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of Technology in Scandinavia

Open source platforms for Industry4.0 solution implementations

Professor Jerker Delsing
Lulea University of Technology
Sweden

Supported by
Productive4.0 and Arrowhead Tools projects
ECSEL-JU grant 737459 and 826452

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Production Automation and Digitalisation is Software the Problem or the Solution

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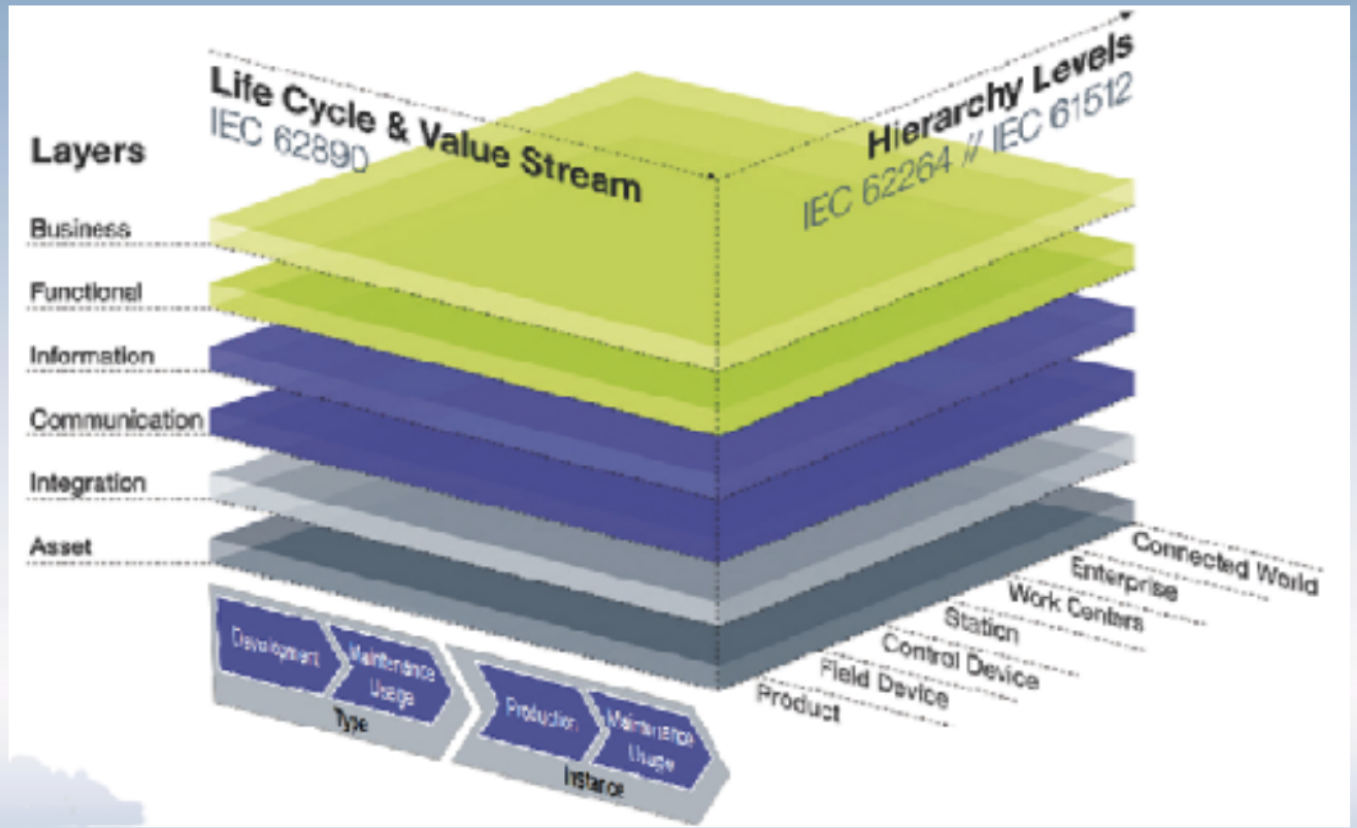
Production Automation and Digitalisation

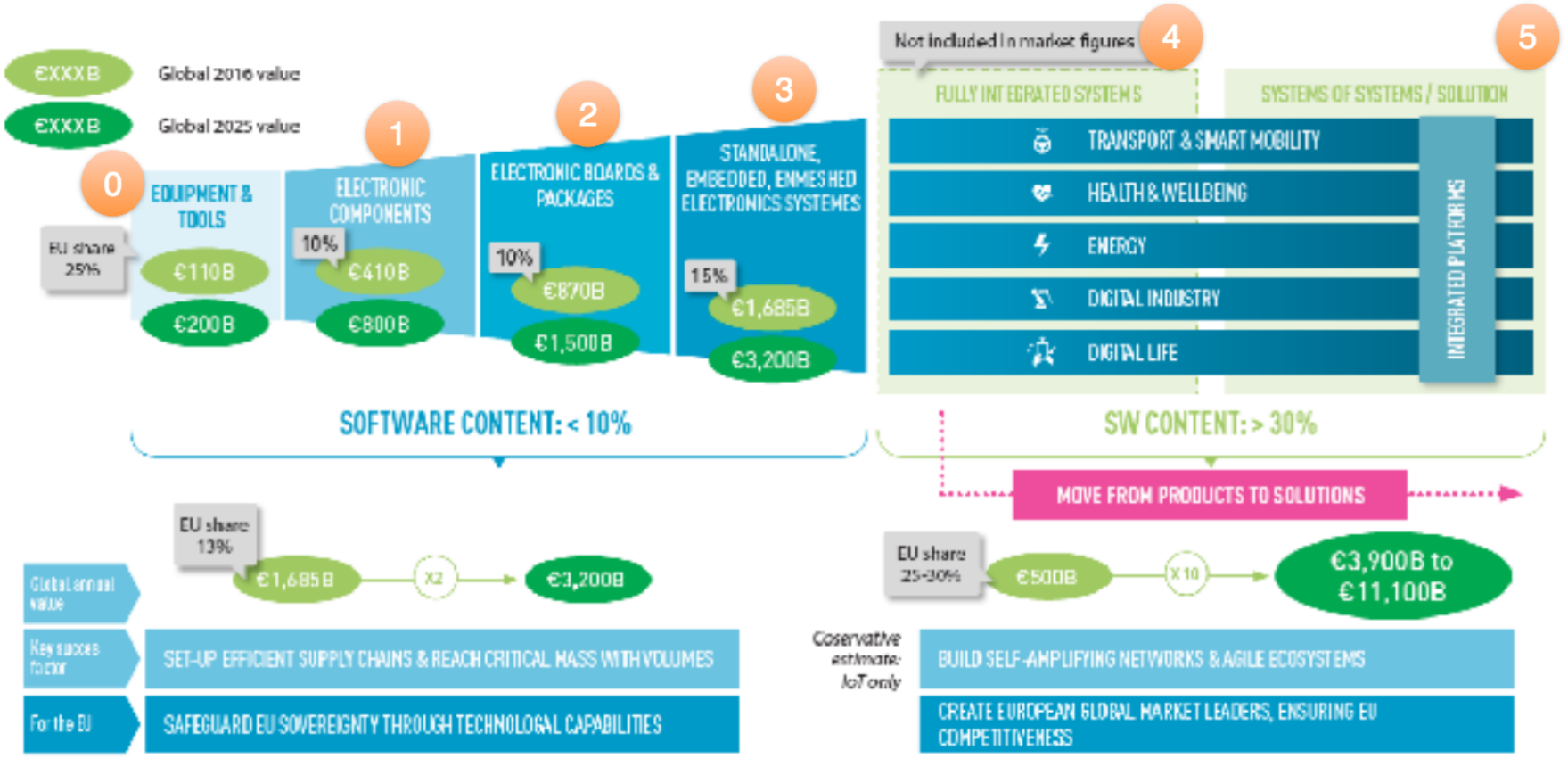
- legacy OT and
- IoT
- CPS
- SoS



Value is shifting across the CPS value chain
Today value is concentrated at 75% upstream
By 2025, 2/3rd of the value will be captured downstream

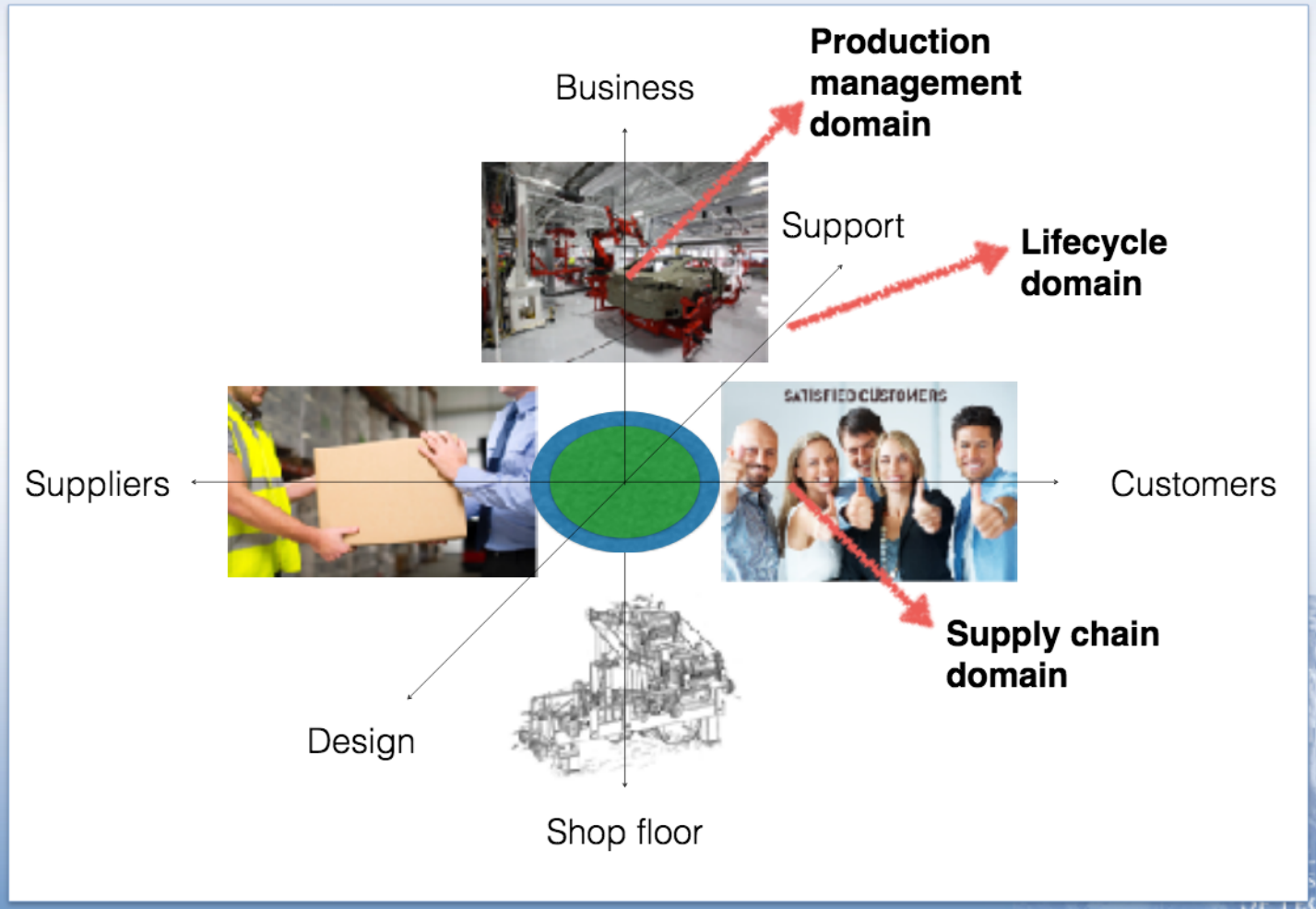
ARTEMIS Industry Association

advancy



Note: rounded figures. (1): 2025 estimate value potential for the Internet of Things, not the full potential for ECS end-applications.
Source: Decision, IDC, MGI, Advancy research & analysis

From enterprise to **multi-stakeholder** operation



Value networks
Information integration enables improvements

Requirements

Information interoperability

Security interoperability

Safety interoperability

Data ownership

Access to data

Real time data

Trusted logs of actions

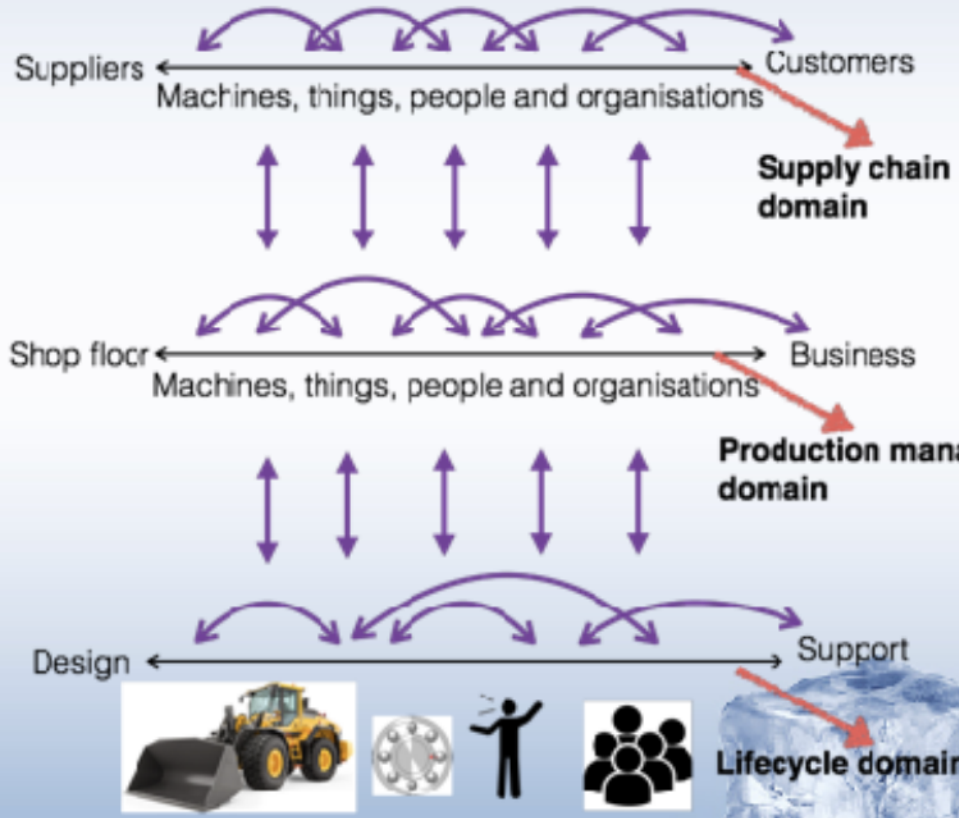
M2M business

Real time monetisation

Run time engineering

…

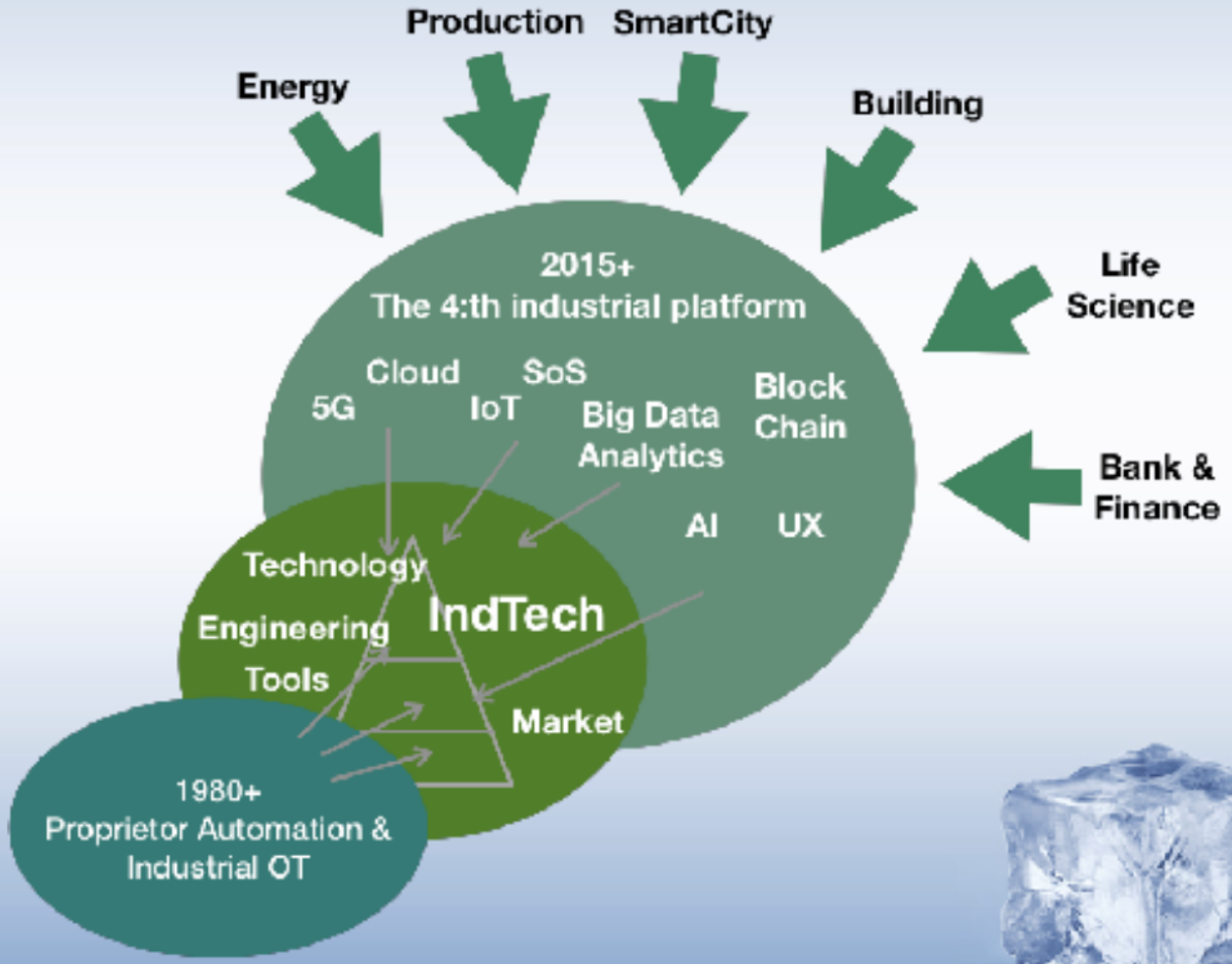
…



Integration needed between:

- Sensors, actuators, controllers
- Machines
- Tools; Analysis, Optimisation
- Groups
- Organisations
- Management: Operational, security, safety, …
- Business: supply chain, customers, life cycle,…
- Engineering: Tools, Engineering procedures, ..

OT - ICT integration



Very large scale IoT and SoS with emerging and evolving requirements and characteristics

- Highly distributed and heterogeneous solutions
- Very large-scale SoS, **10^5 - 10^{10}** IoTs
- IoT error and maintenance and mitigation
- SoS run-time dynamics
- SoS functionality evolution
- SoS scalability
- SoS segmentation for real-time operations, security, safety, ...
- SoS self-mitigation
- SoS self-engineering
- SoS self-management
- Machine to machine business models
- Machine to machine nano-transactions
- Multi-stakeholder autonomous integration and operations
- Management strategies and policies of SoS properties e.g.
  - Operations, Functional evolution, Functional degradation and maintenance, Functional engineering, Security, Safety, Quality of service

The Software perspective

Software diversity from cloud to edge

Software and Hardware Diversity

- Data centres - HPC
- Fog and Edge HPC
- Embedded HPC
- …
- …
- …
- CPS's, IoT's…
- …
- …
- …
- Resource constrained things of the Internet
- Energy constrained things of the Internet

Computing platform diversity

……

SW diversity

OS: 10's
Languages: 100's
Protocols: 1000's
Security: 10,000's
Data ontologies >> 10,000

……

Life cycle diversity

- Production assets - buildings, machines, …
  - 10-100 years
- Automation technology - Sensors, controllers, …
  - 5-20 years
- Personnel technology - smart phones, tablets, ….
  - 1-3 years
- Software
  - Days to Years (~5)
- Business models
  - Months - Many years

Will we ever get there?

- Requirements are a moving target
- Multi billion lines of code!
  - Proprietary SW
  - Open source SW
- SW licenses
- Version incompatibilités
- Buggs!
- Code documentation standards
- ….
- ….

What's may bring us there?

- Architectures
- Interoperability
- Composability
- Integration platforms
- Engineering procedures
  - Design & run time
- Engineering tools
- Tool chains

- Model supported engineering
- Machine supported engineering
- Autonomous engineering
- Solution self adaptation
- Business automation

Paolo Azzoni, From Internet of Things to System of Systems , Market analysis, achievements, positioning and future vision of the ECS community on IoT and SoS, Artemis-IA white paper, 2020, https://artemis-ia.eu/news/whitepaper-from-iot-to-sos.html

Emerging integration platforms

- Architectures
- Interoperability
- Composability
- Integration platforms

Emerging integration platforms

- Architectures
- Interoperability
- Composability
- Integration platforms

- Based on SOA
  - Compare IBM's integration of incompatible computing platforms in the 1970's
  - Eclipse Arrowhead, FiWare, Eclipse BaSyx, …
    - All Open Source SW

IoT-SoS Architectures & Platforms

Features	Arrowhead	AUTOSAR	BaSyx	FIWARE	IoTivity	LWM2M	OCF
Key principles	SOA, Local Automation Clouds	Runtime, Electronic Control Unit (ECU)	Variability of production processes	Context awareness	Device-to-device communication	M2M, Constrained networks	Resource Oriented REST, Certification
Real-time	Yes	Yes	No	No	Yes (IoTivityConstrained)	No	No
Run-time	Dynamic orchestration and authorization, monitoring, and dynamic automation	Runtime Environment layer (RTE)	Runtime environment	Monitoring, dynamic service selection and verification	No	No	No
Distribution	Distributed	Centralize	Centralize	Centralize	Centralize	Centralize	Centralize
Open Source	Yes	No	Yes	Yes	Yes	Yes	No
Resource accessibility	High	Low	Very low	High	Medium	Medium	Low
Supporters	Arrowhead	AUTOSAR	Basys 4.0	FIWARE Foundation	Open Connectivity Foundation	OMA SpecWorks	Open Connectivity Foundation
Message patterns	Req/Repl, Pub/sub	Req/Repl, Pub/sub	Req/Repl,	Req/Repl, Pub/sub	Req/Repl, Pub/sub	Req/Repl	Req/Repl
Transport protocols	TCP, UDP, DTLS/TLS	TCP, UDP, TLS	TCP	TCP, UDP, DTLS/TLS	TCP, UDP, DTLS/TLS	TCP, UDP, DTLS/TLS, SMS	TCP, UDP, DTLS/TLS, BLE
Communication protocols	HTTP, CoAP, MQTT, OPC-UA	HTTP	HTTP, OPC-UA	HTTP, RTPS	HTTP, CoAP	CoAP	HTTP, CoAP
3rd party and Legacy systems adaptability	Yes	Yes	Yes	Yes	No	No	No
Security Manager	Authentication, Authorization and Accounting Core System	Crypto Service Manager, Secure Onboard Communication	--	Identity Manager Enabler	Secure Resource Manager	OSCORE	Secure Resource Manager
Standardization	Use of existing standards	AUTOSAR standards	Use of existing standards	FIWARE NGSI	OCF standards	Use of existing standards	OCF standards

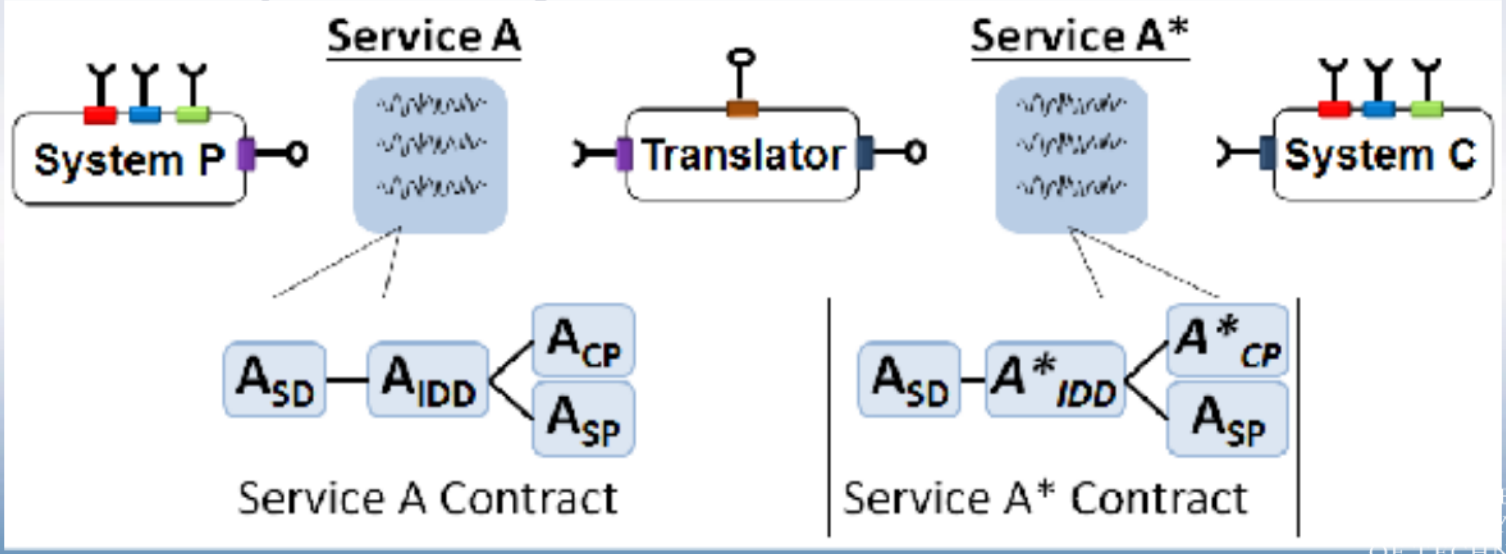
www.arrowhead.eu

C. Paniagua and J. Delsing, "Industrial Frameworks for Internet of Things: A Survey," in *IEEE Systems Journal*, doi: 10.1109/JSYST.2020.2993323.

ARROWHEAD TOOLS

Interoperability and Composability

- Can machines detect mismatches?
  - Protocols, security, data models, functional models, policy models …..
- Instantiate “translators” enabling Interoperability and composability



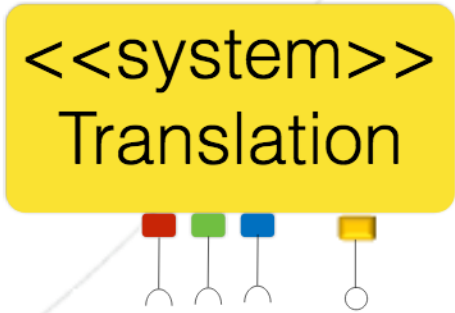
Interoperability based on translation

Translation between different protocols and encoding

e.g. HTTP, CoAP, MQTT, OPC-UA, …

e.g. JSON, XML, CBOR, ….

Code at www.github.com/arrowhead-f



H. Derhamy, J. Eliasson and J. Delsing, "IoT Interoperability—On-Demand and Low Latency Transparent Multiprotocol Translator," in IEEE Internet of Things Journal, vol. 4, no. 5, pp. 1754-1763, Oct. 2017.

ARROWHEAD

Translation of data semantics

Ontology based approaches

Semantic web approach (ISO 15926)

Semantic annotations of XSD files, the meta-data, that describe the exchanged XML messages.

R. Campos-Rebelo, F. Moutinho, L. Paiva and P. Maló, "Annotation Rules for XML Schemas with Grouped Semantic Annotations," IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society, Lisbon, Portugal, 2019, pp. 5469-5474.

ARROWHEAD TOOLS

Translation of data semantics

Machine learning approach

- Model of communicating cyber-physical systems (CPS) with different data representations and semantic definitions that interact in a physical environment (gray) and service-oriented architecture (white) via messages m translated by a function T^{AB}

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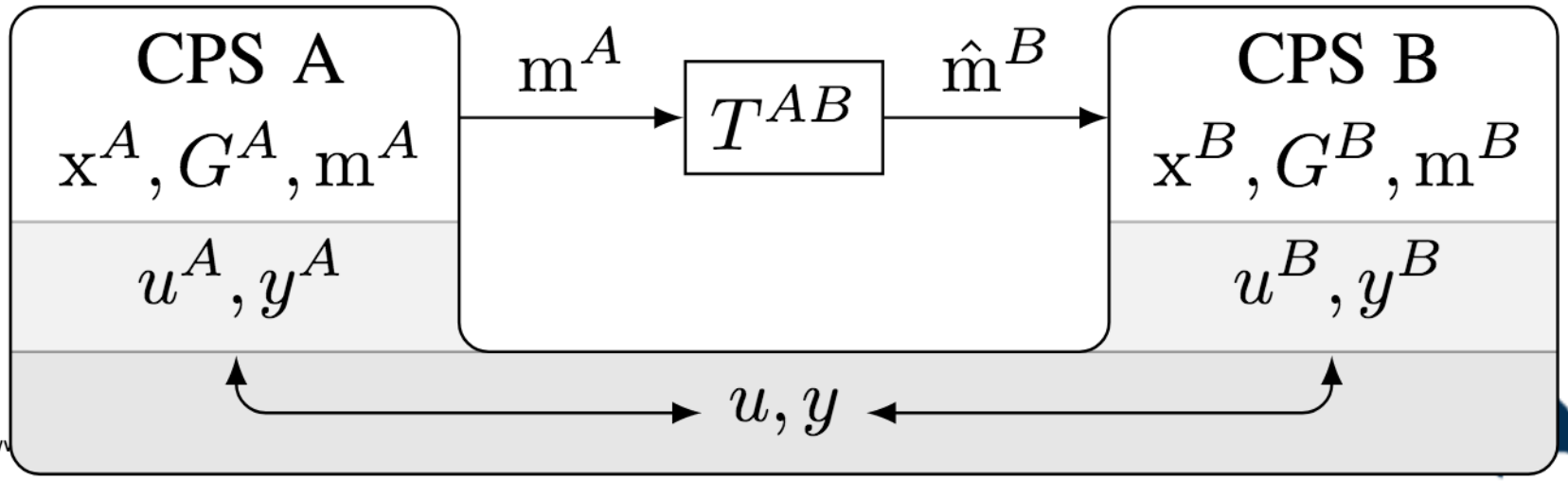
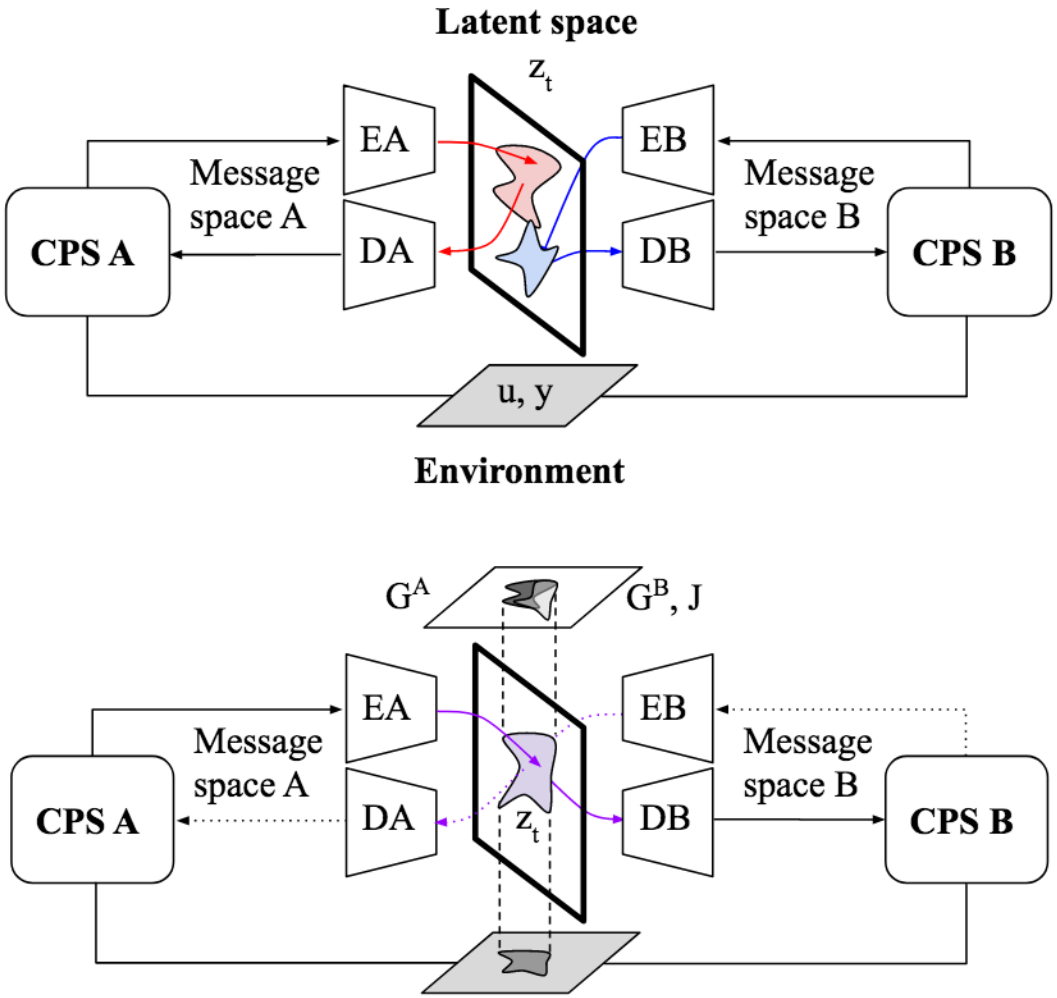


J. Nilsson, F. Sandin and J. Delsing, "Interoperability and machine-to-machine translation model with mappings to machine learning tasks," 2019 IEEE 17th International Conference on Industrial Informatics (INDIN), Helsinki, Finland, 2019, pp. 284-289.

ARROWHEAD TOOLS

Data semantics translation approach



Nilsson, J. (2019). System of Systems Interoperability Machine Learning Model (Licentiate dissertation). Luleå University of Technology. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-76229

ARROWHEAD TOOLS

Solution engineering

- Engineering procedures
  - Design & run time
- Engineering tools
  - Integrated tool chains
- Model supported engineering
- Machine supported engineering
- Autonomous engineering
- Solution adaptation by
  - Self engineering
  - Self validation and verification
  - Self deployment

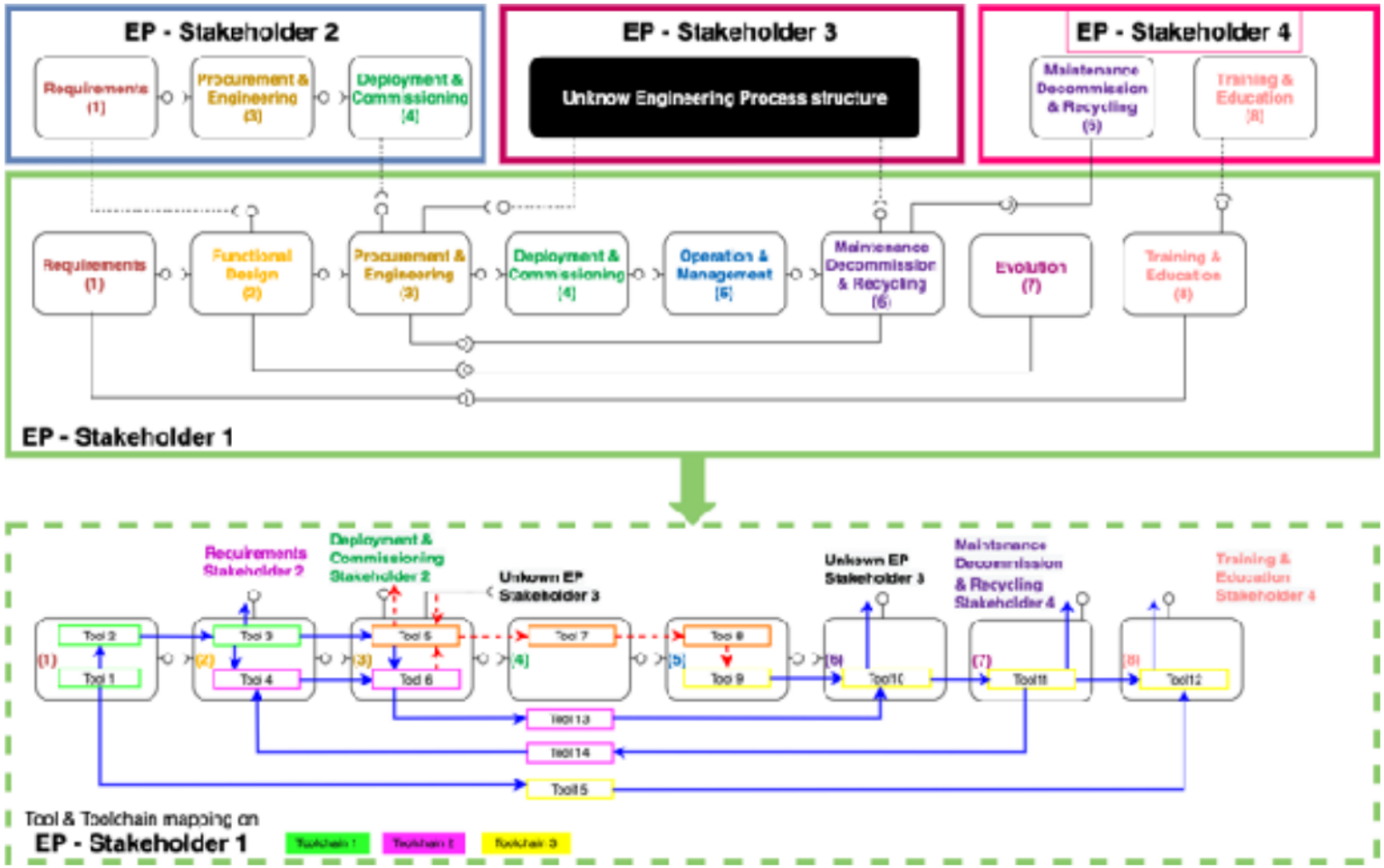
The engineering process

Can it be automated

This research work has been funded by the European Commission, through the European H2020 research and innovation programme, ECSEL Joint Undertaking, and National Funding Authorities from 18 involved countries under the research project Arrowhead Tools with Grant Agreement no. 826452.

ARROWHEAD TOOLS

Engineering process and tools integrated using SOA



www.arrowhead.eu

G. Urgese et.al. , An Engineering Process model for managing a digitalised life-cycle of products in the Industry 4.0, Proc. IEEE NOMS - WS on Management for industry 4.0, April 2020

ARROWHEAD TOOLS

Model supported engineering

Modelling of solutions

Machine supported engineering

Autonomous engineering

Solution adaptation by

- Self engineering
- Self validation and verification
- Self deployment Automatic code creation

Modelling languages

SysML

- Platform profiles
  - Enabling structures solution modelling
  - Supporting automatic code generation

SysML 2

- Stronger support for SoS modelling

ARROWHEAD TOOLS

The business process

Can it be automated

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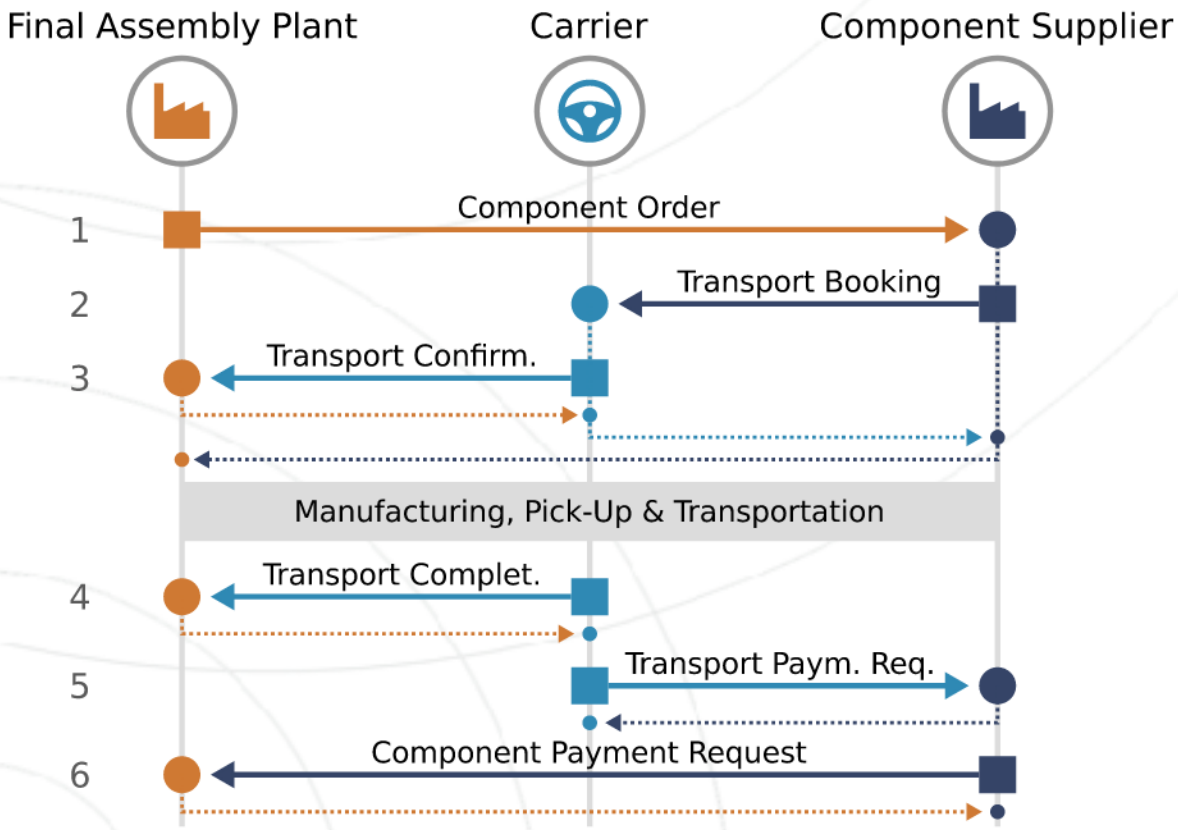
ARROWHEAD TOOLS

What about the stakeholder business relations

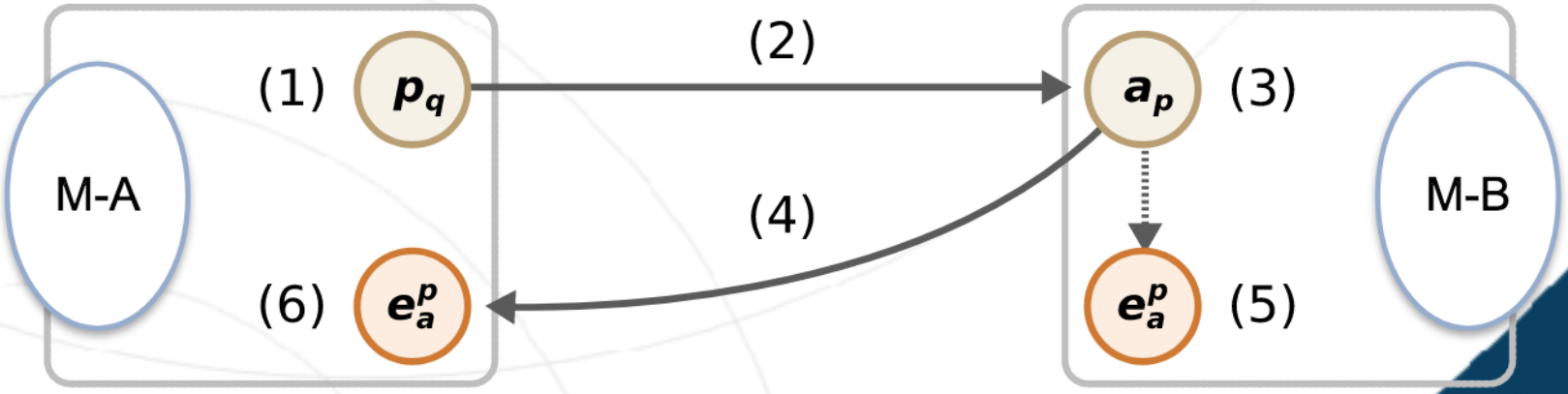
Can such business process be automated?



ARROWHEAD TOOLS

M2M automated business process

1. *A* creates and signs the qualified **Proposal**(p_q).
2. *A* sends p_q to *B*.
3. *B* creates and signs the **Acceptance** (a_p) from p_q.
4. *B* sends a_p to *A*.
5. *B* puts a_p and its hash into an **Exchange**($e^p{}_a$).
6. *A* puts a_p and its hash into an **Exchange**($e^p{}_a$).

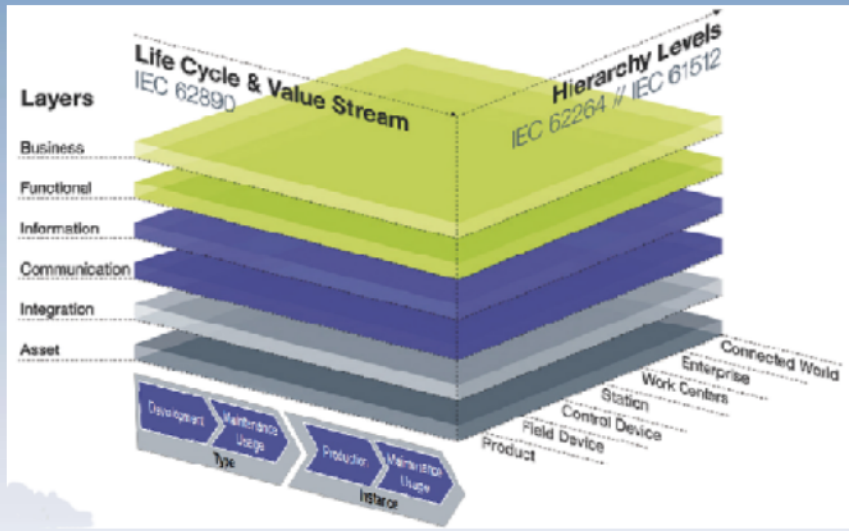


E. Palm, U. Bodin and O. Schelén, "Approaching Non-Disruptive Distributed Ledger Technologies via the Exchange Network Architecture," in *IEEE Access*, vol. 8, pp. 12379-12393, 2020, doi: 10.1109/ACCESS.2020.2964220.

ARROWHEAD TOOLS

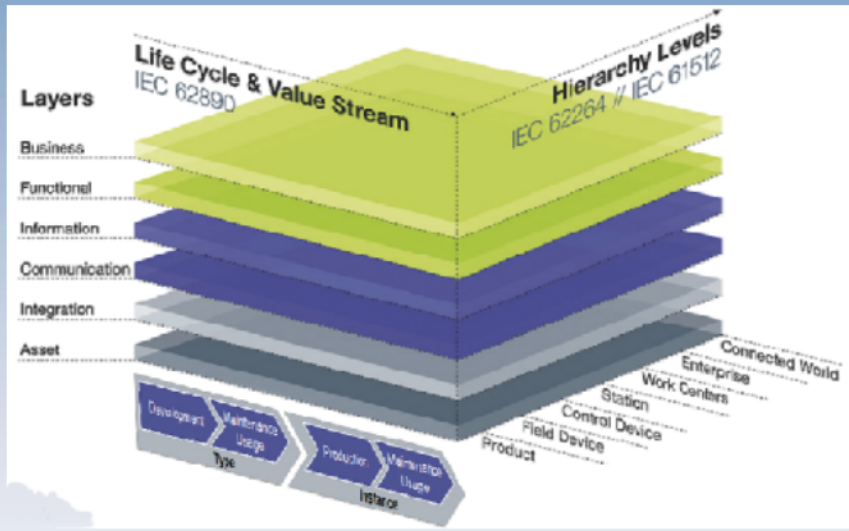
RAMI4.0

- Production operation
  - Automation, Control, ….
- Supply chain integration
  - Dynamic optimisation, …
- Production life cycle
  - Run time engineering
    - Automated evolution engineering
    - Automated maintenance engineering
- From asset to business
  - Automated M2M business transaction



RAMI4.0

- Production operation
  - Automation, Control, ….
- Supply chain integration
  - Dynamic optimisation, …
- Production life cycle
  - Run time engineering
    - Automated evolution engineering
    - Automated maintenance engineering
- From asset to business
  - Automated M2M business transaction
- All can be integrated with SOA based platforms



Identified key concepts

- Architecture and integration platforms
  - SOA
- Interoperability and composability
  - Translation - autonomous
- Engineering processes
  - Automation of SW engineering
- Business integration
  - Automated M2M business processes
- Model supported engineering
  - SysML - SysML 2

So what's the message

- System of Systems - SoS and
- System of Cyber Physical Systems - SoCPS
  - are a critical part of future automation and digitalisation
- **Software is the key enabler**
  - Need for key concepts to reduce complexity e.g.
    - Autonomous translation to bridge technology mismatches
    - SoS, SoCPS and SW models are necessary

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Thanks for listening

Question

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