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Digital Transformation:
Pursuit of Relevance, Excellence, and Leadership

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Digital Transformation: Pursuit of Relevance, Excellence, and Leadership

DIGITAL TRANSFORMATION OF MANUFACTURING. AGENT TECHNOLOGY AND SERVICE ORIENTATION

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Agenda

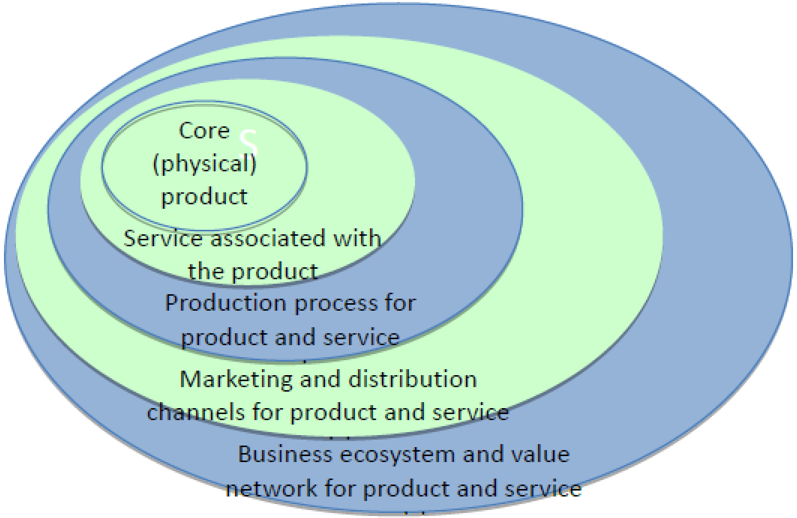
- Digital Transformation of Manufacturing. Objectives. Framework
- Distributing Intelligence in Manufacturing and Services
  - MAS and Holonic Manufacturing Control
  - Mixed Batch Planning and Product Scheduling
  - Product Intelligence
- Service Oriented Manufacturing Architectures
  - Service Oriented Holonic Manufacturing Systems (SoHMS)
  - SOA and MAS. Enterprise Integration
- Evolvable Manufacturing
  - Sustainable, safe and smart manufacturing
  - Cloud Manufacturing
  - Manufacturing Cyber-Physical Systems and the Industrial Internet of Things (IIoT)
- New business models. Big Data and the Contextual Enterprise. Industrie 4.0

Digital Transformation of Manufacturing (DTM). Objectives. Framework

Digital Transformation of Manufacturing: the actual vision and initiative about developing the overall architecture and core technologies:

- Establish an *Internet-scale platform for networked production*
- Encapsulate the right abstractions to *link effectively and scalably the various stakeholders* (product firms, manufacturing plants, material and component providers, technology providers, key services)

Effect: emergence of a smart, safe and sustainable Internet economy for industrial production.



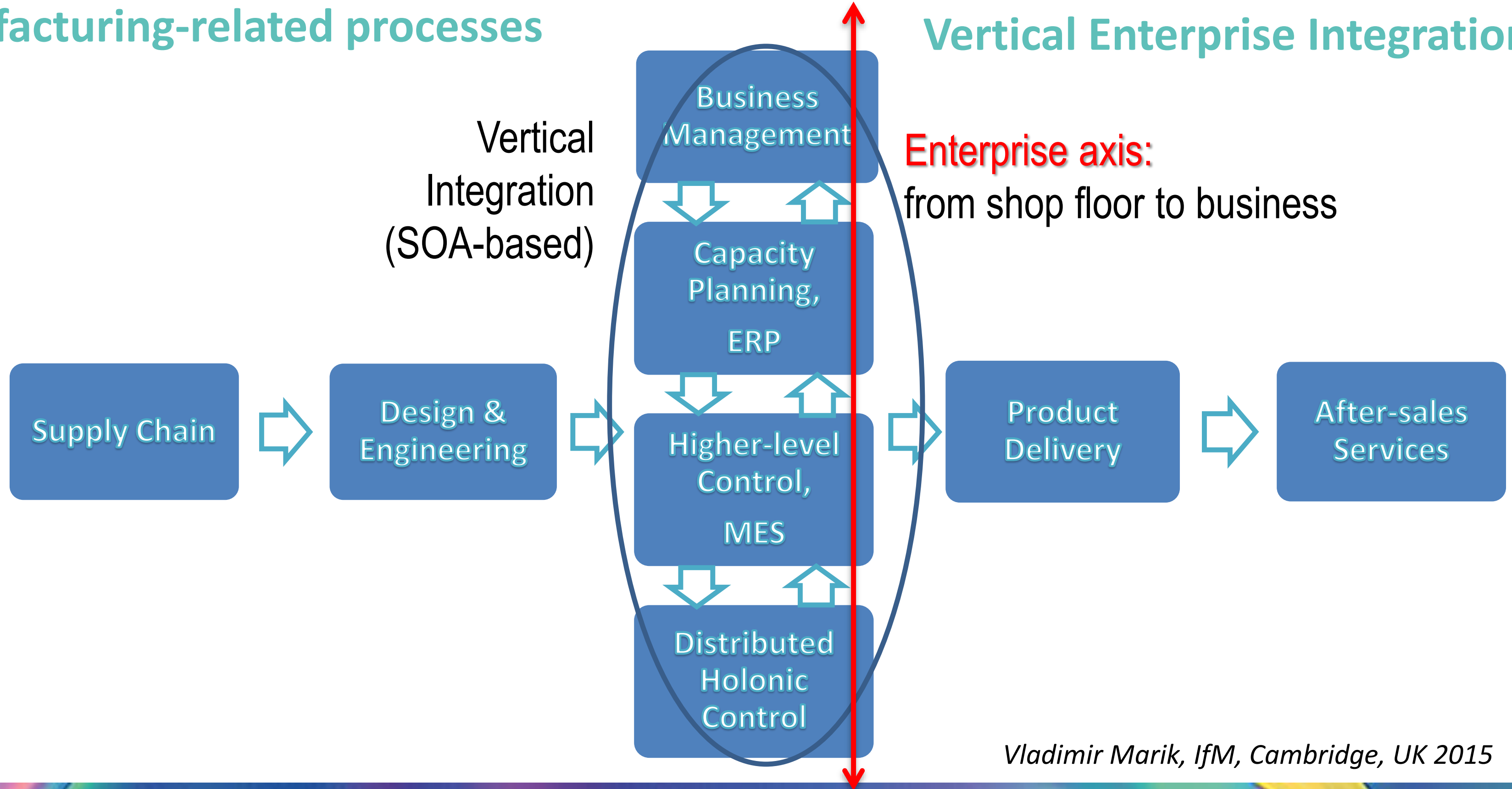
Shifting from good-dominant logic to service-dominant logic [Product-Extension Services] enhances the utility of product delivered to customer (install, configure / tune, repair, maintain/upgrade, etc.). Adding value in customer operations [*Martti Mäntila, Aalto University, 2015*]

Framework for DTM

1. Instrumenting manufacturing resources (machines, robots, …) and environment (material flow, tooling, …), allows: product traceability, production tracking, evaluation of resources' status and QoS, preventive maintenance…
2. Interconnecting orders, products, resources in SOA using multiple communication technologies: wireless, broadband Internet, mobile applications
3. Intelligent, distributed control of production by:
   - **New controls based on ICT convergence in automation, robotics, vision, multi-agent control, holonic organization**: the smart factory.
   - **New operations based on product- and process modelling and simulation**. Ontologies - used as a "common vocabulary" to provide semantic descriptions / abstract models of the manufacturing domain: core ontology – modelling of assembly processes (resources, jobs, dependencies, …); scene ontology – modelling flow of products; events ontology – modelling expected / unexpected events and disruptions: the digital factory.
   - **Novel management of complex manufacturing value chains** (production, supply, sales, delivery, …) for networked, virtual factories:
     - across manufacturing sites: logistics, material flows;
     - across the product life cycle.

Manufacturing-related processes

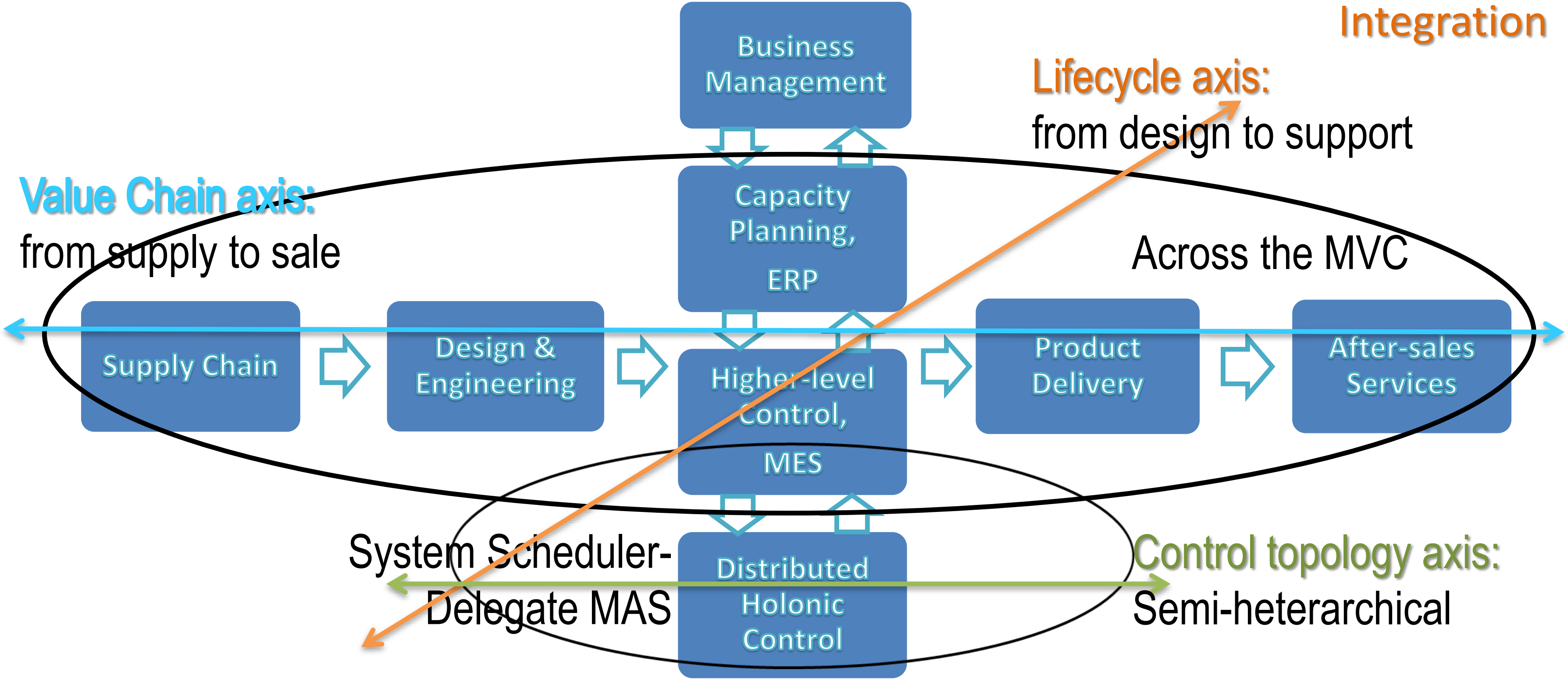
Vertical Enterprise Integration



Vladimir Marik, IfM, Cambridge, UK 2015

Horizontal Integration: MVC, SS-Delegate MAS

End-to-End Engineering Integration



DTM objectives

- Enterprise integration:
  - ✓ **Horizontal integration** through value networks
  - ✓ **Vertical integration** and networked manufacturing systems
  - ✓ **End-to-end digital integration of engineering** across the product lifecycle
- Focus on development:

Agentification for reconfigurability and agility
Distributing intelligence for robustness and flexibility
Services across layers
Integration
Big Data, analytics
Simulation, knowledge modeling, ontologies
Security

DTM - How?

Distributed Intelligent Control at Manufacturing Execution System (MES) and shop floor levels, based on ICT frameworks: *control distributed* over autonomous intelligent units (agents), *multi-agent systems* (MAS), *holonic organization of manufacturing*

Service Oriented Architectures (SOA), used as *an implementation mean for MAS*.

- SOA: a technical architecture, a business modelling concept, an integration source; reinforces the value of commoditization, reuse, semantics and information, and creates business value
- The product = "active controller" of the enterprise resources, provides:
  - ✓ consistency between the material and informational flows;
  - ✓ business and process information systems integration and interoperability.

Manufacturing Service Bus (MSB 2.0) integration model: an adaptation of the Enterprise Service Bus (ESB) technology for manufacturing; *bus communication between manufacturing layers* acting as intermediary for data flows, assures loose coupling of manufacturing modules.

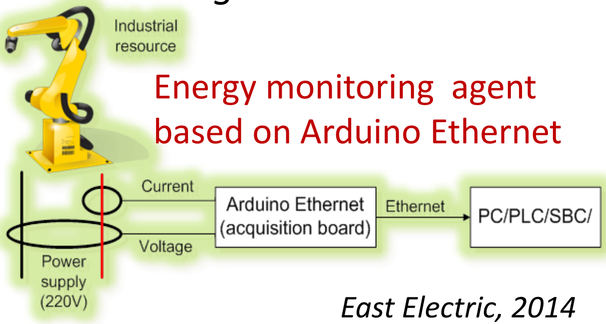
Distributing Intelligence in Manufacturing and Services (DI): what?

MAS and Holonic Manufacturing Control

- DTM and MCPS strongly influenced by agent-based control - distributes intelligence
- MAS technology provides:
  - Agent communication languages (e.g. FIPA-ACL, KQML…) [*Vrba, 2012*]
  - Coordination and Negotiation mechanisms [*Pănescu, 2011; Răileanu, 2013*]
  - (Social) Knowledge Management, incl. Semantics and Ontologies [*Lamouri, 2014*]
  - Coalition formation, collaborative teamwork - shop-floor reengineering for agility [*CoBASA, Barata 2006; Borangiu, 2009; Chen & Băbiceanu, 2006*]
  - MAS Planning and Learning [*Van Belle, 2011; Novas, 2012*]
  - Meta-reasoning [*McFarlane, 2012*]
  - Enable linkage of the virtual world to the real physical world
  - MAS Architectures and Platforms (Aglobe, Jack, JADE,…) [*Leitao, 2012;*]
  - and many theoretical problems in focus (stability, adaptability, nervousness, …) [*Valckenaers, 2010*]

Multi-agent Systems for Distributed Intelligent Manufacturing Control (DIMC): how?

- **DIMC based on multi-agent systems theory**
  - control distributed over autonomous intelligent units (agents)
    - *specialized for various control tasks: operation scheduling, resource monitoring*
    - *advertise their capabilities to other agents*
  - complex tasks solved by cooperation (societal model)
    - *negotiation about providing services; communication via short messages*
- **Agents tightly linked with physical system**
  - need to ensure real-time responsiveness
  - yet software agents work in soft real-time
- **Integration with PLC-based control (transport, material routing)**
  - agents considered as an intelligent layer over classical control
  - PLC-based control (IEC 61131-3) still in place to ensure real-time responsiveness
  - IEC 61499 (function blocks) seem to be promising successor



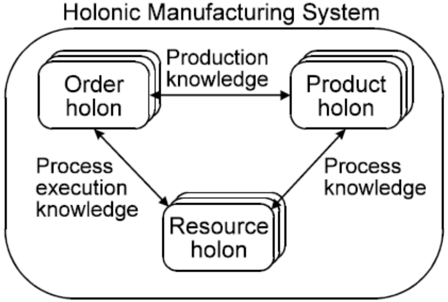
East Electric, 2014

Multi-agent Systems for DIMC: why?

- **Agent-based DMIC advantages over traditional centralized control**
  - control system not programmed for particular shop floor layout:
    - *templates of agents describing behavior of specific components* (resources, orders, …)
    - *control system made-up dynamically of individual agent instances*
    - *complexity of programming does not increase with size of system*
  - robustness against failures:
    - *if part of the system fails, the rest continues to be operational*
    - *dynamic discovery of alternative solution* (no “precomputed” ones)
- **MAS is the implementing framework for holonic manufacturing (control) Systems (HMS)**
  - [Holon] ← [Physical Asset] + [Agent = Information counterpart]
  - Physical Assets :
    - *resources* (technology, humans - reflect the producer’s profile, capabilities, skills),
    - *orders* (reflect the business solutions),
    - *products* (reflect the client’s needs, value propositions),

  are represented by holons collaborating in holarchies to reach a common goal [aggregate order]

Holonic Manufacturing Systems (HMS). Semi-heterarchical control

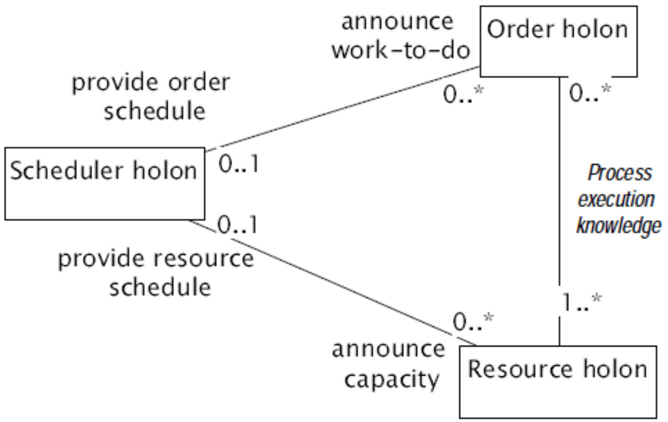


The **Holonic paradigm:** a decentralized control architecture composed by a *social organization of intelligent entities*, called Holons, with specific behaviours and goals, collaborating in a holarchy defined by a reference architecture [*PROSA (Van Brussel et al., 1998), HABPA (Chirn and McFarlane, 2000), CoBASA (Barata, 2003) or ADACOR (Leitão and Restivo, 2006)*].

Basic Holons:

- Resource Holon: contains a *physical part* (a production resource, and an *information processing part* (controls the resource)
- Product Holon: holds the *process and product knowledge* to assure the correct making of the product with sufficient quality
- Order Holon: a *task in the manufacturing system*; it is responsible for performing the assigned work correctly and on time

Staff Holon: *assists* the basic holons in performing their work (*generates an optimal schedule and gives it as advice*).



Basic + Staff → Decoupling robustness & agility from system optimization

Source: PROSA, Valckenaers et al

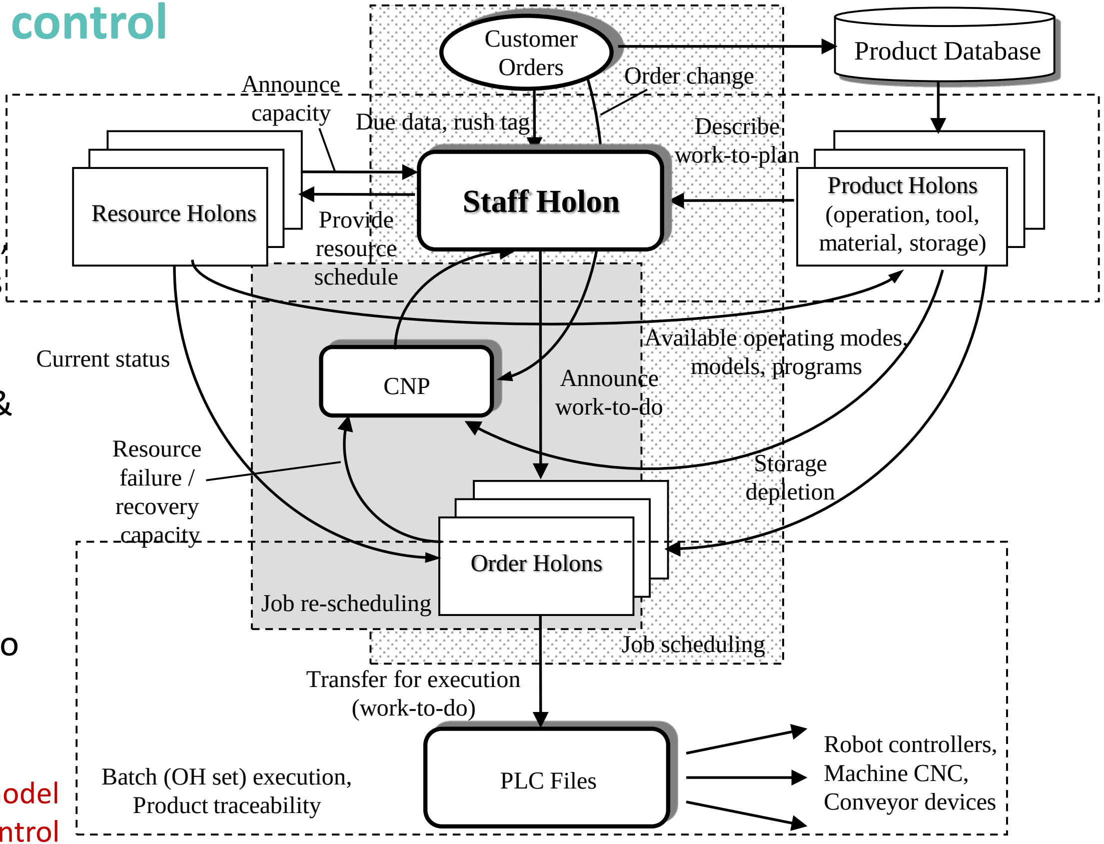
The Holarchy. Semi-heterarchical control

Dynamic reconfigurability of the MES

- *Semi-heterarchical control of production*
- *Control modes switched by the Staff Holon* at: resource break down, performance degradation, poor QoS, high power consumption, rush orders

Control modes:

1. **Hierarchical, centralized** (mixed batch planning & product scheduling with resource allocation): *optimization* by a System Scheduler embedding the Staff Holon at full batch horizon – advice
2. **Heterarchical, decentralized** (product re-scheduling, resource re-allocation): robustness to failures & agility to market changes by delegate MAS (OH on Intelligent Embedded Devices)



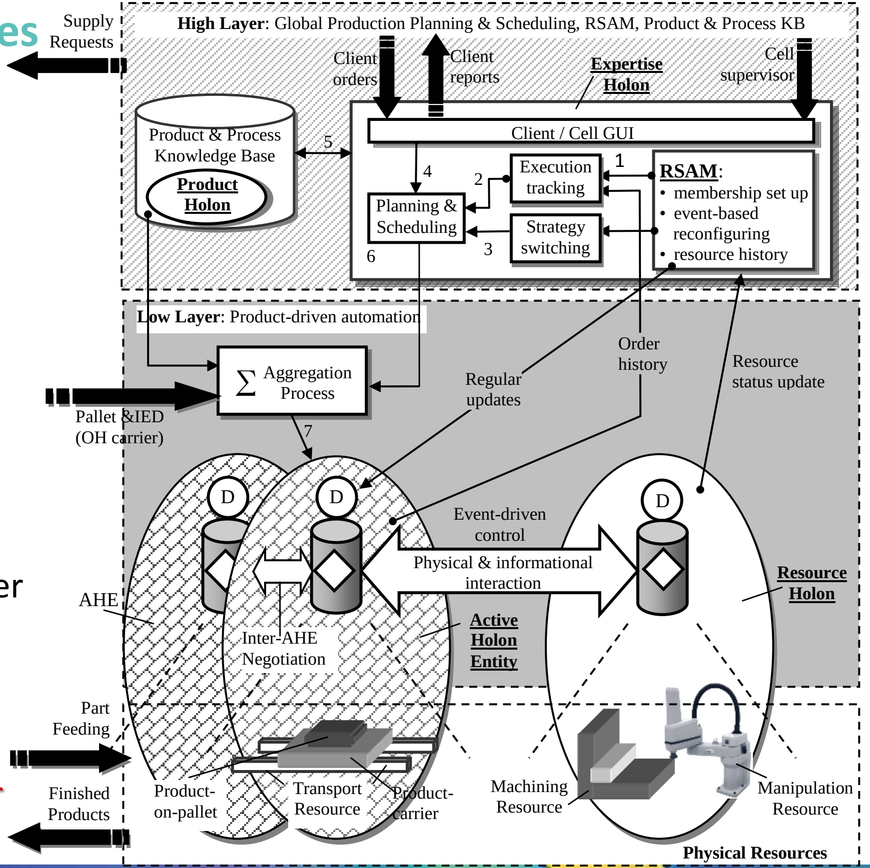
The **Holarchy** – Holon collaboration model for semi-heterarchical control

Active holon entities. Intelligent embedded devices

1- Read Resource Service Access Model (RSAM);
2- Information about order execution;
3- Send strategy switching signal;
4- Transfer raw orders;
5- Read and write product recipes;
6- Transfer planned and/or scheduled orders;
7- The result of the aggregation process is the **Active Holon Entity** - AHE (a mobile Order Holon executing on **Intelligent Embedded Device** - **IED**)

Aggregation = IED + OH + Product in execution + Product carrier

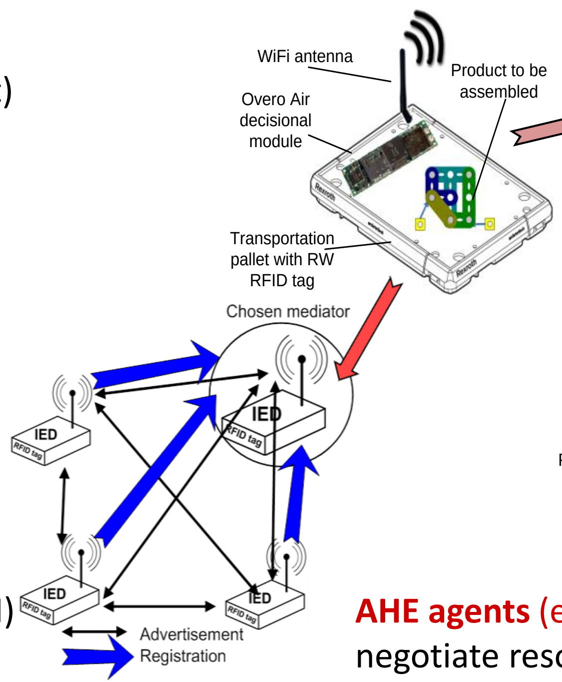
(IED + OH = AHE; AHE + Product in execution + Product carrier = Intelligent Product)

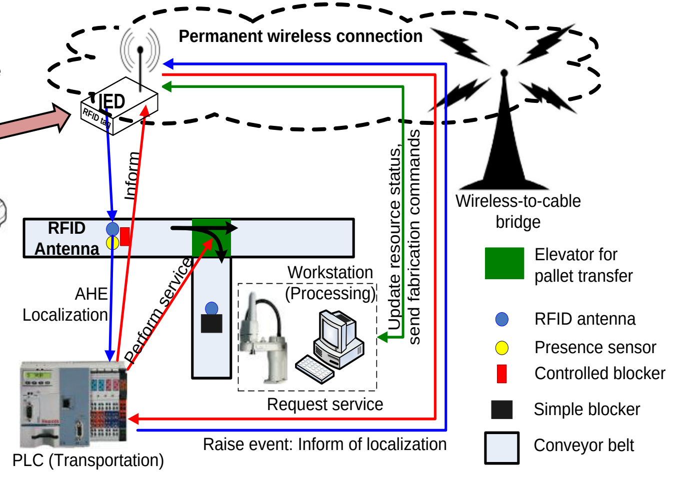


2-layer generic architecture for semi-heterarchical shop-floor control with *resource service access reconfiguring* (RSAM)

Agent-based product routing. Product-driven automation (with IP)

- **Low-level control (LLC) layer**
  - real-time control on PLC
  - IEC61131 (ladder logic, structured text)
  - promising successor – IEC 61499
- **High-level control (HLC)**
  - software agent (C++/Java)
  - agent runtime environment (JADE)
  - usually running on PC or general-purpose module in PLC chassis
- **HLC↔LLC interface**
  - agents get notifications from LLC on important events (task completion …)
  - RH agents send commands to HLC (OH)
  - technologies: COM/DCOM, OLE, blackboard, IEC 61499 interface FBs, direct access to PLC data table (Rockwell)





CIMR Research Center, 2015

AHE agents (embedded intelligence on products): negotiate resources and take collective decision on "next operation assignment" at shop floor disturbances (e.g., resource breakdown, high power consumption, low QoS)

Product intelligence

Intelligent product: "A physical order or product that is linked to information and rules governing the way it is intended to be made, stored or transported that enables the product to support or influence these operations"

Characteristics of Intelligent Products → Integration in Manufacturing, Supply Chain

Information-oriented (communicates its status)

- Possesses a *unique identity*
- Is capable of *communicating effectively with its environment*
- Can *retain or store data* about itself

Decision-oriented (assesses & influences its status)

- *Deploys a language* to display its features, production requirements etc.
- Is capable of *participating in or making decisions* relevant to its own destiny

- Able to match physical goods to order information
- Access to a network connection [directly or indirectly]
- Linked to static and dynamic data about item – across multiple organizations
- Able to respond to queries
- Priority, routing, production, usage decisions can be made [on behalf of] the item

[*Wong et al., 2002, McFarlane et al, 2003*]

Levels of Product intelligence

Level 1 (Information-oriented)

- *Represent the (customer) needs* linked to the order: e.g. goods required, quality, timing, cost agreed
- *Communicate with the local organisation* (and with the customer for the order)
- *Monitor/track the progress of the order* through the industrial supply chain

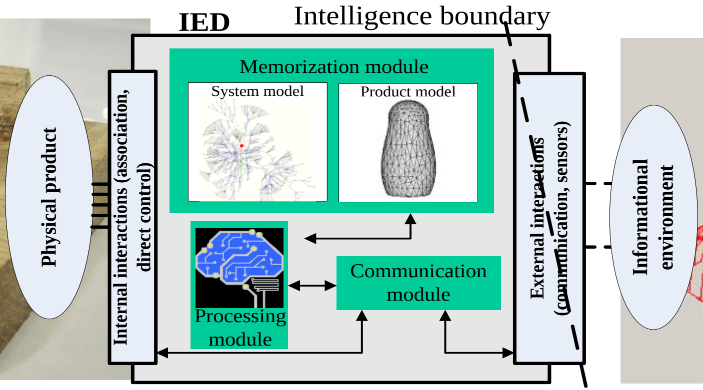
Level 2 (Decision-oriented)

- [Using the preferences of the customer] *influence the choice between different options affecting the order* when such a choice needs to be made
- *Adapt order management* depending on conditions

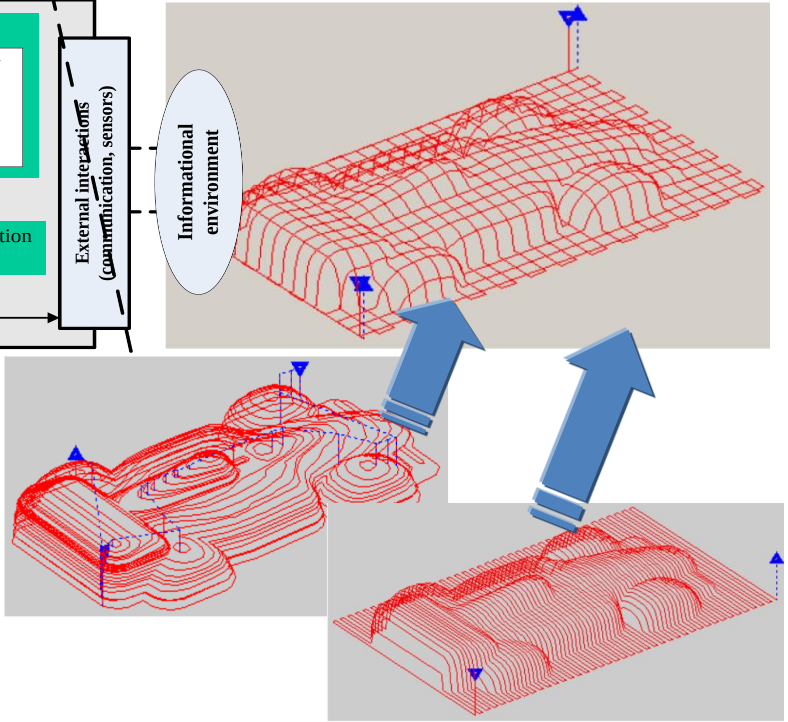
Common Threads

- Customer directly shapes order
- Customer directly shapes execution of order — STATIC
- Customer can influence who executes the order
- Customer can change aspects of the order execution — DYNAMIC
- Customer can change aspects of the order during execution
- Customers influence is automated — AUTONOMOUS

Example: Product Intelligence @ design & execution stage



- Location of [Product] Intelligence: at object (on IED)
- Embeds: Order Holon (OH)
- Feasible OH tasks: execution, quality control, monitoring
- History: CARE, CAE, product design, CAQC spec.
- Stores:
  - ✓ product data (operation list, precedence data)
  - ✓ digital shape description, shape quality indicators (local/global)
  - ✓ machining strategy, tool path, tool offset
  - ✓ resource data (machine requirements, set up)

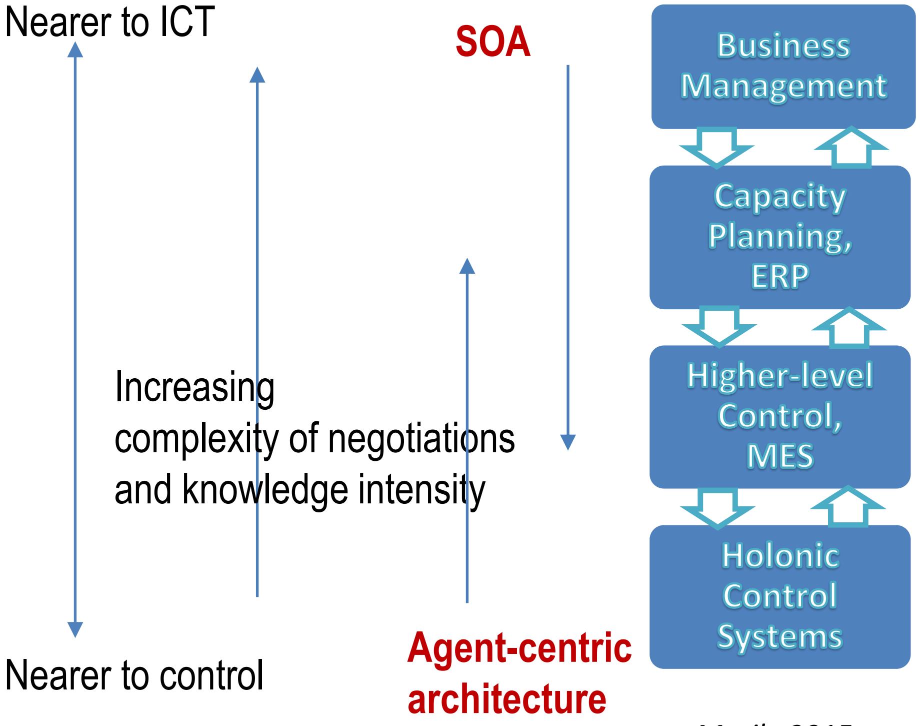


CIMR Center, University Politehnica of Bucharest, 2012

Service-oriented Manufacturing Architectures (SOMA)

- Integrating the concepts of services into HMS → **Service-oriented Holonic Manufacturing Systems** (SoHMS).
- SoHMS uses a structure based on *repeatability and reusability of manufacturing operations*.
- **Process families**: formed by a collection of process modules representing *manufacturing operations*.
- Adopting principles of SoA into HMS → manufacturing operations are standardized into MServices realized by one or several resources. Resource's capabilities ← the collection of MServices it offers
- The **service** - *main element of negotiation and exchange among holons*.
- Fractal mode of SoHMS - three abstract capability layers:
  - ✓ ***Expose Layer***: determines *how manufacturing services are presented to the system* in terms of richness of description and identification (from the manufacturing ontology);
  - ✓ ***Compose Layer***: determines the strategies and methods to *compose complex process workflows by combining individual services* to reproduce the desired results;
  - ✓ ***Consume Layer***: concerns the strategies for executing atomic or composite MServices (how to *access and invoke the MService*).

SOA and MAS. Enterprise Integration



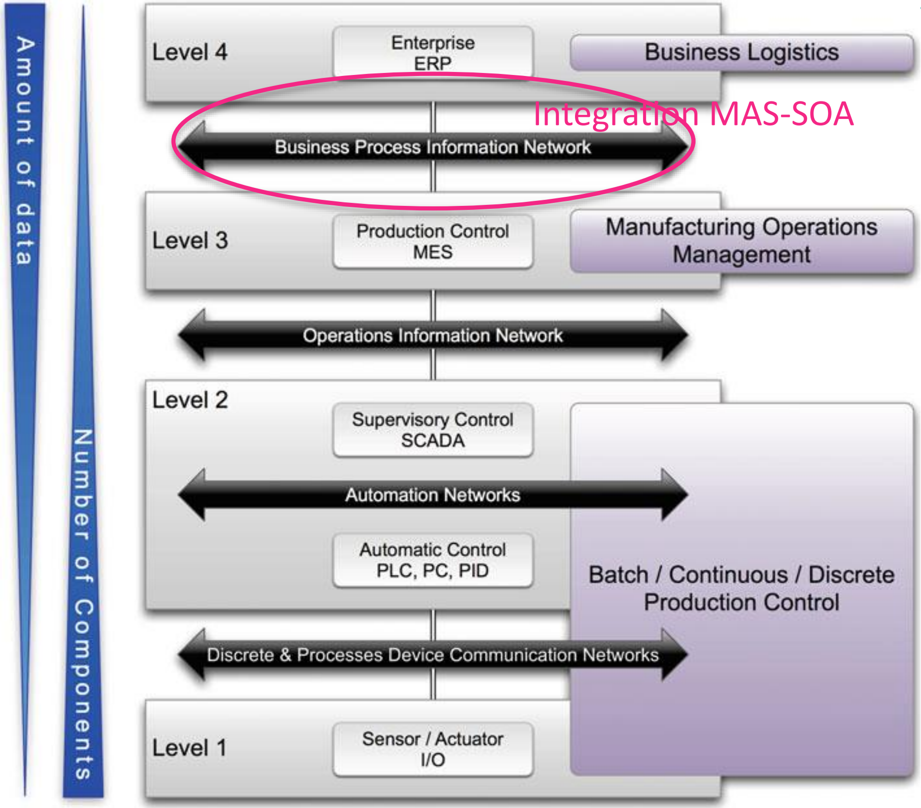
Marik, 2015

SOA – MAS duality → SOMA

- MAS used as implementing framework for Holonic semi-heterarchical control (delegate MAS, distributed MES, RSAM)
- SOA dual, used in integration of enterprise business layer, MES and shop floor layer
- SOA more and more accepted as a natural technology
- FIPA is not evolving any more
- SOA used more and more also on HL Distributed Control level, even on the holonic level

SOA and MAS

- Heterogeneous communication networks and components: difficulties to achieve *vertical integration* and *scalability* of the system
- Application of SOA in the factory automation domain: encapsulating the functionality and the business logic of the different components in the production environment (i.e., legacy software and devices) by means of Web Services (WS)s
- Encapsulated components behave like plug-and-play ones; can be added or removed as needed, independently of their internal operation.
- WSs on factory floor: autonomous modular components executing underlying control logic/devices they encapsulate
- The production process defined by workflows, decomposed into production tasks. Is carried out by invocations to WSs, to be coordinated: *orchestration*, *choreography*



Control hierarchy levels in manufacturing enterprises, standard ANSI/ISA 95 (the level 0 has been omitted).

Evolvable Manufacturing

R&D problem: What models, methods and tools are required to help designing Production Systems based on intelligent modules that can be plugged / unplugged to create systems of different complexity order by cooperating to achieve a certain goal, and with little reprogramming?

Learn
- Self learning

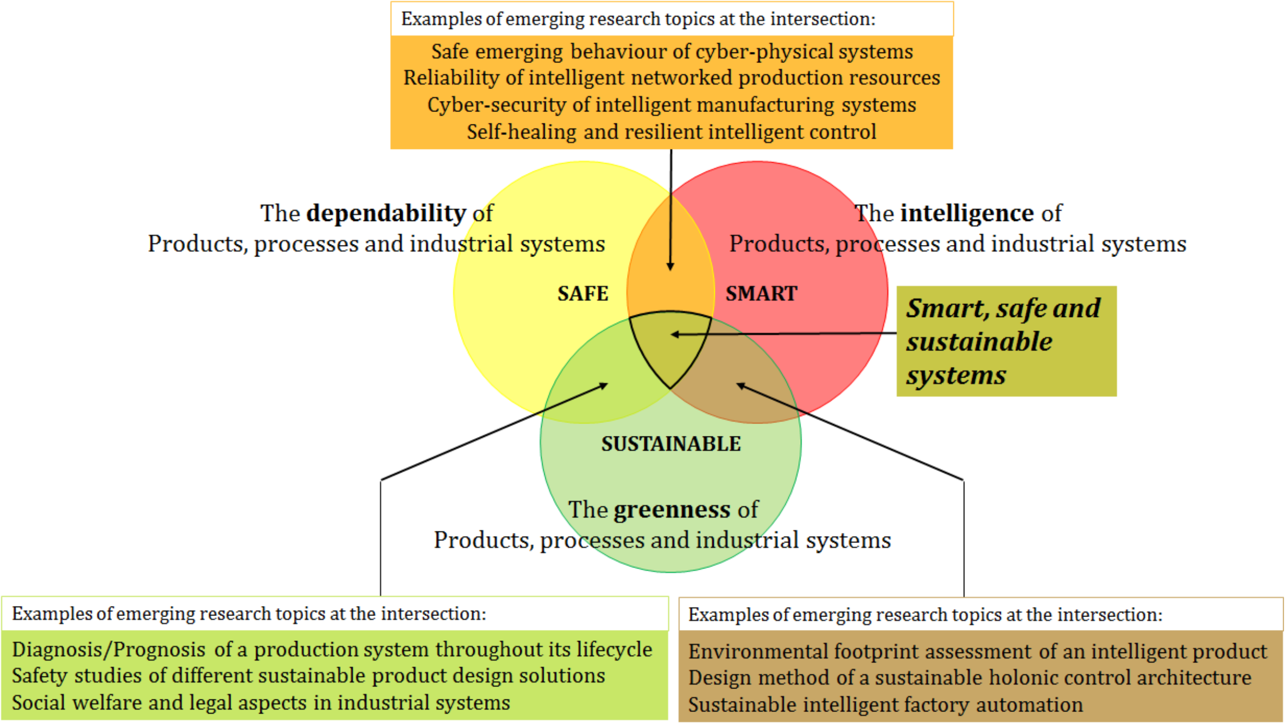
Adapt
- Local intelligence
- Adapt at runtime (current status, needs)
- Evolve

Reconfigure
- Self reconfigurable
- Self healing

Evolvable Systems:
- Ability of the system to evolve together with the product and the requirements - process modifications
- Addition / removal / exchange of modules
- Undergo smaller modifications on-the-fly
- Run-time changes
- Re-use of expensive equipment
- Improved Diagnosis and Maintenance
- Run-time Reconfiguration
- Learning with experience

Avoid Reprogramming – Very Expensive!

Sustainable, Safe and Smart Manufacturing



Damien Trentesaux, Theodor Borangiu, André Thomas, Computers in Industry, 2016

Safe

Refers to the *reliability*, *availability*, *security*, *testability* and *maintainability* dimensions of products, processes & industrial systems evaluated through dependability studies

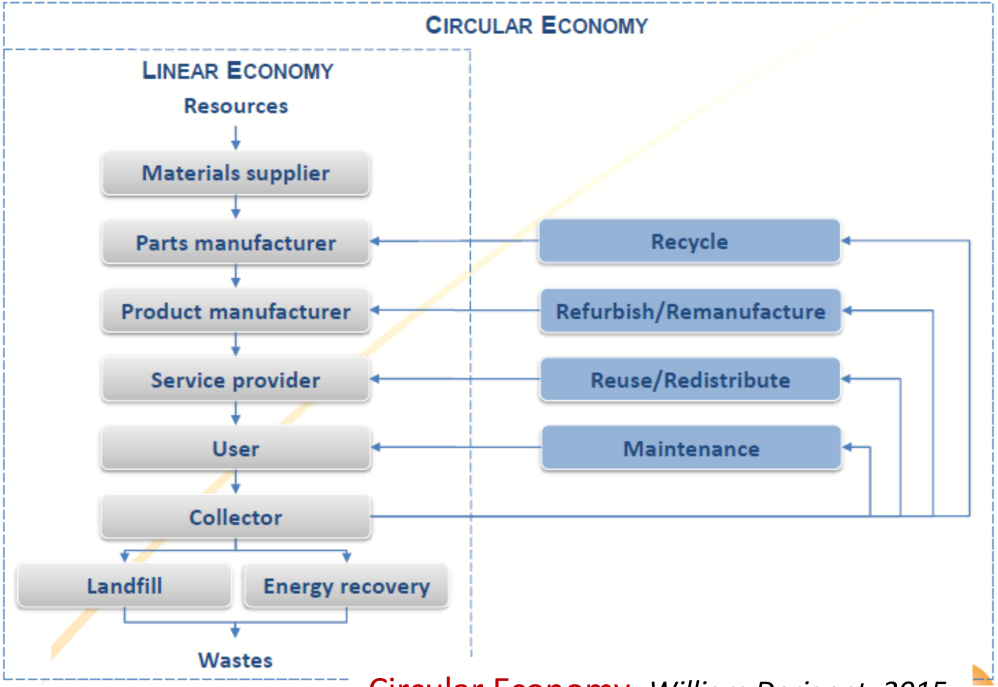
Smart

Refers to *learning*, *adapting* and *reconfiguring* capabilities of products, processes & industrial systems through intelligence distribution, collaboration and cognitive computing

Sustainable

Refers to the *greenness* dimension of products, processes and industrial systems to maintain an equilibrium between economic, social & environ-mental requirements and constraints

Sustainable, safe and smart manufacturing



Circular Economy, *William Derigent, 2015*

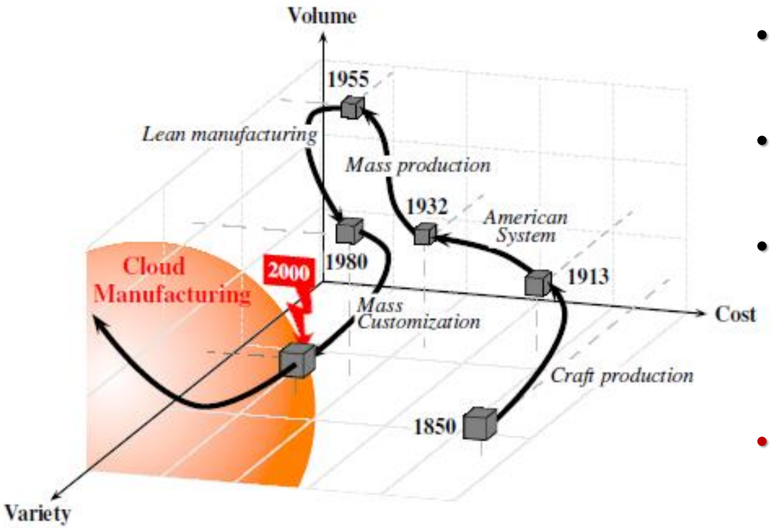
Sustainable manufacturing: *US Dept. of Commerce, 2012*
"The creation of manufactured products that use processes which minimize negative environ-mental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound".

Circular economy: *Benoit Jung, Eric Levrat, 2015*
An economic concept that fits in the context of sustainable development; is based on the concepts of *green economy*, *usage economy* and *industrial ecology.*

Reconsider conventional life cycle (BOL, MOL, EOL): replacing EOL with restoration, shift towards the *use of renewable energy*, *eliminate the use of toxic chemicals* and *reduce waste*.

Cloud manufacturing (CMfg)

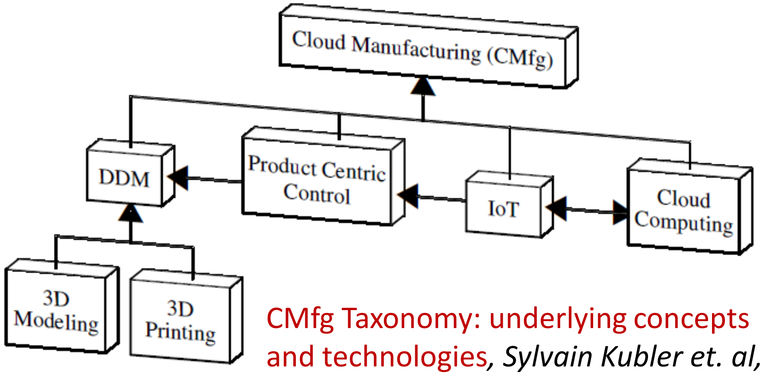
CMfg: *moves* from **production-oriented** processes to ***customer- and service-oriented manufacturing process networks*** [by modeling single manufacturing assets as services similar to SaaS].



Volume-Variety-Cost relationship in manufacturing paradigms [*Sylvain Kubler et al., Springer SCI, 2016*]

- **Craft Production**: specific customer order, allows *high product variety and flexibility* (highly skilled craftsmen treated each product as unique). Slow and expensive model.
- **"American System"**: *standardized parts for products*.
- **Mass Production**: making of products at lower cost through *large-scale manufacturing*. Limited variety of products, time and cost reduction.
- **Lean Manufacturing**: multi-dimensional approach with *wide variety of management practices* (JIT, quality systems, work teams, cellular mfg.)
- **Mass Customization**: combines business practices from Mass Production and Craft Production → a *customer-centric model*. Based on theories & technologies making manufacturing systems intelligent, faster, more flexible and interoperable (→ IMS).
- **Cloud Manufacturing**: *service-oriented networked product development model.* Service consumers can configure, select, and use customized product realization resources and services [from CAE, CARE software to reconfigurable manufacturing systems].

Cloud Manufacturing Taxonomy



CMfg Taxonomy: underlying concepts and technologies, *Sylvain Kubler et. al, Springer SCI, 2015*

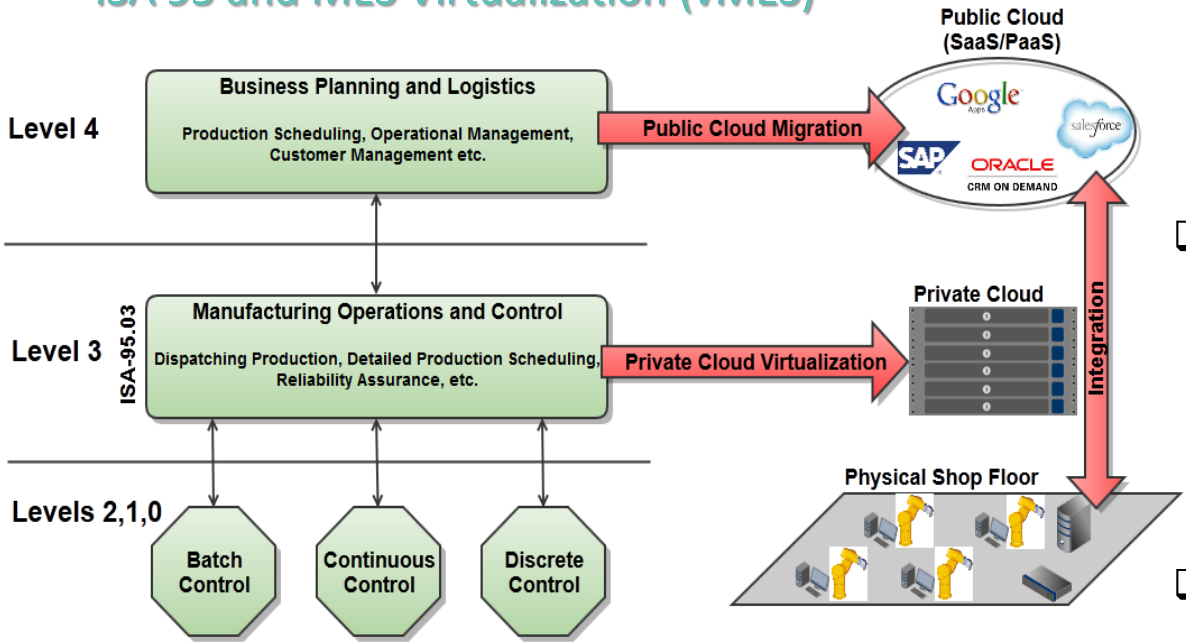
CMfg applications:

1. **Manufacturing resources** and **abilities** can be intelligently **sensed** & **connected** into a *wider Internet*, and automatically managed and controlled using IoT and (or) Cloud solutions.
2. **IoT** - core enabler for *product-centric control* and increasing *servitization*.

- **CMfg**: all *manufacturing resources and abilities* for the manufacturing life cycle - *provided in different service models*
- **IoT**: novel network architectures seamlessly *integrating smart connected objects* and distinct *cloud service providers*
- **Product Centric Control**: *the product directly requests processing, assembly and materials handling from available providers* while it is in execution & delivery. The **product**:
  - Monitors its own status;
  - Notifies the user when something goes wrong
  - Helps the user to find and access the necessary product-related models & and info. from manufacturers in the CMfg ecosystem
  - Eases the synchronization of product-related data and models
- **Direct Digital Manufacturing**: *novel 3D printing and 3D modeling technologies*. The *need for tooling and setup is reduced* by producing parts directly based on a *digital model*.

CMfg: MES and Shop floor Virtualization

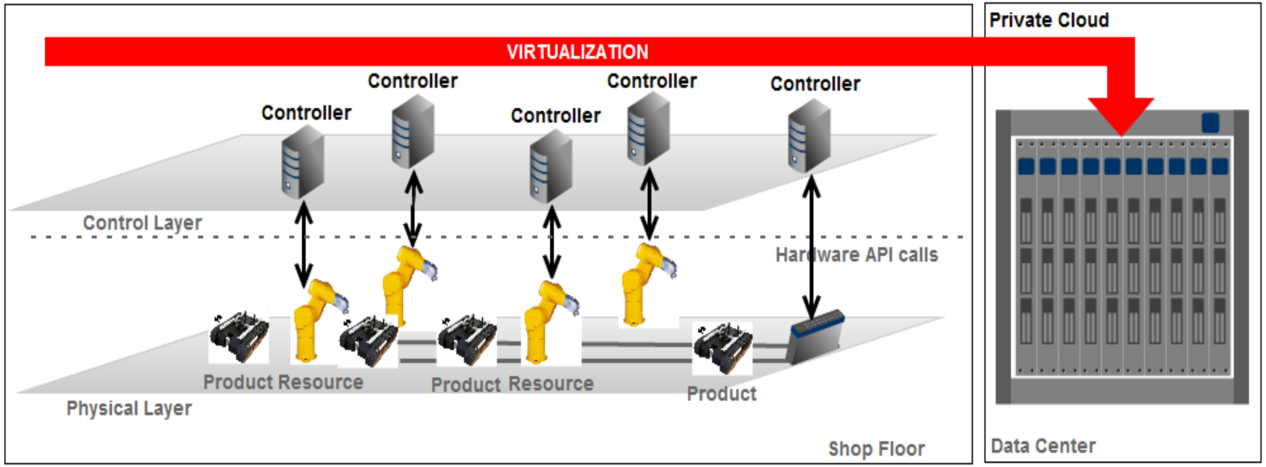
ISA 95 and MES Virtualization (vMES)



Octavian Morariu, SOHOMA'14, Nancy

- **Levels 0, 1 and 2**: process control levels, directly control the physical shop floor equipment in order to execute the current production operations for product execution
- **Level 3:** MES level , consists of activities executed to prepare, monitor and complete the production process on levels 0, 1 and 2 (planning, scheduling, monitoring, CAQC)
- **Level 4**: ERP level that executes the financial and logistic activities

CMfg: MES and Shop floor Virtualization



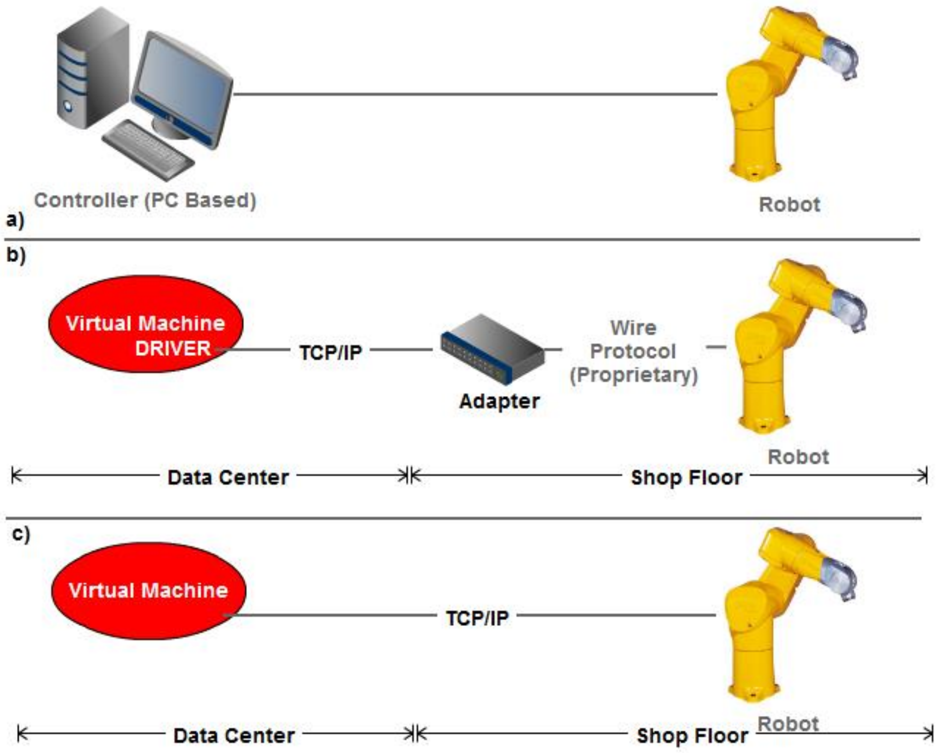
[*IBM CloudBurst platform, University Politehnica of Bucharest, 2016*]

- This separation between hardware and software provides high flexibility and agility to the manufacturing solution.

- The basic concept of MES and shop floor virtualization involves *migration of all workloads* that were traditionally executed on physical machines located on the shop floor to the data centre, specifically to the private cloud infrastructure as virtual workloads.

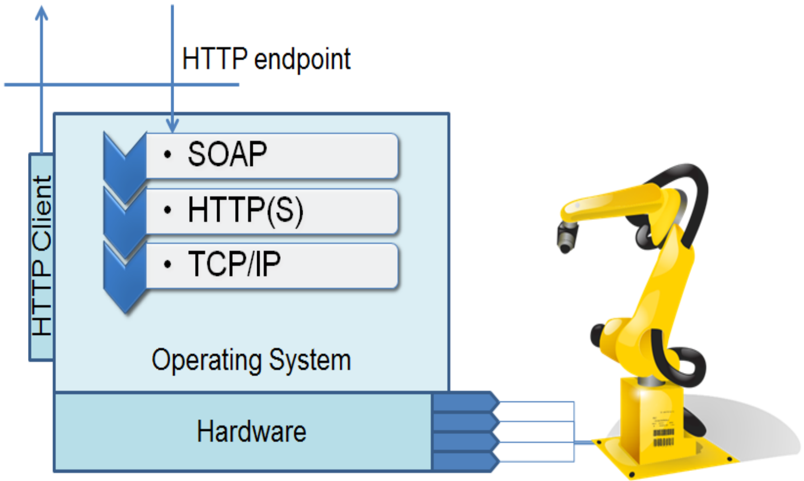
- The idea is to run all the control software in a virtualized environment and keep only the physical devices on the shop floor.

CMfg: Shop floor Virtualization



- a) Initial state without virtualization
- b) and c) : two alternatives to *workload virtualization*:
  - b): A **proprietary wire protocol** is used, the virtualization process involves a **local controller on the shop floor providing the physical interface** for the wire protocol
  - c): Resource can be accessed by **TCP/IP directly**: **virtualizing the workload directly** and mapping a virtual network interface to it, which will be used to control the resource.

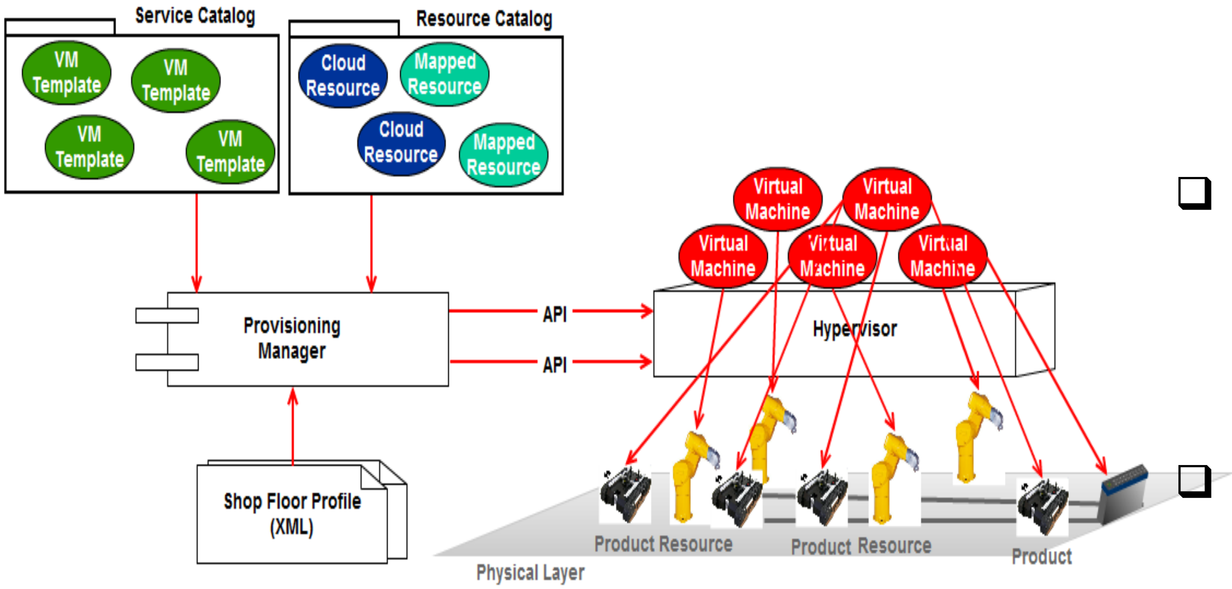
CMfg: Virtualization of Intelligent Product (embedded on IED)



General architecture of SOA-enabled device for CMfg
[*O. Morariu, Th. Borangiu, SOHOMA 2015, IfM Cambridge, UK*]

- Virtualization: allows **moving the processing from the product pallet device to the cloud environment**, either in a dedicated workload or in a **shared workload**
- The **shared workload model is best suited for multi-agent system** based MES implementations.
- The virtualization process: implies the mapping of the physical sensors and actuators installed on the product pallet to the virtual machine by **using a thin hypervisor on the product pallet and WI-FI network connection**.

CMfg: Shop floor Profiles and Provisioning Manager

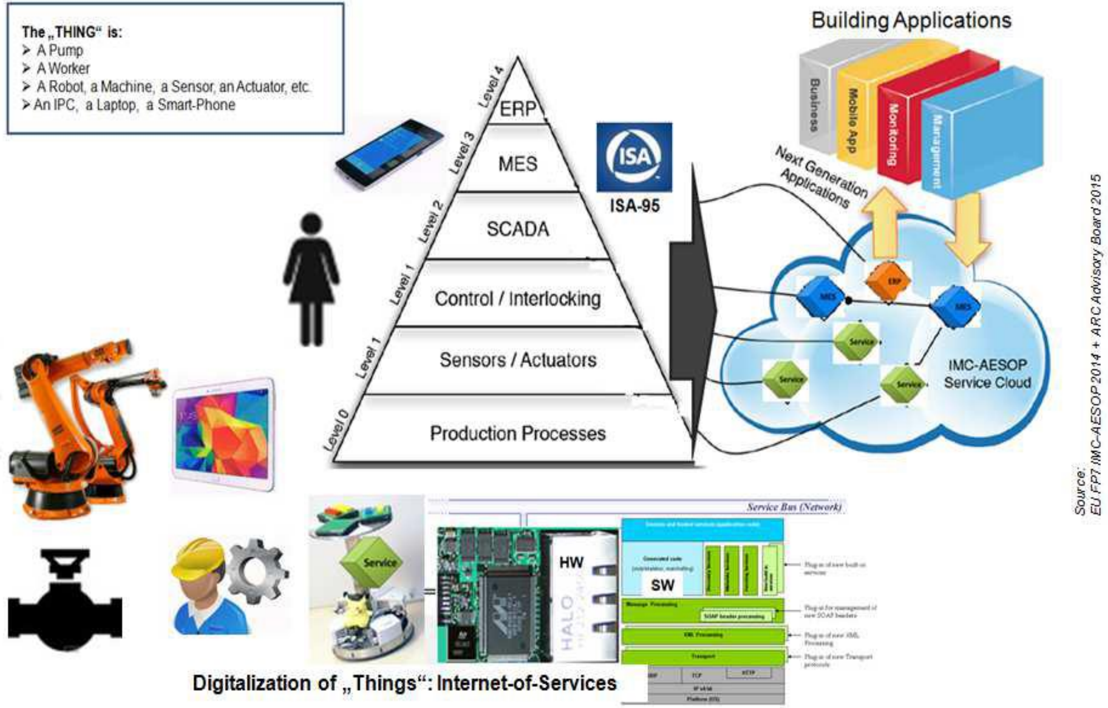


[*IBM CloudBurst platform, University Politehnica of Bucharest, 2016*]

The PM is responsible for **parsing the shop floor profiles** and **creates the workload instances** based on their definition in the private cloud environment. To do so, it calls the **Hypervisor APIs**.

- The binding between workload templates and virtualized resources is done using **shop floor profiles**.
- Shop floor profiles are XML files and contain a complete or partial definition of the manufacturing system virtual layout and mappings.
- The shop floor profile is workload centric and basically contains a list of workload definitions.
- The shop floor profiles are loaded by the **provisioning manager** (PM).

Manufacturing Cyber-Physical Systems and the Industrial Internet of Things

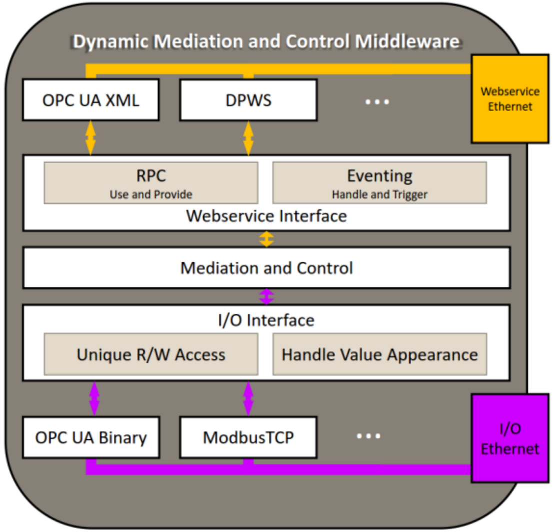


Building applications in the Service-Cloud of
Digitalized Things in Industrial Cyber-Physical Systems

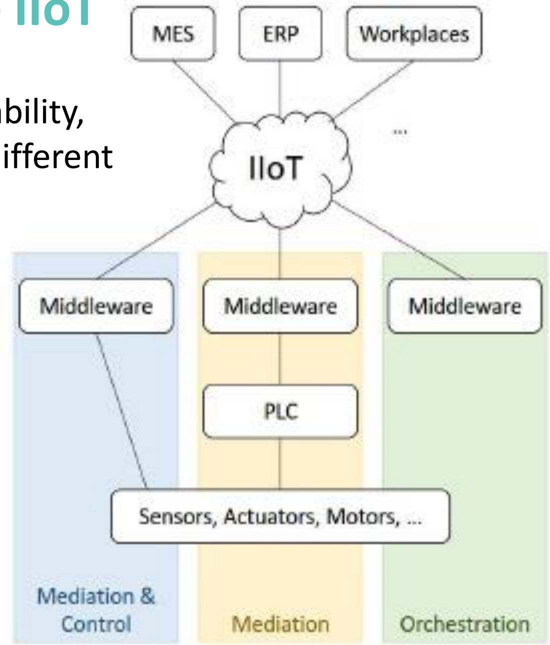
- Cyber-Physical Systems (CPS): ICT systems (sense, actuate, compute, communicate) *embedded in physical objects*, *interconnected* through several networks including the Internet, and providing businesses with a wide range of innovative applications based on digitalized data, information and services.
- Big data (digital and machine-understandable): facilitates the creation of new functionalities and applications based on the *collaboration of heterogeneous systems in the cyberspace*, many times represented in *cloud of services.*
- Web services implement these ecosystems.
- Industrial Internet-of-Things (IIoT): structural & behavioral infrastructure *integrates legacy manu-facturing devices to the web service ecosystem*.

Manufacturing CPS and the IIoT

IIoT needs connectivity and interoperability, communication integration between different kinds of things.



Kliesing, Colombo, IEEE INDIN2016



Class 1 LL protocol - "**I/O**": Modbus TCP, Profibus, OPC UA Binary
Class 2 HL protocol - "**Webservice**": DPWS, OPC UA

Mediation and control middleware

- Offers *dynamic combination* of: (HL) web services, composite data; (LL) handle value appearance, event notification
- Middleware software based on unified *interfaces for the interoperability* with protocols within classes 1 LL and 2 HL
- *Possible roles* enabling the integration of existing manufacturing systems into IIoT:
  - ✓ Direct connectivity to a fieldbus: used to control a manufacturing system with its actuators, sensors and all other devices
  - ✓ Mediation from HL web service commu-nocation to LL fieldbus communication
  - ✓ Orchestration of foreign web services, offered as a service to other IIoT members, like MES or ERP systems.

New business models. Big Data and the Contextual Enterprise. Industrie 4.0

Big Data in the Manufacturing Value Chain

Production enterprises using big data across the value chain. Big data has the potential to enable *7 performance improvement levers for manufacturers* (PL), affecting the entire value chain; these levers are related to the 5 components of the Manufacturing Value Chain (MVC), [*McKinsey Global Institute, 2014*]:

MVC 1. Research & Development and Product Design

1) Product lifecycle management (PL1): PLM platforms integrate datasets from multiple systems to enable effective collaboration. Examples: platform for "*co-creation*" to create new products; OEM *co-creates designs with suppliers*. Designers and manufacturing engineers can share data and quickly and cheaply *create simulations to test designs,* the *choice of parts and suppliers,* and *related manufacturing costs*.
2) Design to value (PL2): extract crucial insights from the increasing volume of customer data to *refine existing designs* and help *develop specifications for new models*.
3) Open innovation (PL3): inviting external stakeholders to *submit ideas for innovations* or even *collaborate on product development* via Web-based platforms.

Big Data in the Manufacturing Value Chain

MVC 2. Supply Chain Management

4) **Advanced demand forecasting and supply planning**: Data from across the value chain (through collaborative supply chain management and planning) allow manufacturers to *shape demand and smooth spiky order patterns.*

MVC 3. Production: The IIoT allows manufacturers to use **real-time data from sensors** to track parts, monitor machinery, and guide actual operations

5) **Digital factory**: Taking inputs from product development and historical production data), manufacturers can apply advanced computational methods to *create a digital model of the entire manufacturing process* (to be used to design and simulate efficient production).

6) **Sensor-driven operations**: optimize operations by *embedding real-time data from networked sensors in the supply chain and production processes*.

MVC 4. Marketing and sales: sensors embedded in products that can generate **data about actual product usage and performance** (*real-time input on emerging defects and adjust the production process*).

MVC 5. After-sales services: using sensor data from products once they are in use to *improve service offerings*: create proactive smart preventive maintenance service packages.

Big Data in the Manufacturing Value Chain

Big data levers can deliver value along the manufacturing value chain in terms of cost, revenue, and working capital

	Lever examples	Impact: Cost	Impact: Revenue	Impact: Working capital	Subsector applicability
R&D and design	• Concurrent engineering/PLM[1]	+20–50% PD[2] costs	-20-50% time to market		High – Low complexity
	• Design-to-value • Crowd sourcing	+30% gross margin -25% PD[2] costs			High – Low complexity B2C – B2B
Supply chain management	• Demand forecasting/ shaping and supply planning	+2–3% profit margin		-3–7% onetime	FMCG[3] – Capital goods
Production	• Sensor data-driven operations analytics	-10–25% operating costs	Up to +7% revenue		Capital intense – CPG[3]
	• "Digital Factory" for lean manufacturing	-10–50% assembly costs	+2% revenue		Capital intense – CPG[3]
After-sales services	• Product sensor data analysis for after-sales service	-10–40% maintenance costs	+10% annual production		Capital intense – CPG[3]

1 Product lifecycle management.
2 Product development.
3 Fast-moving consumer goods and consumer packaged goods.
SOURCE: Expert interviews; press and literature search; McKinsey Global Institute analysis

1. Big data enables *innovative services* and *new business models* in manufacturing. Sensor data have made possible innovative after-sales services.
2. Investments required to develop interfaces and protocols to *share data effectively across the extended enterprise*
3. Standardization of interfaces according to SOA and ESB concepts; *interoperability of* HL (business) and LL (shop-floor devices) *communication protocols*
4. Need to have a *free interchange of data* among marketing & sales, R&D and production
5. Many of the Big Data levers also require access to *data from different players in the value chain*.

Emerging Model for Contextual Enterprise: from Mobile to Cognitive

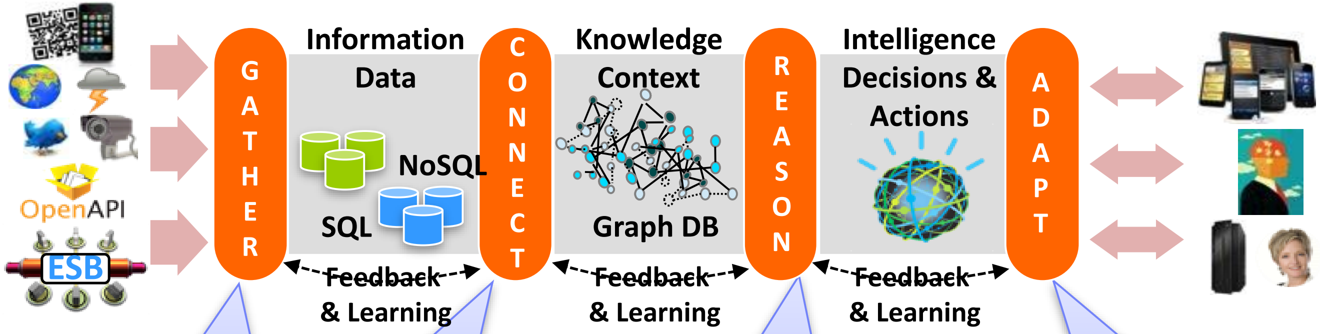
IBM experience with data integration, analytics, and cognitive computing is leading to an *emerging model for contextual systems* that can be deployed across the ecosystem from mobile to cloud

- Data integration: [InfoSphere, EDW, MDM]

- Analytics [BigInsights, Streams, SPSS, Cognos]

- Cognitive Computing [Watson]

- Support for pervasive data-centric security, privacy, provenance, and latency appropriate delivery



Gather

Collect all relevant data from a variety of sources, keep everything you can as long as you can.

Connect

Dynamically extract features and create metadata from diverse data sources to continually build and update context.

Reason

Analyze data in context to uncover hidden information and find new relationships.

Analytics add to context via metadata extraction, use con-text to exploit information.

Adapt

Compose recommended interactions, use context to deliver action.

Learn from user behavior interaction patterns to improve context.

Industrie 4.0

- German governmental initiative to support the processes connected with the industrial revolution based on CPS (2013): enterprise integration, networking, digital engineering
- General Goals:
  - Efficient control of complex distributed systems as a society of autonomous units
  - Integrating virtual world (where each physical element incl. sensors, products, human operators, robots is represented by a SW unit/information counterpart) with the physical world (CPS)
  - Optimize decision making and efficiency (Cost Effectiveness, High Performance and Energy Efficiency)
  - New business models and approaches to value creation
- Followed by Advanced Manufacturing Partnership 2.0 (USA), Made-in-China (China), Industrial Value Chain Initiative (Japan)….

Industrie 4.0

New directions opened:

- Philosophy of MAS applied to manufacturing, planning, engineering, distribution channels, life cycle management…
- Unified communication environment (LL, HL, ptp/WS, Internet): IIoT, …..
- Networked embedded systems: access to elements of the physical world any time from any level (CPS)
- Cloud systems covering and providing services to all components of the architecture
- Open SOA used in implementations
- No standards, but rather recommended platforms/environments – but FIPA standards still used where appropriate…..IEEE Standard for Ontologies in Robotics P1872-2015

Challenges:

- Big Data for real time shop floor processes; storing data: velocity, variety, veracity
- Communication: intelligent embedded shop floor devices
- Security: certificate generation at run time using OpenSSL and JADE; PKI-based solution

Conclusions

- Industry 4.0:
  - Stimulates all the structural and behavioral models integrating Virtual Word and Physical World in the Internet; Industrial IoT; RT communication; total integration
- Results in Distributed Intelligent Control strongly influenced the Industry 4.0 visions:
  - Supports decentralized way of thinking, system approach, integration of autonomous units, system reconfigurability and scalability….
- MAS is the backbone of the Distributed Intelligent Control – MAS is the key philosophy behind the Industry 4.0,but
  - Additional techniques and tools are needed for enhancements: Big Data, Ontologies, simulation tools, SCADA and security modules; predict the unexpected; security; FT & HA
- SOA – dual to MAS, used more and more as implementation of MAS in different layers; provides interoperability between enterprise business, MES and shop floor layers
- CMfg – new models for service delivery – DDM; shift towards customer- and service-oriented manufacturing process networks

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GMR

Conference Chair:

Paulo Leitão, Polytechnic Institute of Bragança, PT
José Barata, New University of Lisbon, PT

The Workshop's Theme

The theme of the SOHOMA'16 Workshop is "Distributed, agent-based intelligent control in service-oriented architectures for the digital transformation of manufacturing".

Session Code	Title of Special Session SOHOMA'16	Proposed by
EngHIReconf	"Engineering and Human Integration in Flexible and Reconfigurable Industrial Systems"	José Barbosa, (PT) Armando Colombo, (DE) Matthias Foehr, (DE) Giacomo Tavola, (IT)
CCPMS	"Cloud and Cyber-Physical Systems for Smart Manufacturing"	Theodor Borangiu, (RO) Radu Băbiceanu, (USA) Florin Anton, (RO) Octavian Morariu, (RO)
SusIMS	"Sustainability issues in intelligent manufacturing systems"	Flavio Tonelli, (IT) Adriana Giret, (SP) Damien Trentesaux, (FR)
PHMCPS	"Should Intelligent Manufacturing Systems be dependable and safe?"	William Derigent, (FR) Alexandre Voisin, (FR) André Thomas, (FR)

Workshop Topics

- Customer-oriented logistics
- Intelligent Manufacturing Systems
- Modelling of discrete event systems in manufacturing
- Multi-Agent Systems in industry
- Distributed Intelligence and product driven automation
- Holonic Manufacturing Execution Systems
- Intelligent Products: concepts, architecture, implementation, use cases
- Internet of Things / Physical Internet
- Swarm intelligence in manufacturing
- Industrial Internet and digital manufacturing
- Dynamic and green infrastructure for sustainable manufacturing
- Operational research applications in CAD/CAM/CAE
- Predictive maintenance and risk management in manufacturing
- Mixed production planning and scheduling
- Predictive resource maintenance
- Virtual factory, supply chains and logistics
- Manufacturing Integration Framework
- Cloud Manufacturing and resource virtualization
- Computing and Service Oriented manufacturing
- Servitization and Product-Service Systems (PSS)
- Multi-robot systems in manufacturing
- Bio-inspired theories for smart manufacturing and evolutionary robotics
- Big Data and the contextual enterprise
- Cyber-Physical Manufacturing Systems and Industry 4.0

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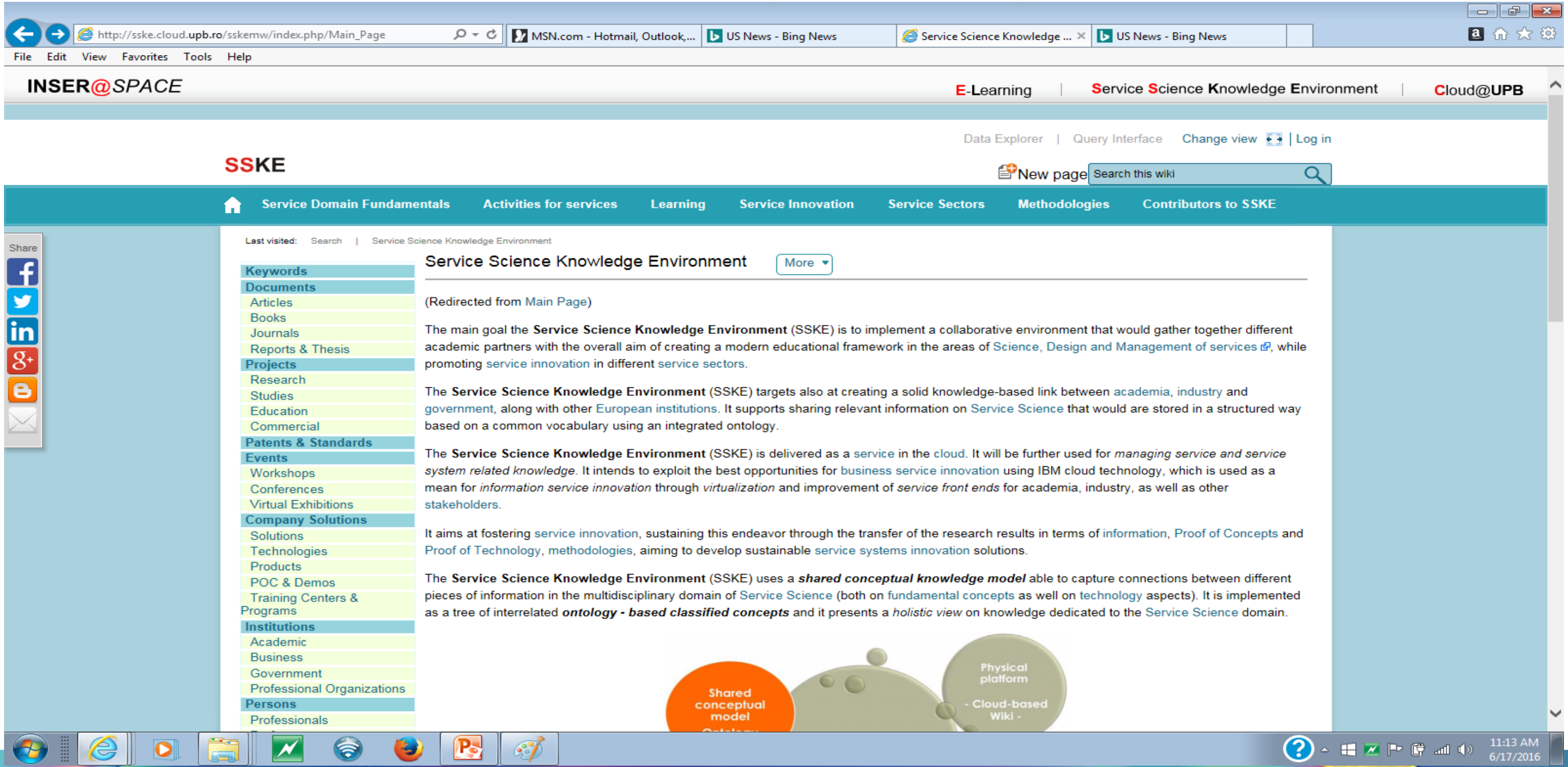

Thank you!