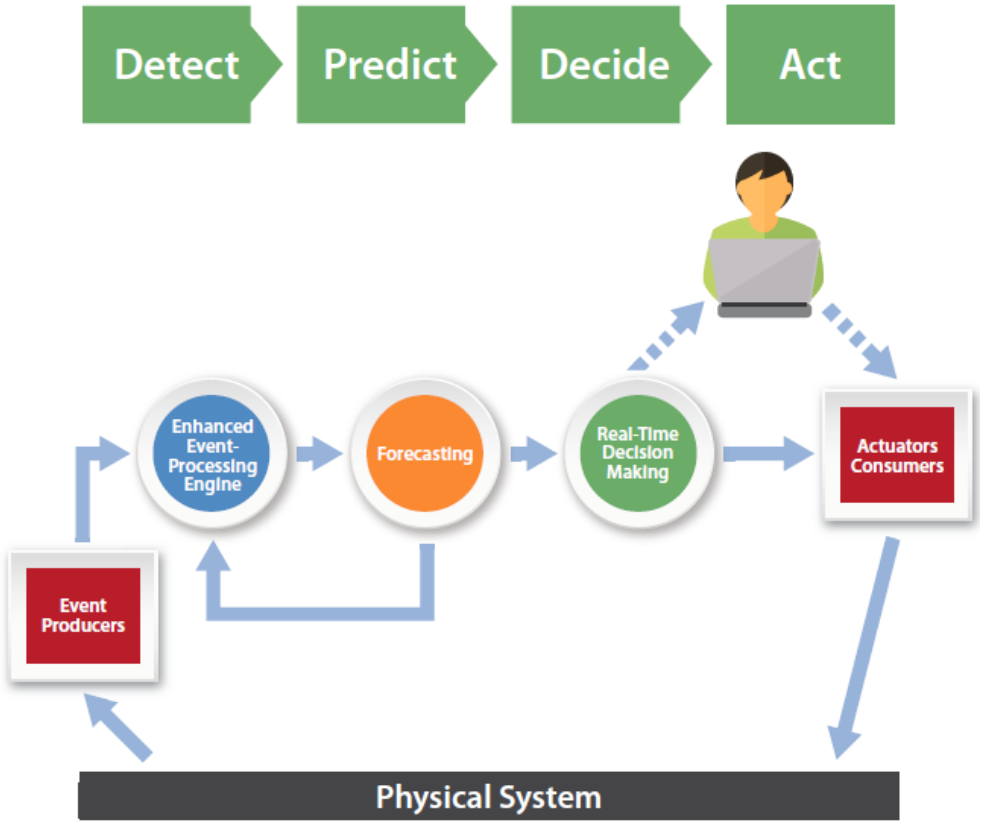


- Developed by Jay Kreps, creator of Apache Kafka (2014)
- Used by LinikedIn and Yahoo

Source: Julien Forgeat (2015) Data processing architectures – Lambda and Kappa, Ericsson Research Blog.

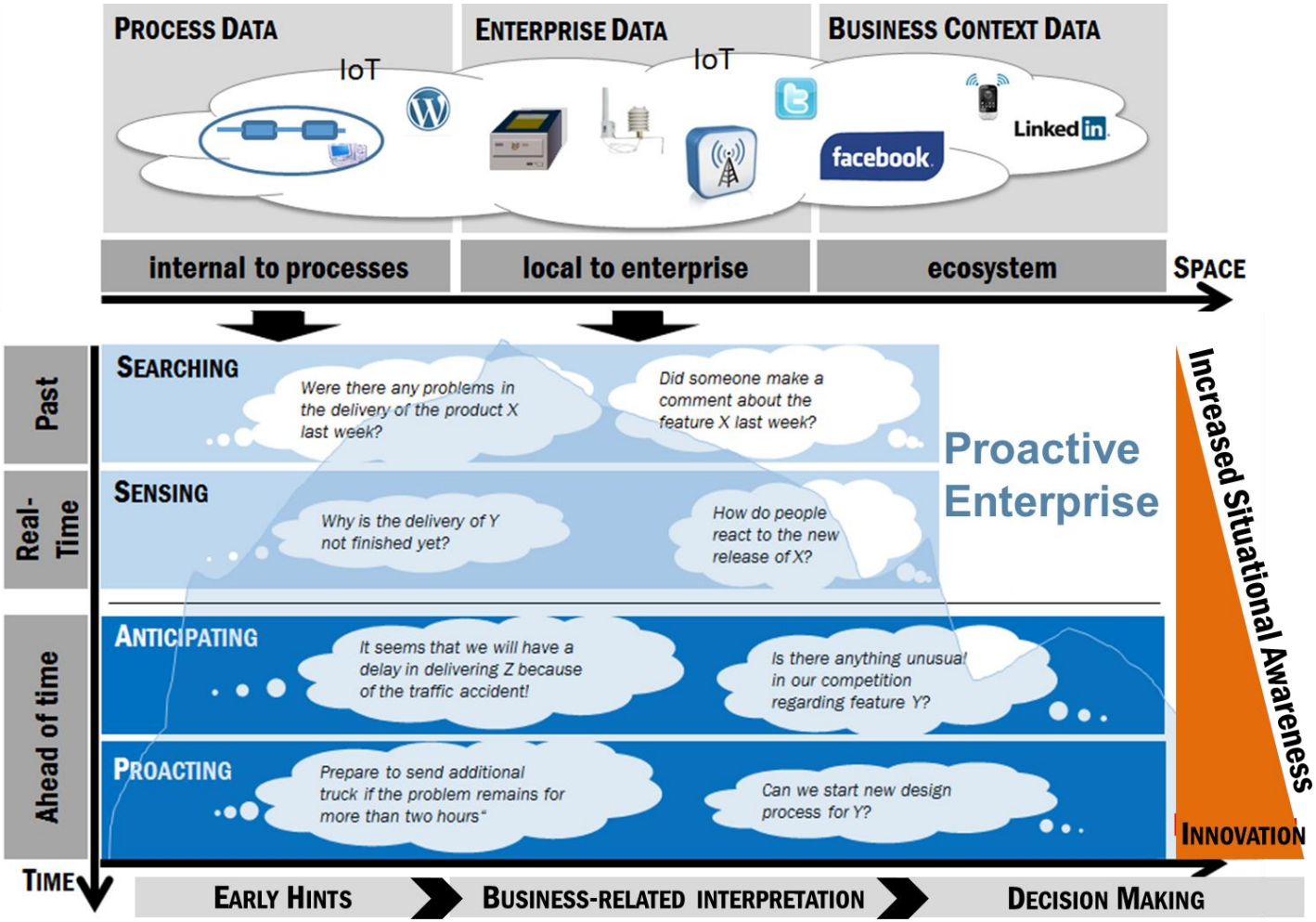
Proactive computing





Source: Etzion O. (2016). Proactive Computing: Changing the Future. RTInsights.

The Proactive Enterprise



Outline

- Introduction
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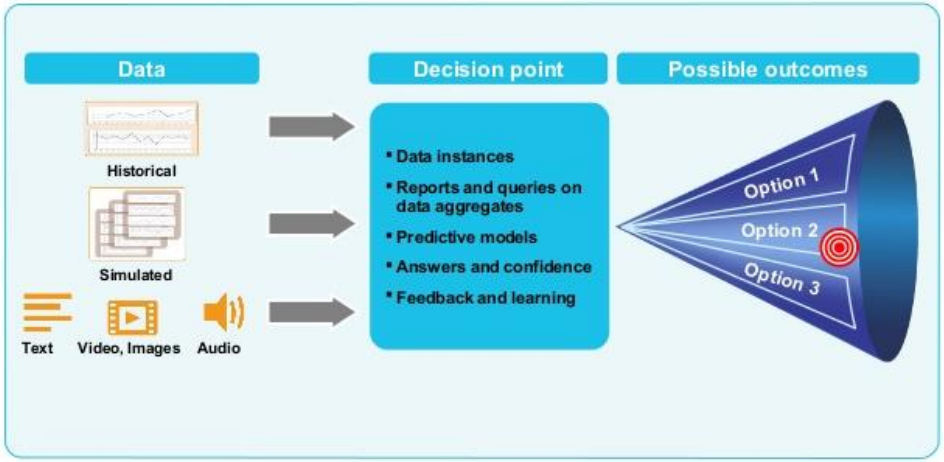
Data analytics

Data-in-Motion is the new oil, but …

99%

Manufacturing Data Value is Lost

80% of all available data are uncertain

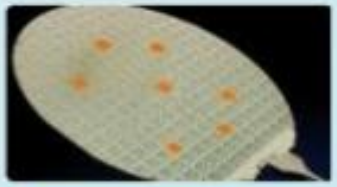


Uncertainty arises from many sources

Process Uncertainty

Processes contain "randomness"

Uncertain travel times



Semiconductor yield

Data Uncertainty

Data input is uncertain

GPS Uncertainty

Testimony

{Paris Airport}

Ambiguity

Contaminated?

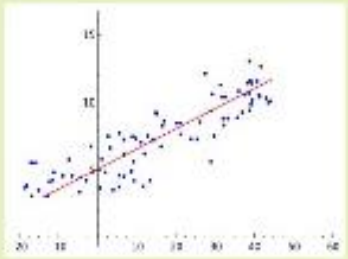
{John Smith, Dallas}
{John Smith, Kansas}

Rumors

Conflicting Data

Model Uncertainty

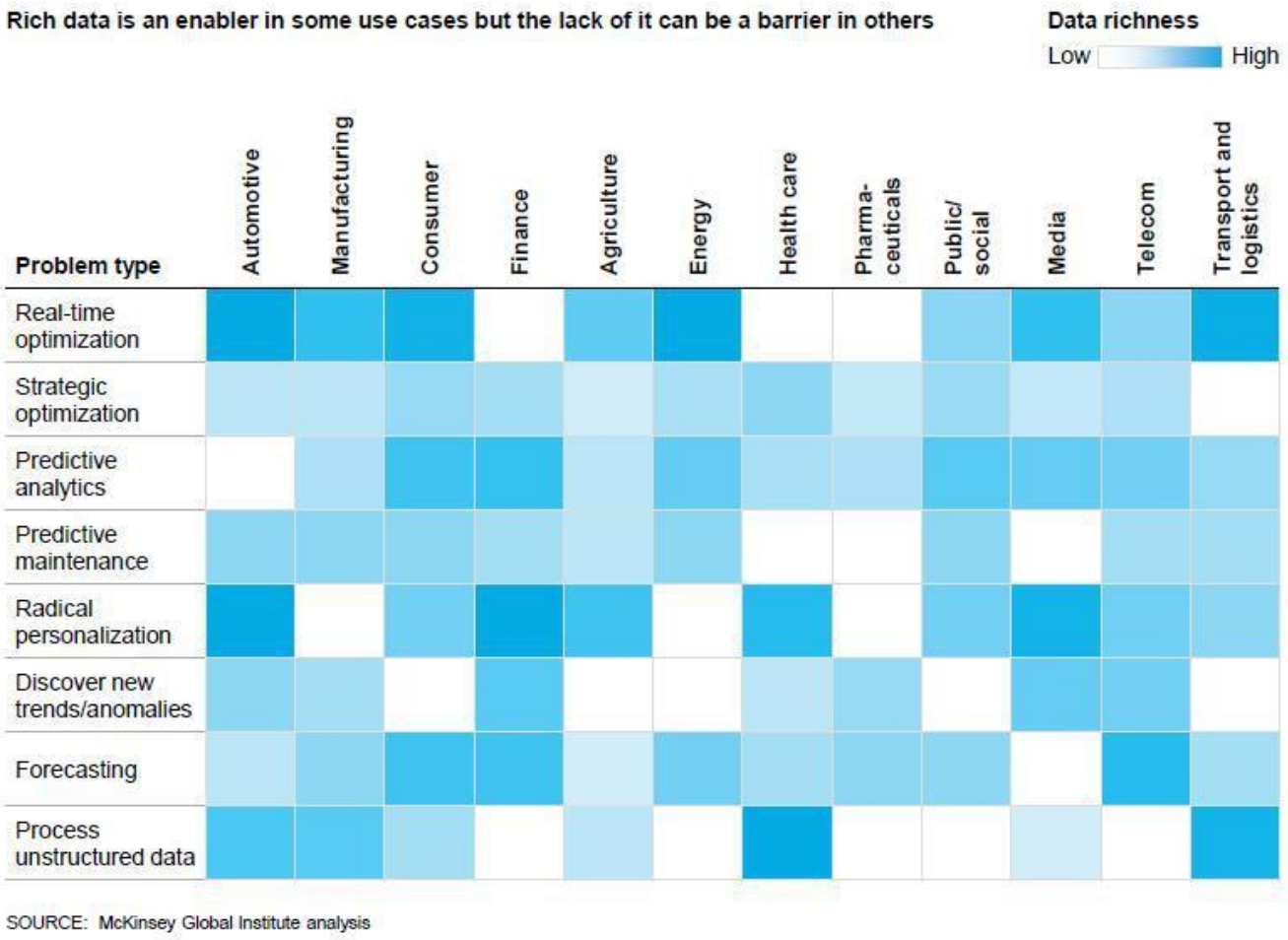
All modeling is approximate



Fitting a curve to data

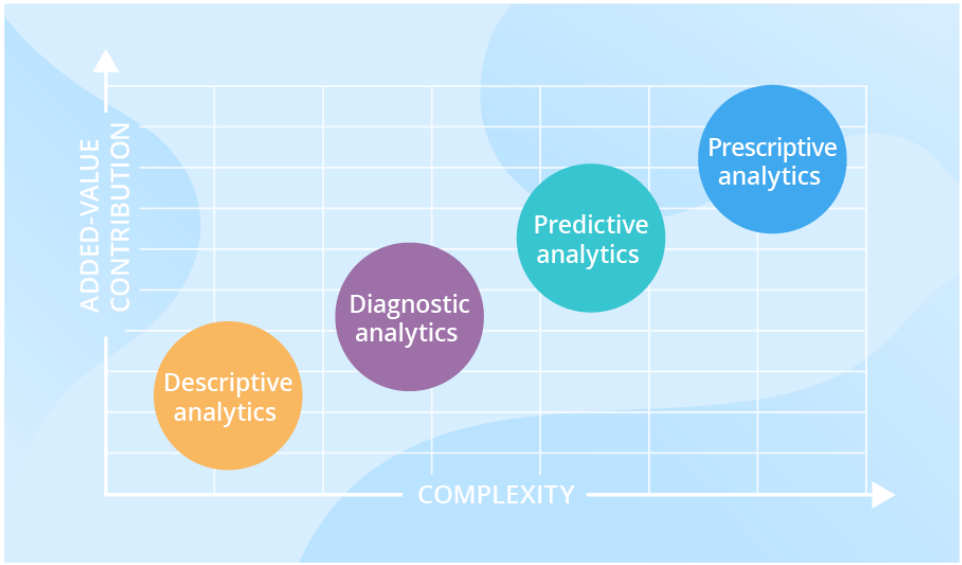
Forecasting a hurricane
(www.noaa.gov)

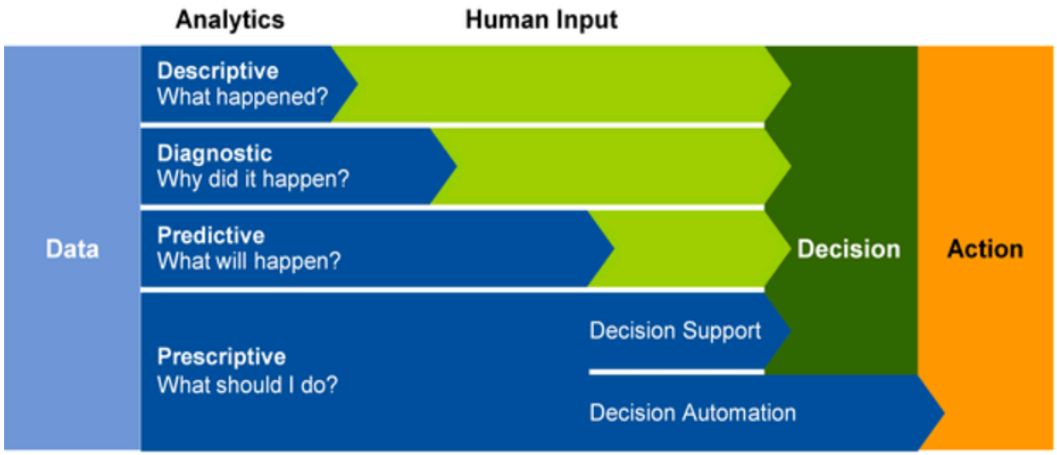
Potential in manufacturing



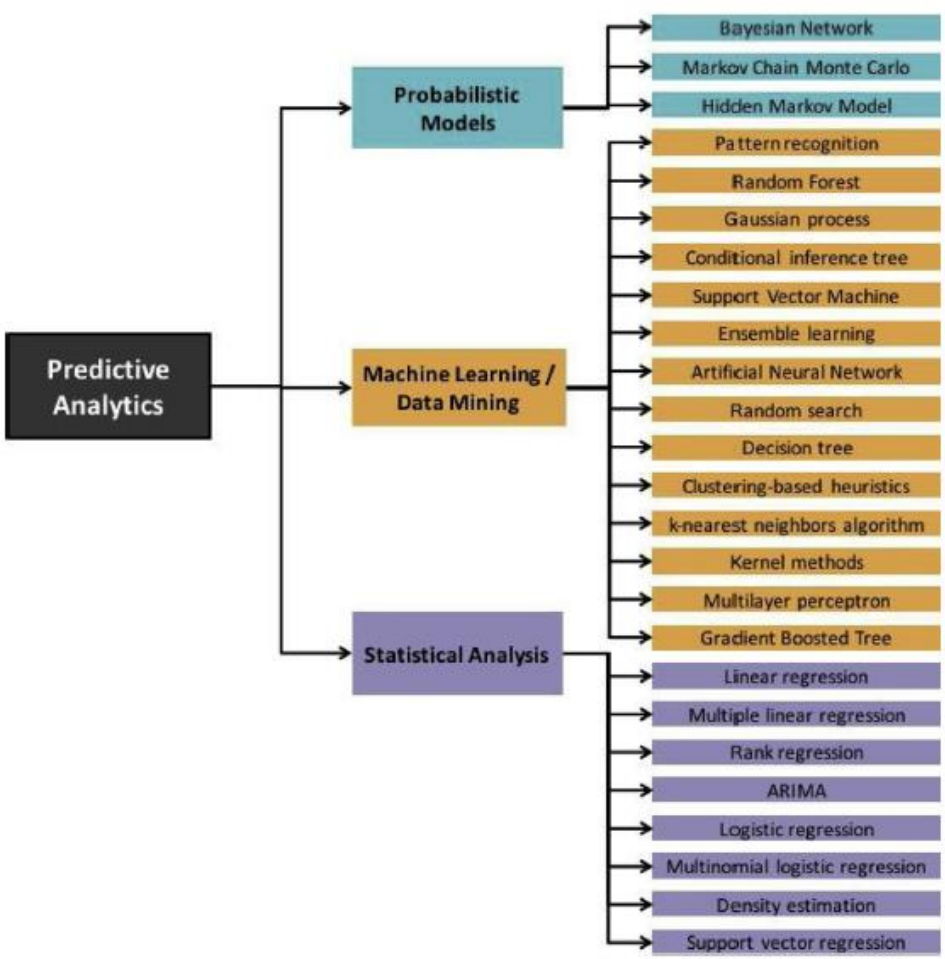
SOURCE: McKinsey Global Institute analysis

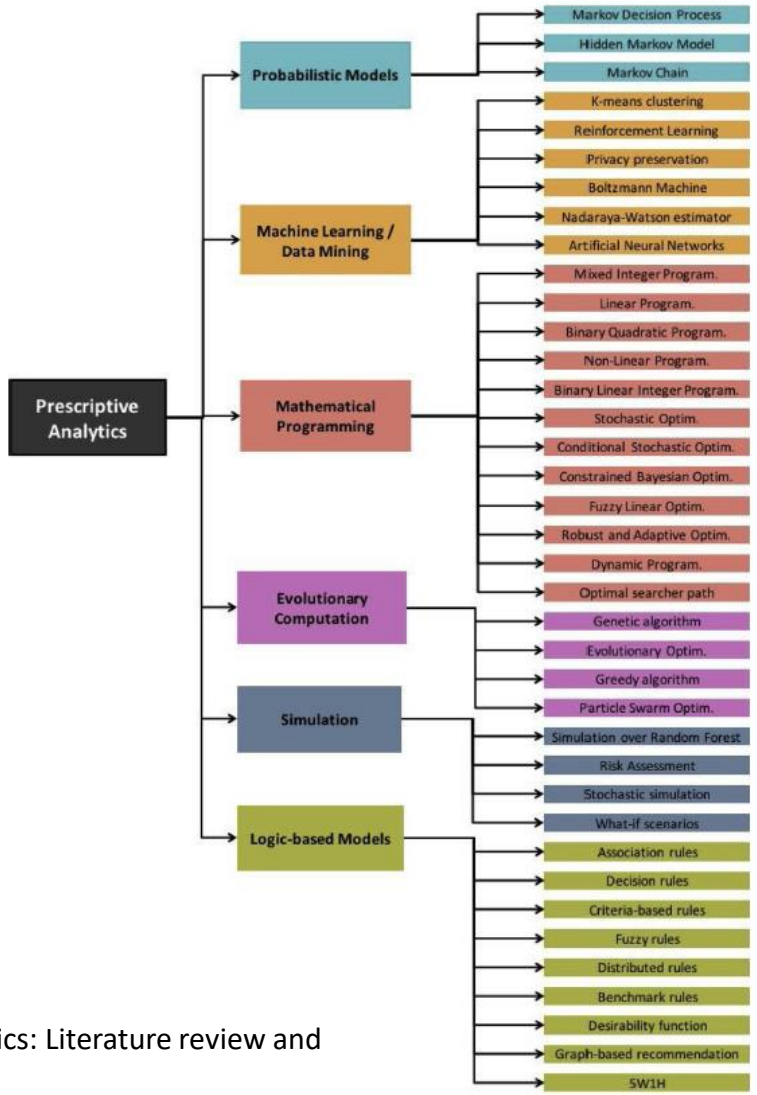
Data analytics categories





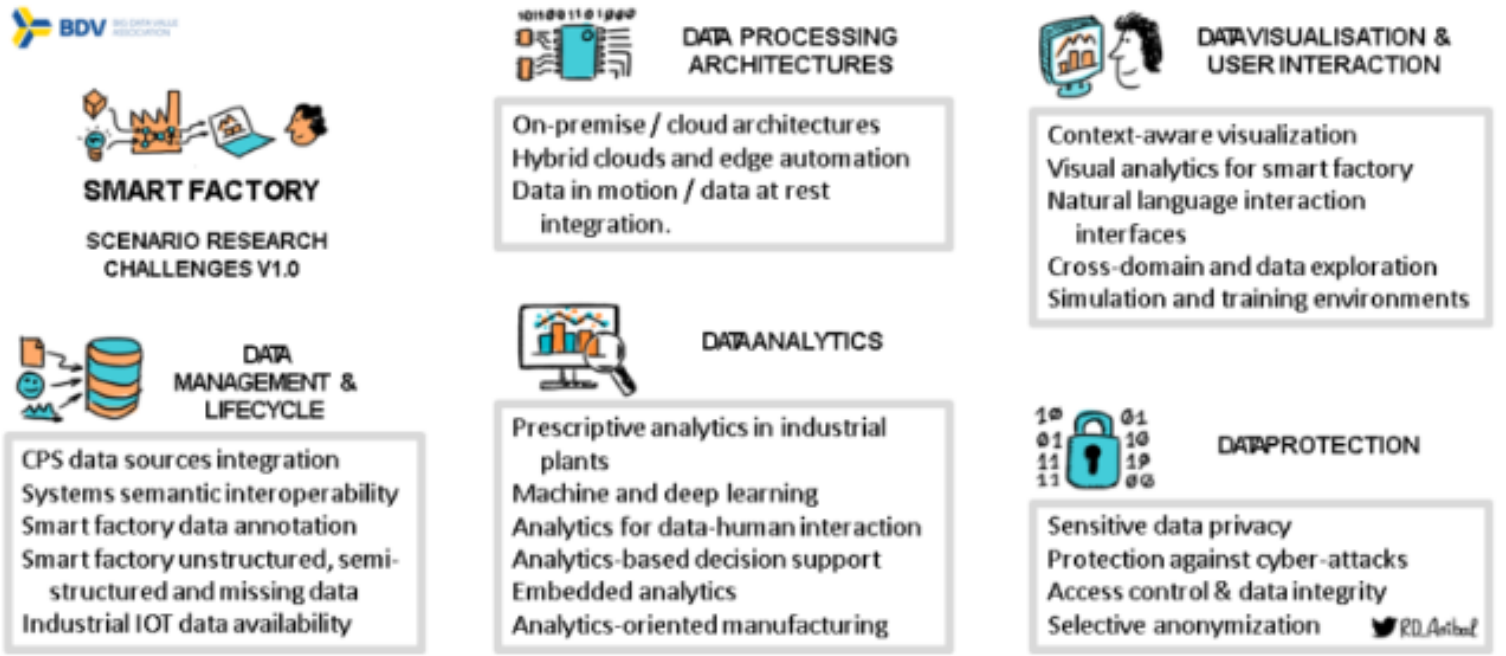
Classification of methods





Lepenioti, K., Bousdekis, A., Apostolou, D., & Mentzas, G. (2020). Prescriptive analytics: Literature review and research challenges. *International Journal of Information Management, 50*, 57-70.

Big data challenges in manufacturing



http://www.bdva.eu/node/1002

(Deep) Machine learning and AI

Opportunities of machine learning

Machine learning opportunities in manufacturing

Highest-ranked use cases, based on survey responses	Use case type	Impact	Data richness
Predict failure and recommend proactive maintenance for production and moving equipment	Predictive maintenance	1.3	1.0
Optimize complex manufacturing process in real time—determine where to dedicate resources to reduce bottlenecks and cycle time	Operations/logistics optimization (real time)	1.1	1.0
Predict future demand trends and potential constraints in supply chain	Forecasting	0.8	0.7
Identify design problems in pre-production to reduce ramp-up time to maximum output (i.e., yield ramp)	Predictive analytics	0.6	0.3
Identify root causes for low product yield (e.g., tool-/die-specific issues) in manufacturing	Discover new trends/ anomalies	0.5	0.7
Detect defects and quality issues during production using visual and other data	Process unstructured data	0.4	0.7

McKinsey Global Institute (2016) The Age of Analytics: Competing in a Data-Driven World, December 2016.

Machine Learning types

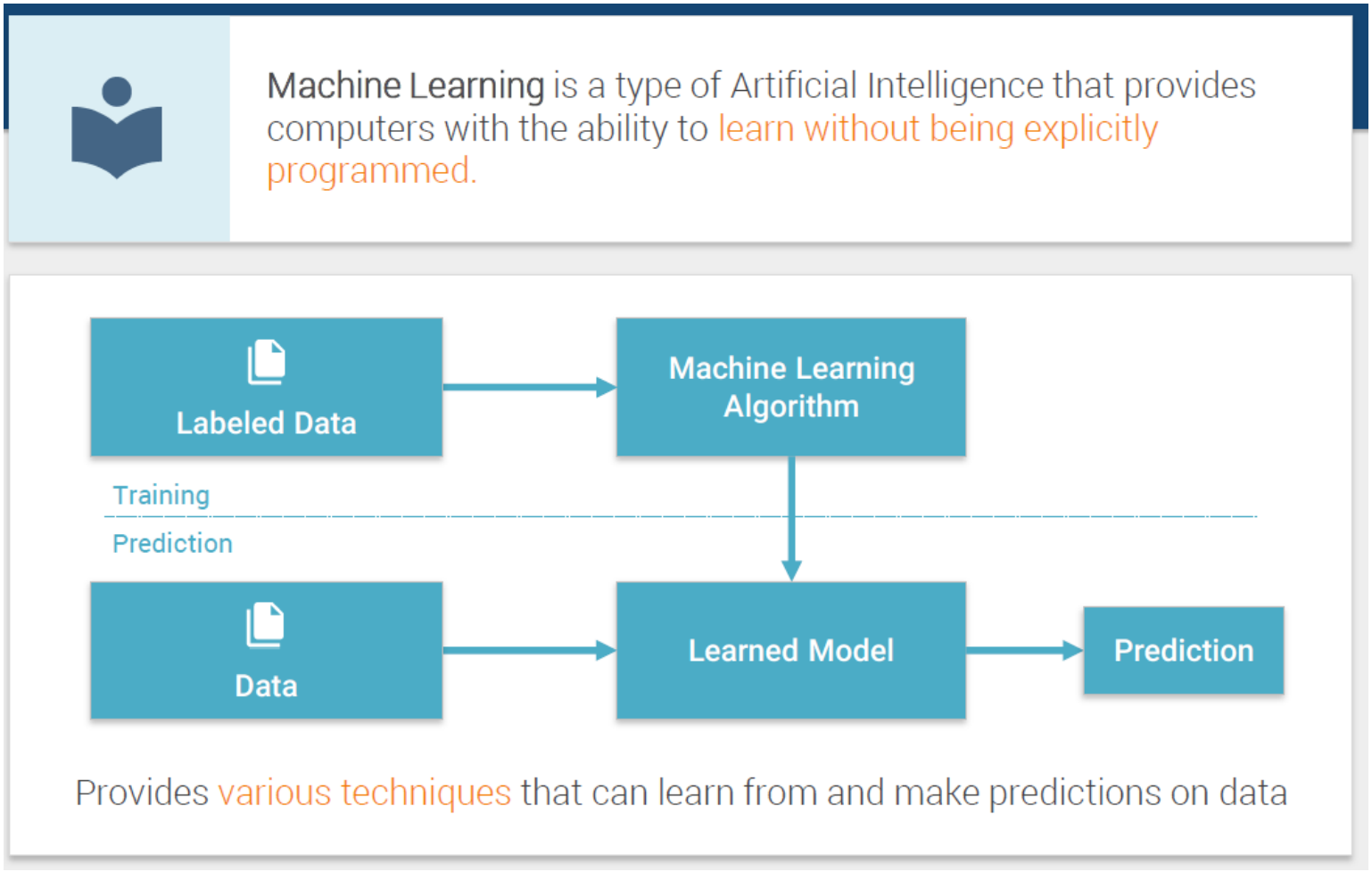
Supervised learning
- Teach the computer how to do something, then let it use its new found knowledge to do it
- Learning with teacher
- Inferring a function from labelled training data
- Training data includes desired outputs (labels)

Unsupervised learning
- Teach the computer how to do something, then let it use its new found knowledge to do it
- Learning without teacher
- Finding hidden structure in unlabelled data
- Training data does not include desired outputs (labels)

Semi-supervised learning
- Training data includes a few desired outputs (labels)

Reinforcement learning
- Rewards from sequence of actions

Machine learning methodology



Some well-known ML algorithms

Regression
- Least Squares Regression
- Linear regression
- Logistic regression

Classification
- Naïve Bayes
- Neural Networks
- Support Vector Machines (SVM)
- Kernel estimation (k-Nearest Neighbors)
- Random forests

Clustering
- K-Means
- Hierarchical clustering
- Spectral clustering
- Density-based algorithms (DBSCAN, OPTICS)

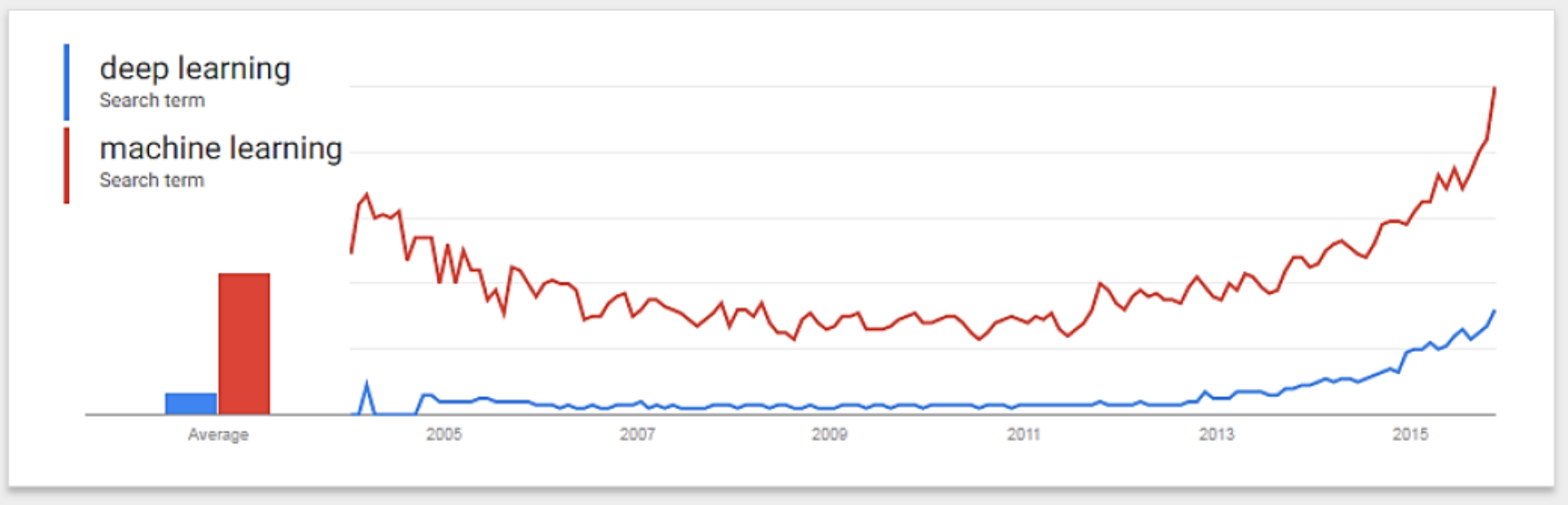
What is deep learning?

Part of the machine learning field of learning representations of data. Exceptional effective at learning patterns.

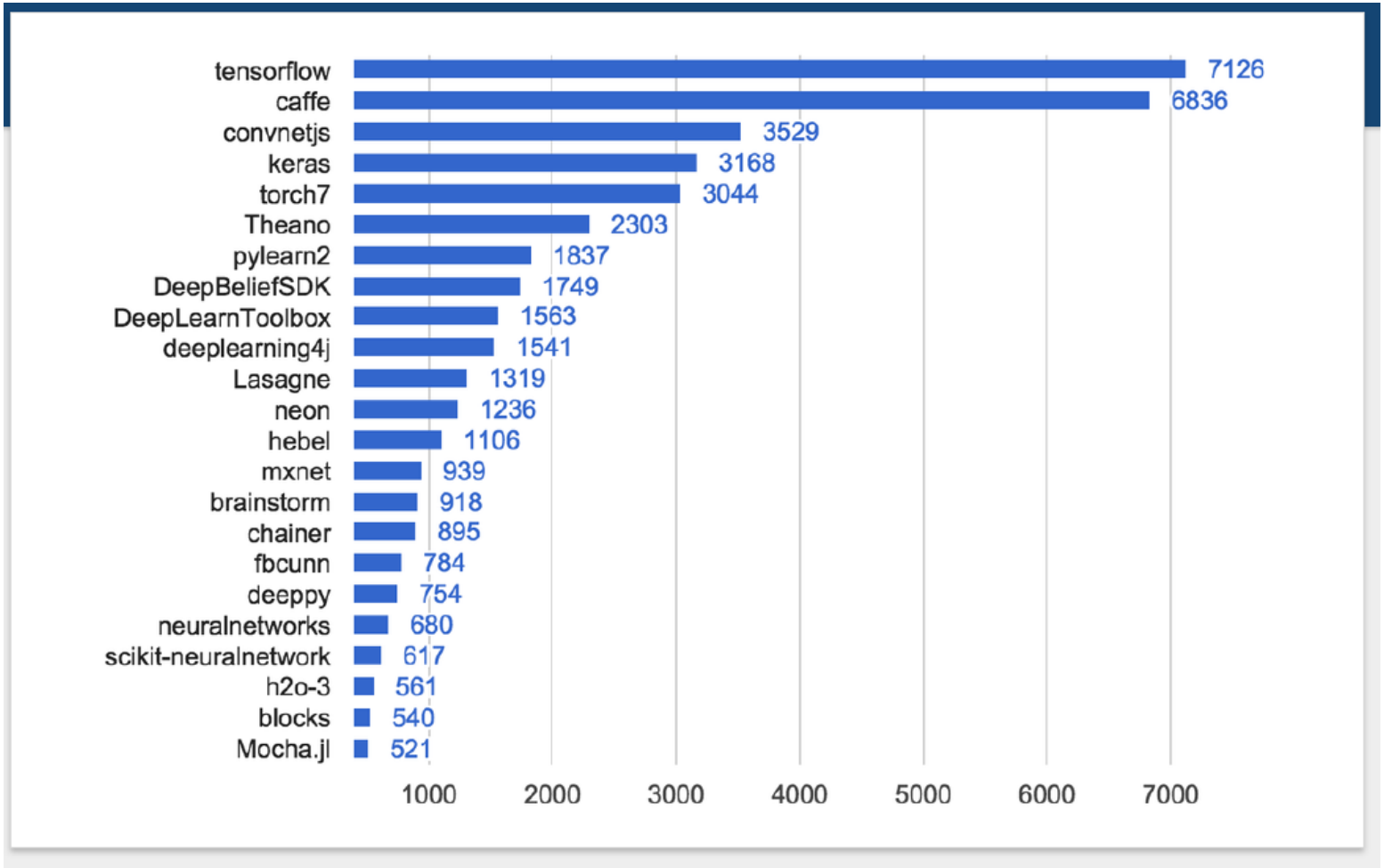
Utilizes learning algorithms that derive meaning out of data by using a hierarchy of multiple layers that mimic the neural networks of our brain.

If you provide the system tons of information, it begins to understand it and respond in useful ways.

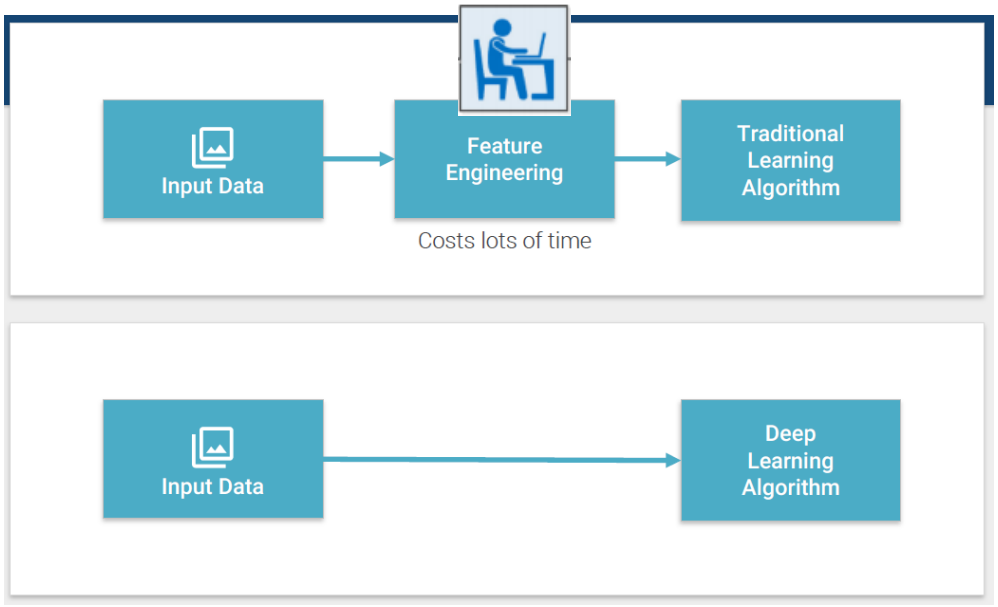
Deep learning trend and applications

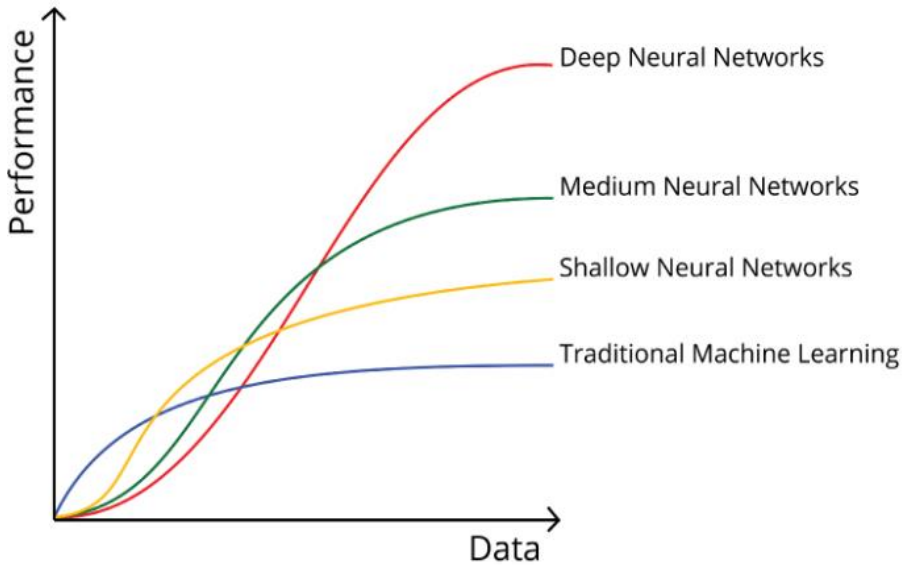


Deep learning tools

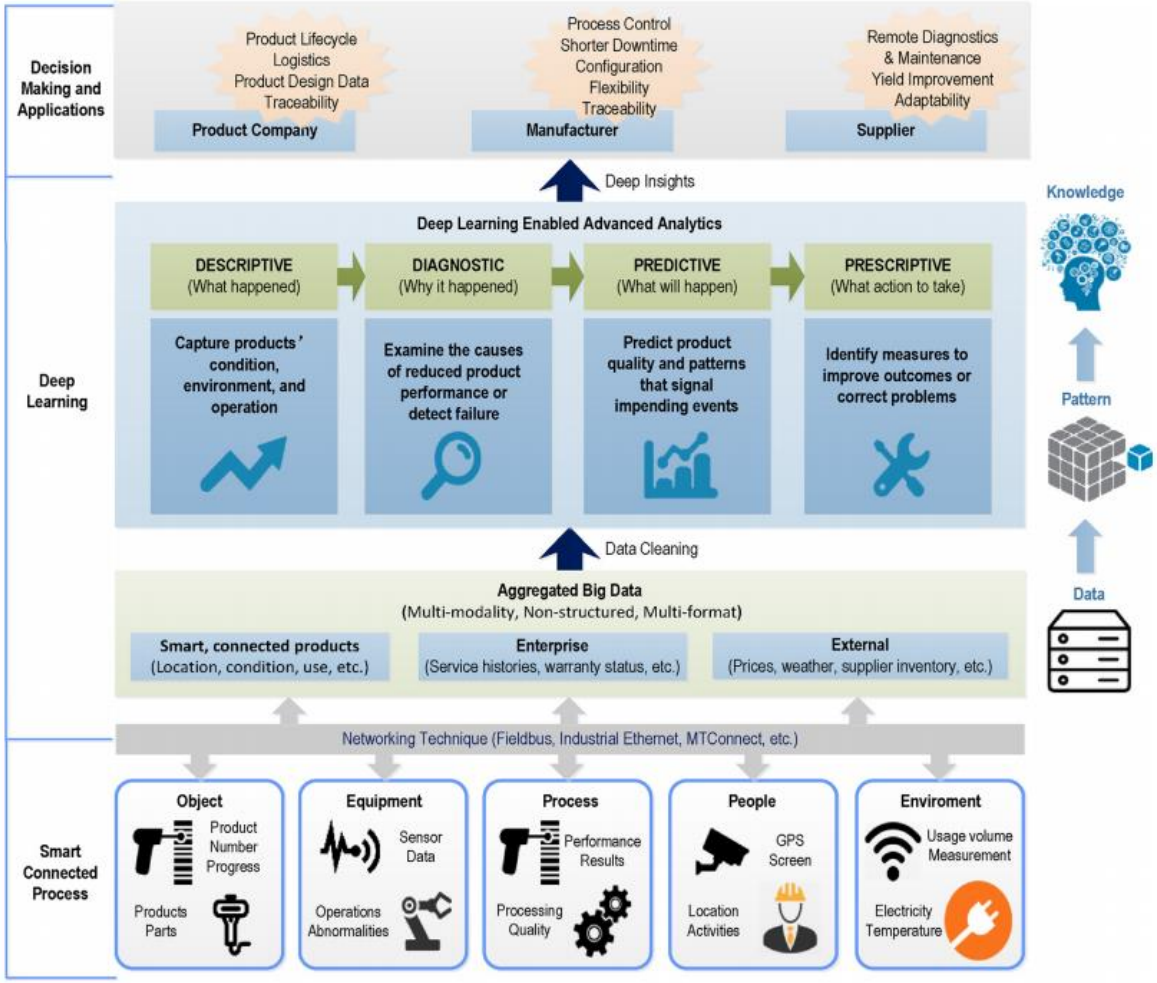


Machine learning vs deep learning





Deep learning enabled advanced analytics for smart manufacturing



Deep learning requirements

Large data set with good quality *(input-output mappings)*

Measurable and describable goals *(define the cost)*

Enough computing power *(AWS GPU Instance)*

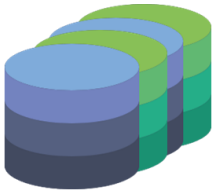
Excels in tasks where the basic unit *(pixel, word)* has very little meaning in itself, but the combination of such units has a useful meaning

However, in manufacturing…

- … data quality is usually poor.
- … data quantity is usually low.
- … computational infrastructures are usually weak.

Important to have high quality dataset

- *Valid, consistent, easily accessible, described and documented*



Important to have high quantity data

- *Stable process has less negative event to be correlated*
- *Stable process has less statistical deviation*

Process Experts and Data Experts must work side by side

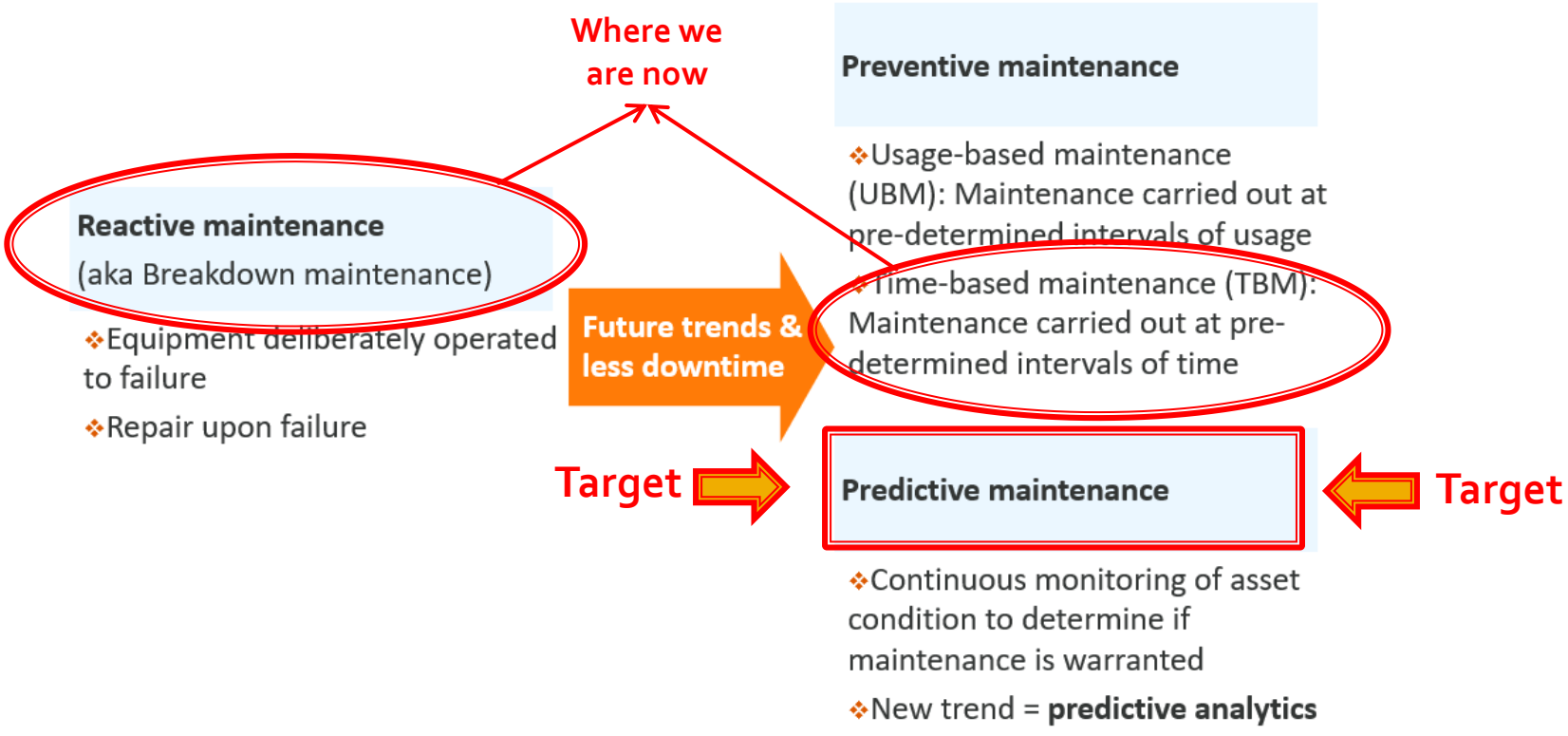
Outline

- Introduction
- Architectures
- Technologies
- Algorithms
- Applications

Predictive maintenance

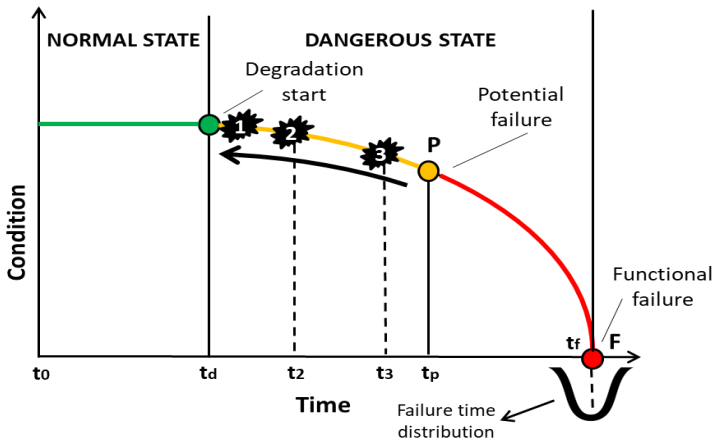
Maintenance strategies

The future trend is to move from reactive to preventive & predictive maintenance

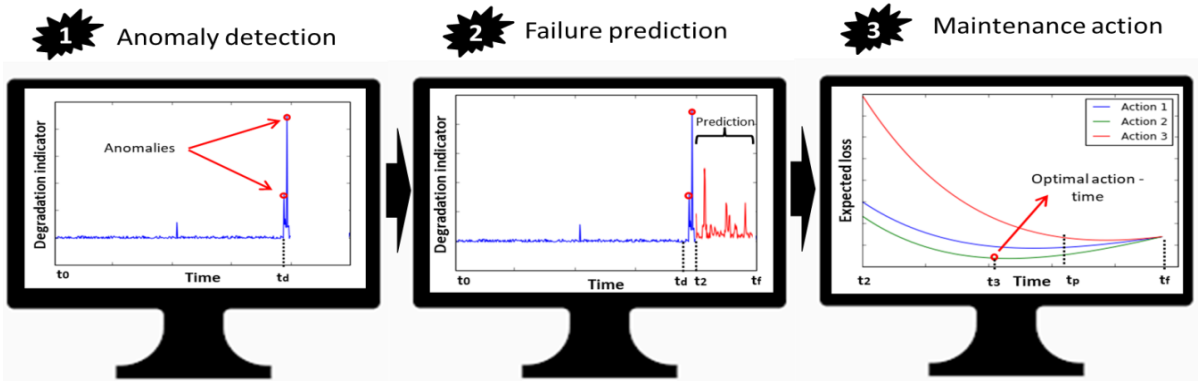


Predictive maintenance

- **Predictive maintenance** uses condition monitoring equipment (e.g. sensors) in order to track the performance of equipment, to detect abnormal behaviour, to predict future failures and to support decision making about proactive actions.



- The **P-F Curve** is a common way to represent the **behaviour of an asset** before actual functional failure has occurred.
- There is a sense in which **failure is a process**, not an event.
- The P-F interval can be seen as an **opportunity window** during which decision making ahead of time can eliminate the anticipated functional failure or mitigate its effect.



Impact of predictive maintenance

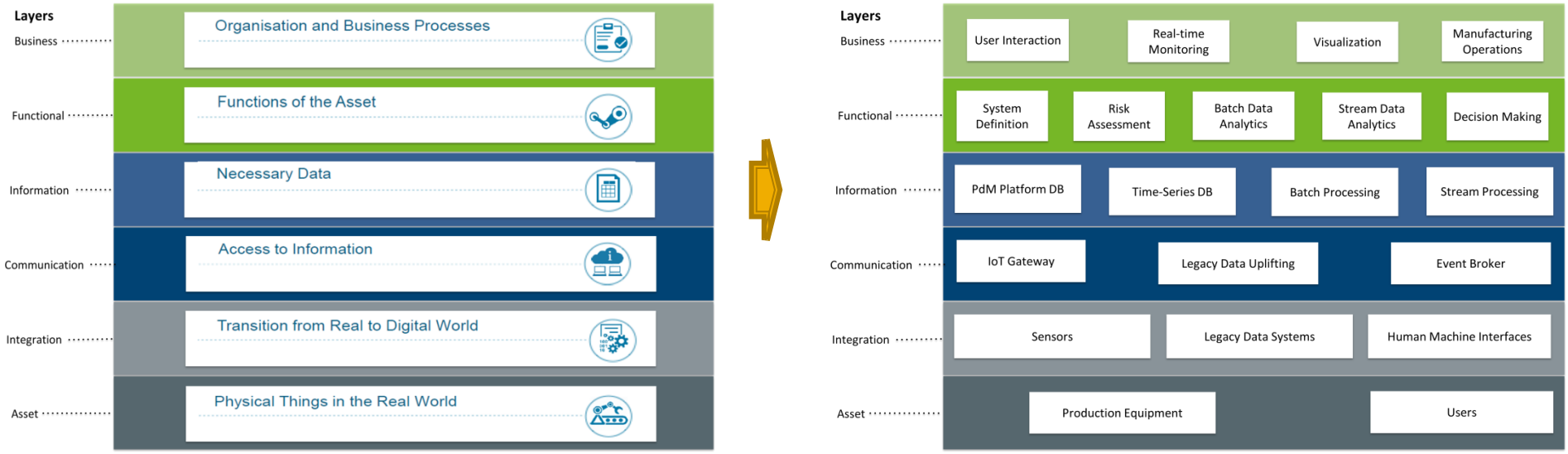
- OEE average improvement

- Reduction of MTTR

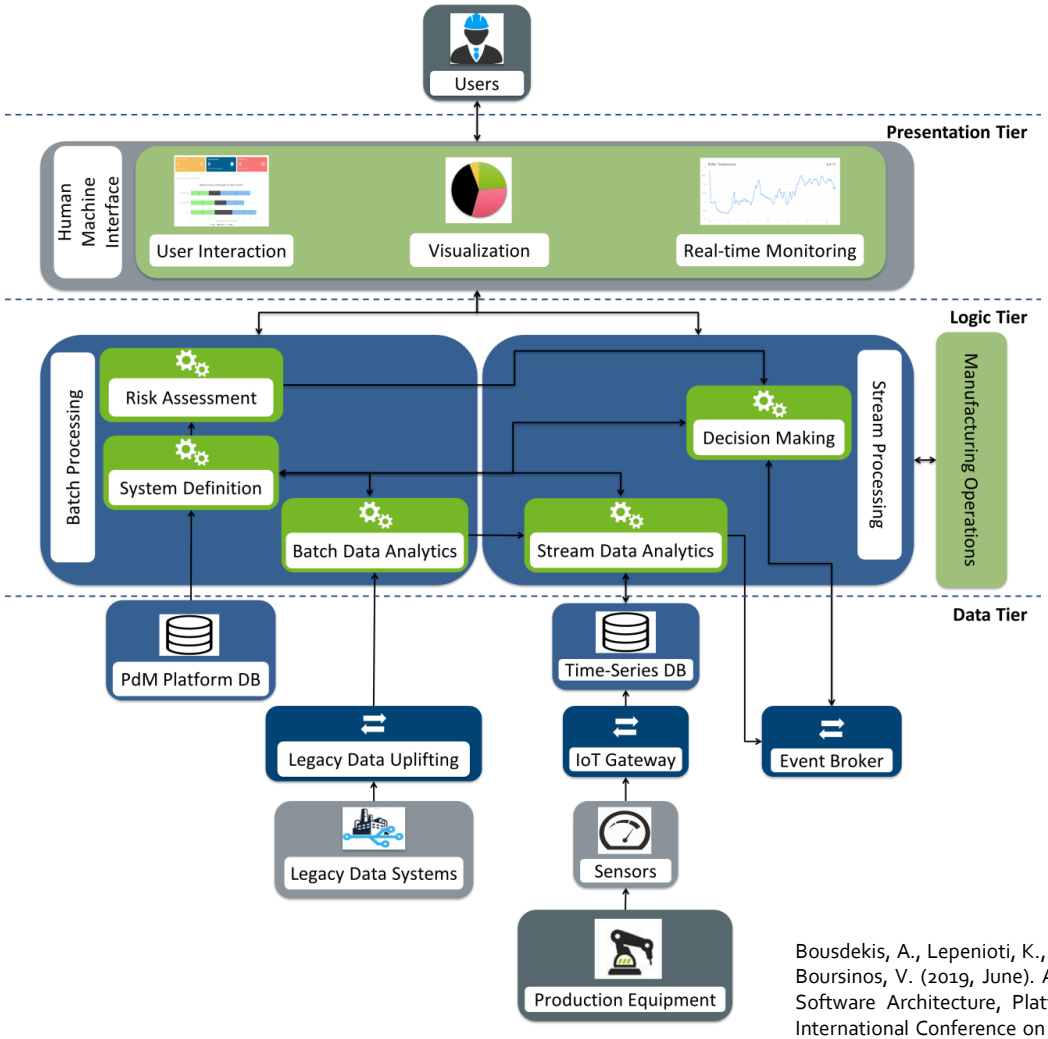
- Reduction of MTBF

- Reduction of Total Cost of Maintenance

RAMI4.0-compliant predictive maintenance (1/2)



RAMI4.0-compliant predictive maintenance (2/2)



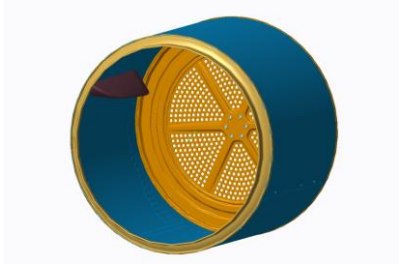
RAMI 4.0 Layers Index

- Business Layer
- Functional Layer
- Information Layer
- Communication Layer
- Integration Layer
- Asset Layer

Bousdekis, A., Lepenioti, K., Ntalaperas, D., Vergeti, D., Apostolou, D., & Boursinos, V. (2019, June). A RAMI 4.0 View of Predictive Maintenance: Software Architecture, Platform and Case Study in Steel Industry. In International Conference on Advanced Information Systems Engineering (pp. 95-106). Springer, Cham.

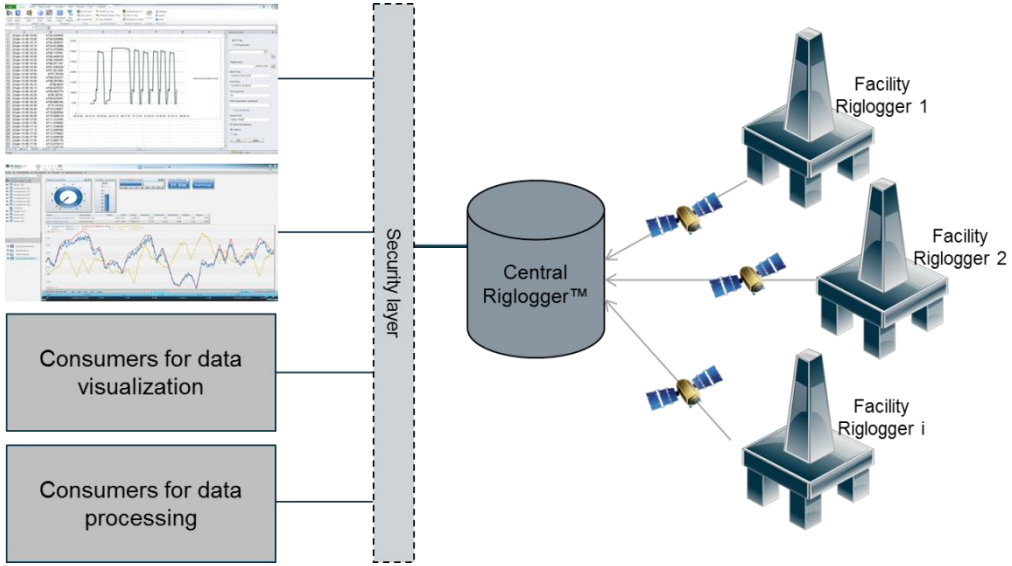
Home appliances industry

The Whirlpool case



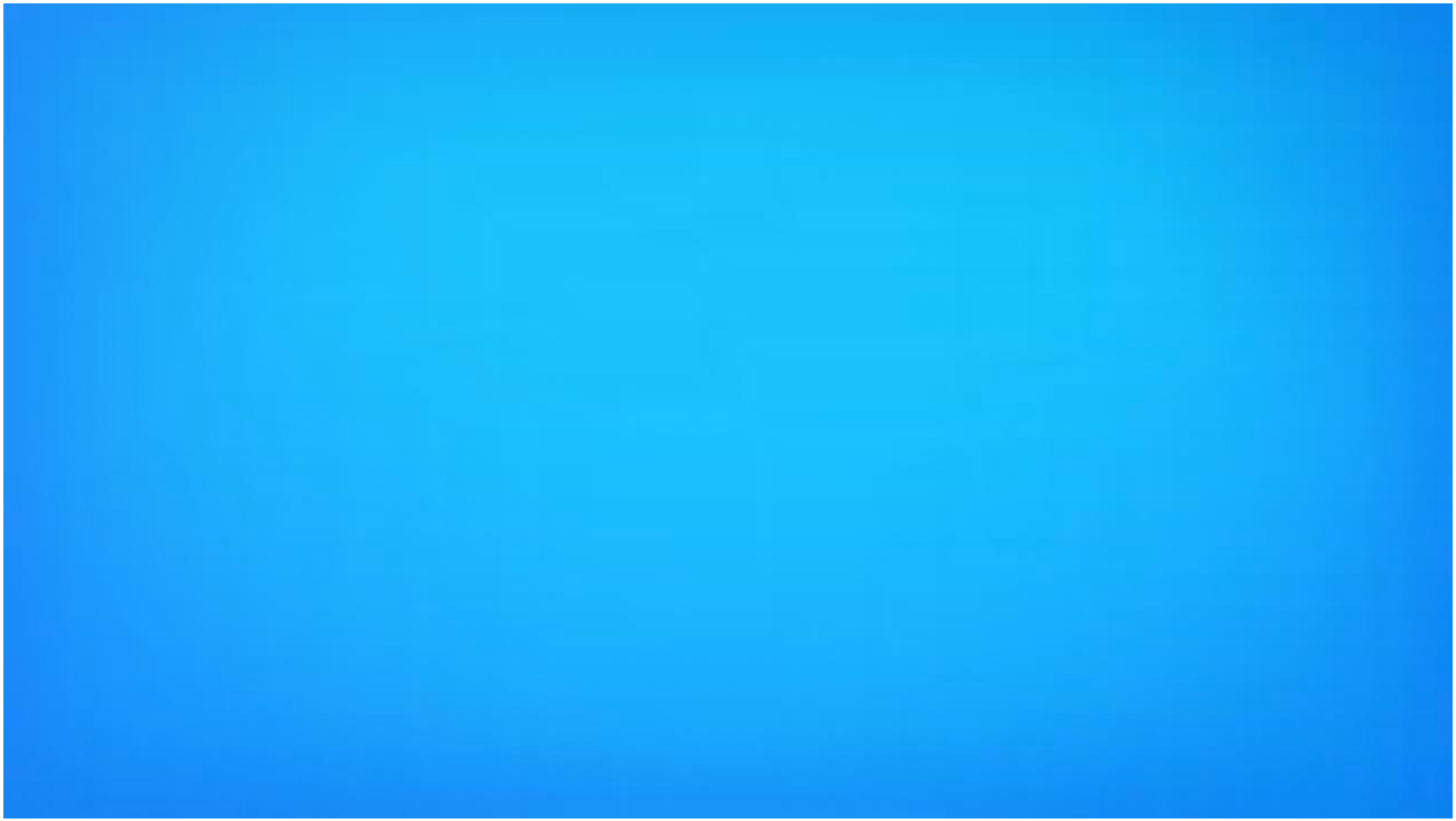
Oil and gas industry

The MHWirth case



Steel industry

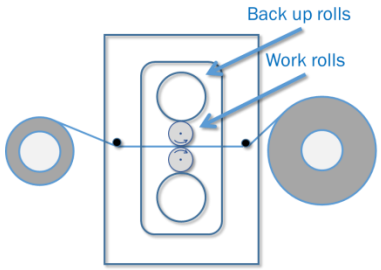
The M. J. Maillis case



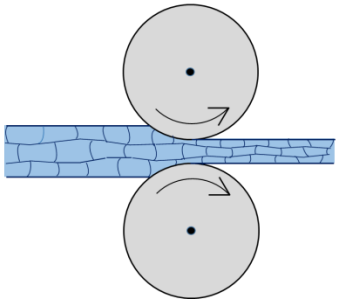
Setup and process

M. J. MAILLIS

Roll Mill Stand



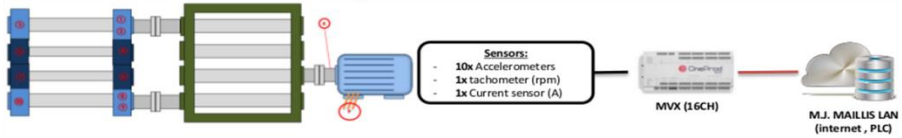
Deforming and Reducing the Grain Size



Raw material

Cold rolling mill

Infrastructure Setup for Sensor Data Collection



Front view of rollers

Rear view of rollers

Thank you