50 YEARS OF MANUFACTURING AT CAMBRIDGE

Setting out Digital Transformations - A supply chain perspective

5th June 2017

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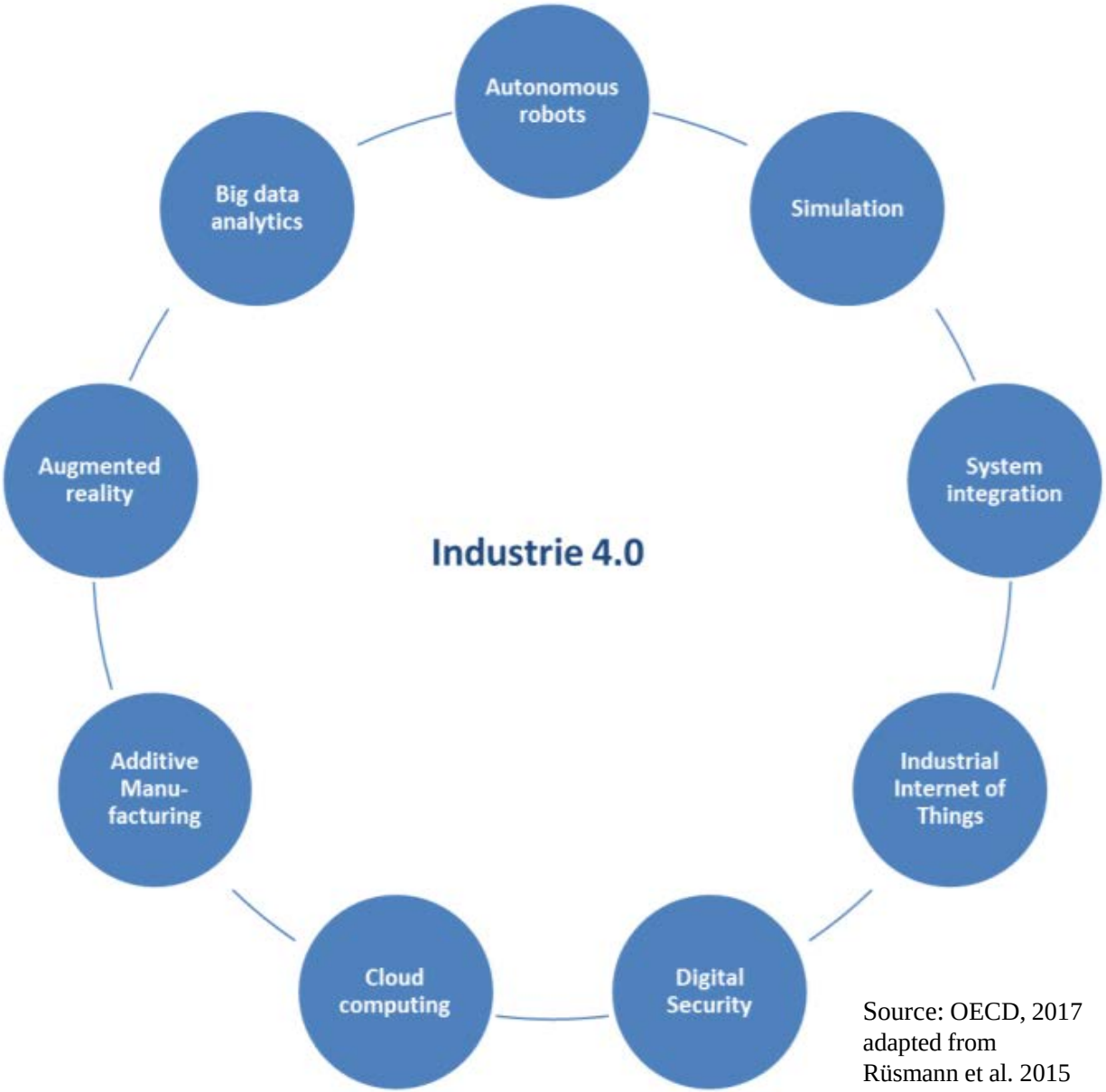
Overview

- Conceptualizing the digital supply chain
- Emerging digital scenarios
  - digital transformations across the end-to-end SC
  - observations from industry
  - challenges and opportunities
- Experimentation in digital supply chains – some examples regarding patient centric Pharmaceuticals
  - Process, Pack, Patient-centric Apps
- Future research

Industrie 4.0

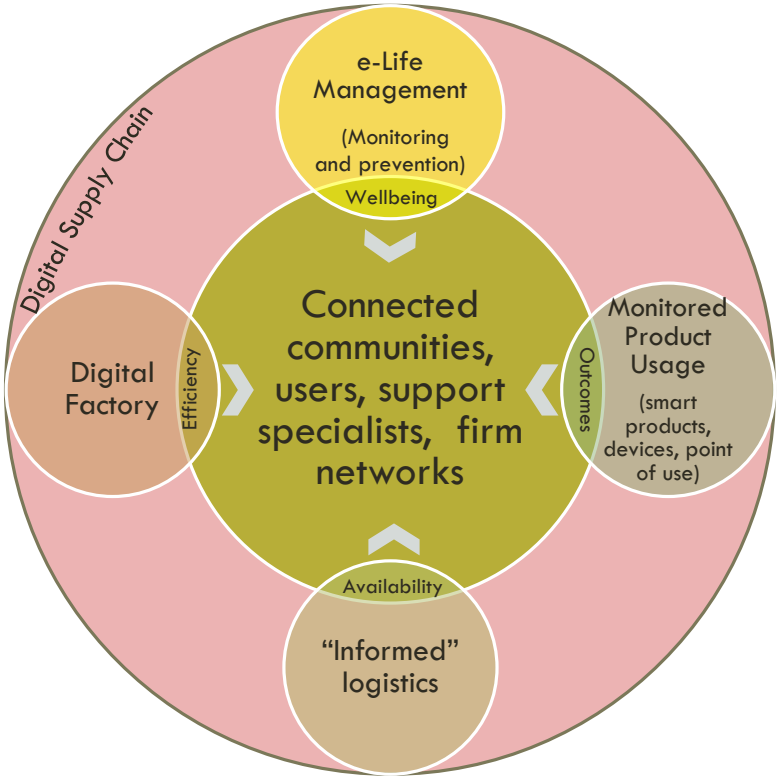
Nine technologies ‘transforming’ industrial production

But how do these impact the supply chain?



Source: OECD, 2017 adapted from Rüsmann et al. 2015

Conceptualising the digital supply chain - Framing the literature



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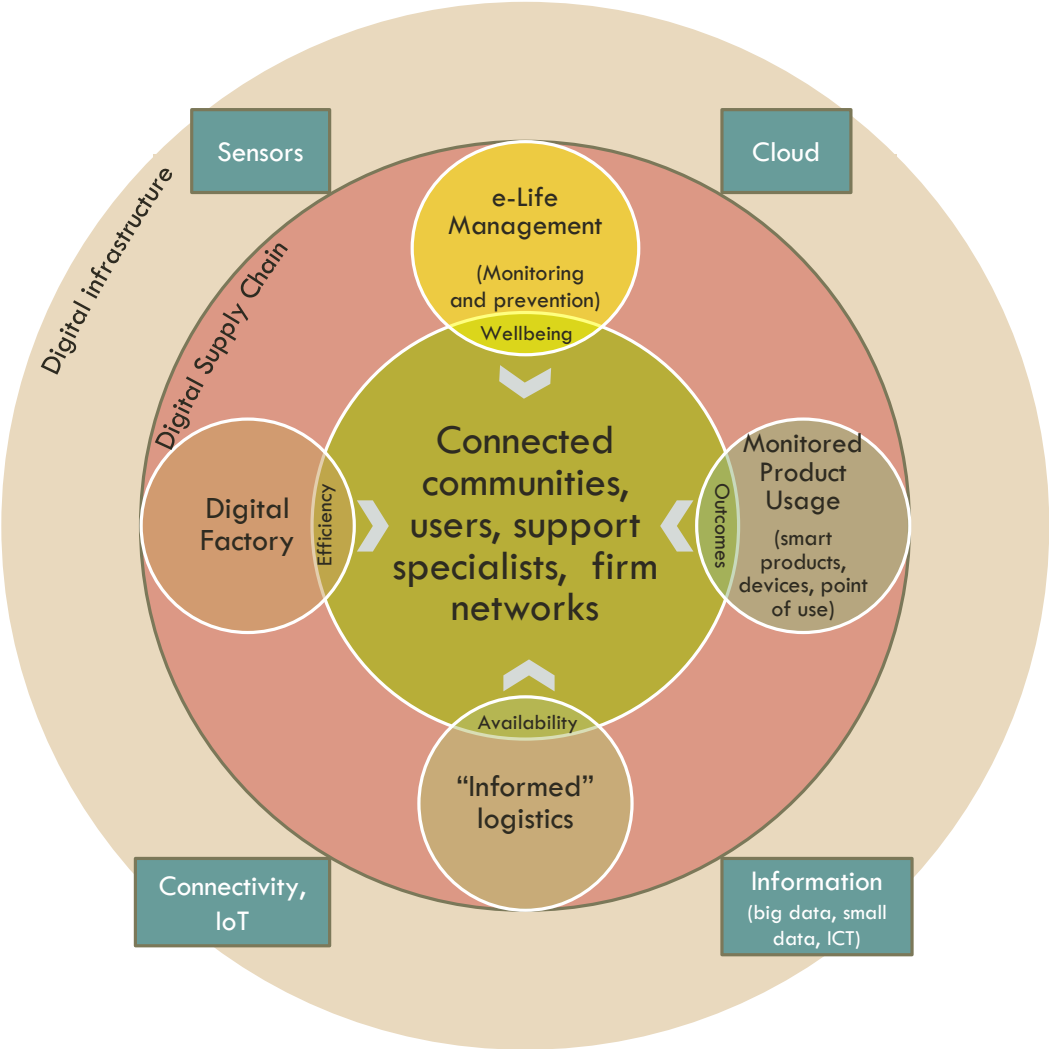

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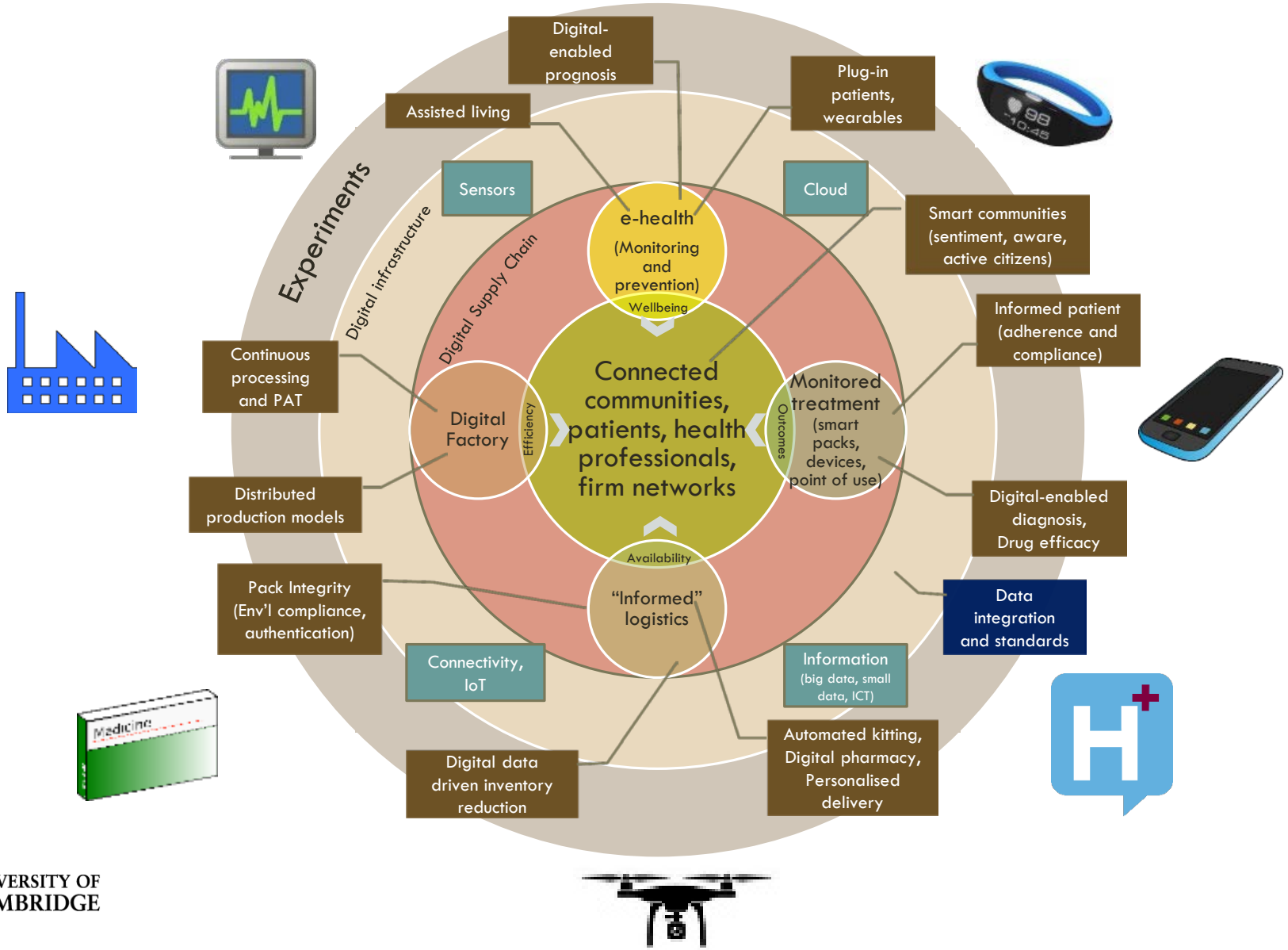
DIGITAL SUPPLY CHAINS – PHARMACEUTICALS

ReMediES
RE-configuring MEDIcines End-to-end Supply



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Industry problem driven research and collaboration e.g.

Non-competing partners Digital SC peer group
(to share initiatives, define needs and shape the research agenda)

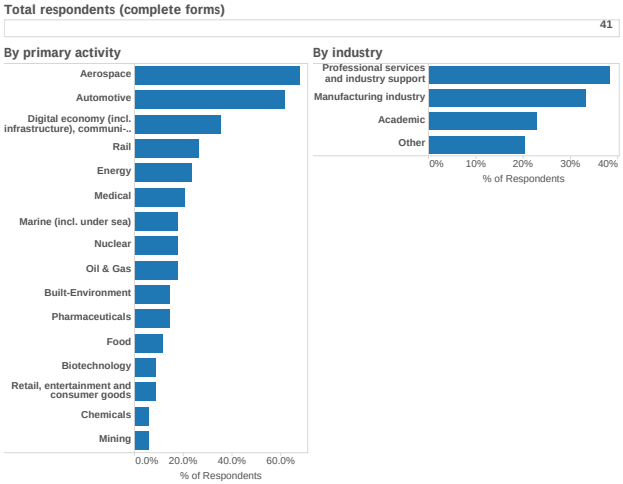
ABB · CATERPILLAR · Electrolux · Rolls-Royce · PHILIPS · GRUNDFOS · IKEA · LEGO · wavin · gsk GlaxoSmithKline

Pre-competitive Digital SC (Pharma) sector collab'n
(to develop new capability, link with IfM research)

AstraZeneca · gsk GlaxoSmithKline · UNIVERSITY OF CAMBRIDGE · cpi · SAP · INTERSYS

Understanding the Digital SC context – open access
(to explore new opportunities, challenges facing industry)

bsi.



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Architecting the digital supply chain

the implications of digitalisation on global manufacturing

29 and 30 September 2016, Møller Centre, Cambridge

The annual Cambridge International Manufacturing Symposium is the chance to hear from world-leading business figures and thinkers on the challenges facing modern manufacturing. It is a unique event that brings together senior industrialists and leading academics to share approaches and experiences in this strategic domain, covering the following key themes:

- Supply chain transformation and E2E network integration
- Technology-disrupted supply chains
- Impact of sustainability and the circular economy
- Risk and resilience of global supply networks
- Service supply network design
- Emerging multinationals (EMNCs)
- Digitally-enabled customer-centric supply chains
- Corporate lean programmes - new horizons
- Next generation global sourcing

The Symposium includes keynote speakers from the world's leading companies and universities, mixed with informal networking opportunities. It aims to create a growing community of international manufacturing enthusiasts and to inspire 'thought leadership' in this exciting field.

Confirmed speakers for the Symposium include:

- **Haydn J Powell**, Global Supply Chain Manager, **Caterpillar Inc**
- **Per Berggren**, Industrial Strategy Manager, **IKEA Industry**

Previous speakers include:

- **Rolls Royce, Coca-Cola, Cisco, Jaguar Land Rover, Johnson Matthey, Schneider Electric, TATA, LEGO, Unilever, Bombardier, Huawei, Oxford Instruments, BIS, Genzyme, Nestlé, Cambridge University Press.**

To keep up to date with the latest announcements and programme details, please visit

www.ifm.eng.cam.ac.uk/events/cimsymposium16 | Twitter: @ifmcambridge

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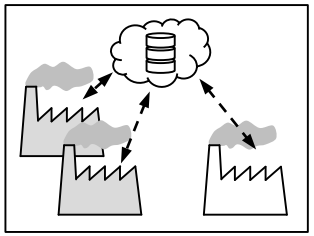
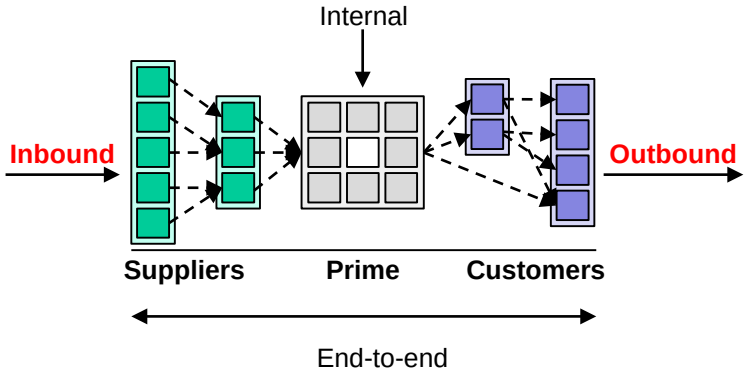
Future digital supply chain scenarios

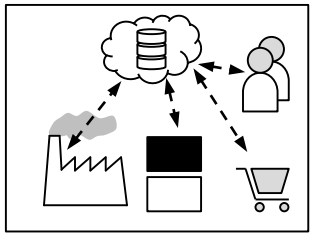
What types of firms could benefit from these digital transformations?

1. Automated e-Sourcing





6. e-Commerce Fulfilment



1	**Automated e-Sourcing** Seamlessly connected automated replenishment in line with real-time KPI monitoring, with predictive disruption analytics (all tiers back to mine)

6	**e-Commerce Fulfilment** Web-based order management (configuration, pricing etc.) and inventory deployment to multiple points of sale, covering last-mile and direct delivery (all tiers through to end users)

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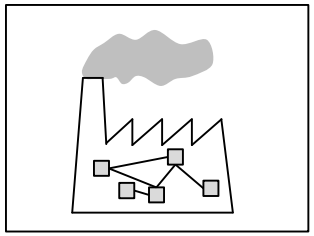
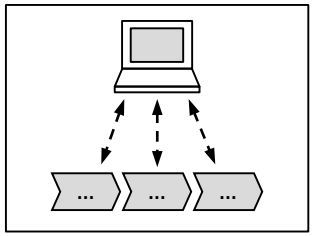
Future digital supply chain scenarios

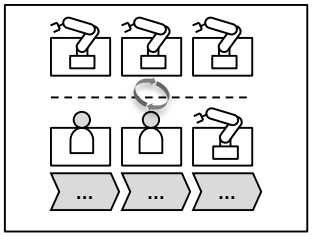
2. Digital Factory Design



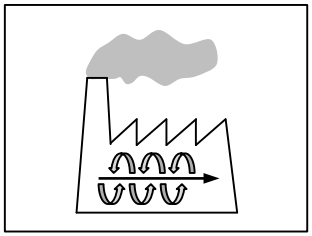
3. Real-time Factory Scheduling

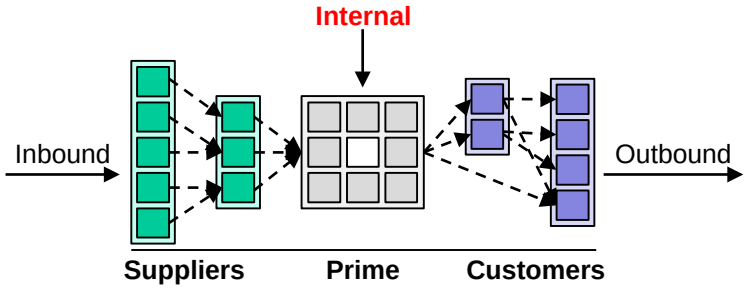


4. Flexible Factory Automation



5. Digital Production Processes





2	**Digital Factory Design** Digital 3D modelling systems for factory layout design, process and material flow simulation
3	**Real-time Factory Scheduling** Advanced factory execution systems with sensor-enabled, smart devices, real-time data KPI monitoring, predictive maintenance
4	**Flexible Factory Automation** Advanced manufacturing plant/machine reconfiguration, scale flexibility, varied levels of human-robot-collaboration
5	**Digital Production Processes** Application of digital production processes (e.g. additive manufacturing, continuous processing) with advanced process analytics

What types of firms could benefit from these digital transformations?

Future digital supply chain scenarios

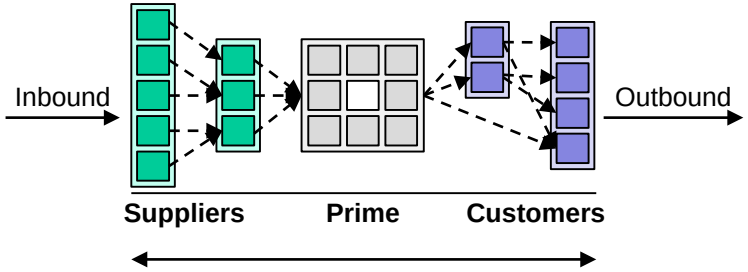
What types of firms could benefit from these digital transformations?

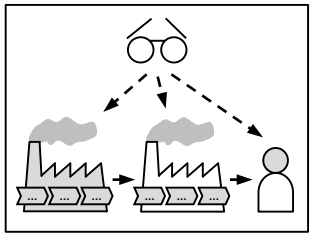
7 Extended Supply Chain (near) real-time Monitoring Extended 'end-to-end' supply chain visualisation 'watch towers' for near real-time monitoring and decision making

8 Digital Product Quality Digital product quality management systems for connecting 'traceability islands' back from customers to suppliers (root cause analytics)

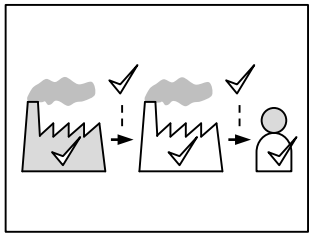
9 Digital Supply Network Design Design tools to architect supply network configuration – optimisation and visualisation of site location, capacity, inventory etc.

10 Product Lifecycle Management Nextgen PLM systems that provide accurate, up-to-date product information accessible throughout the value chain and product lifecycle

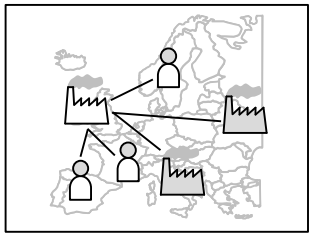




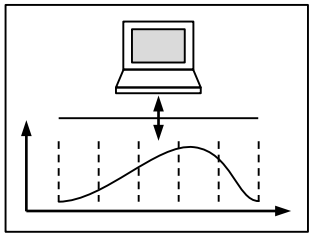
7. Extended Supply Chain (near) real-time Monitoring



8. Digital Product Quality



9. Digital Supply Network Design



10. Product Lifecycle Management

Future digital supply chain scenarios

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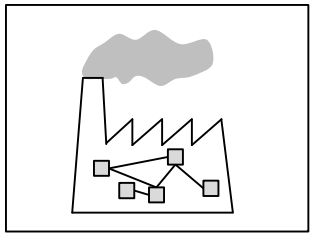

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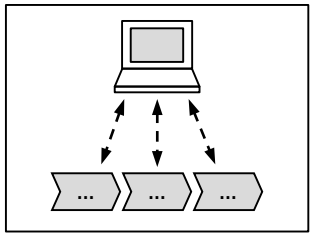

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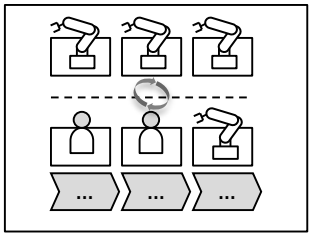

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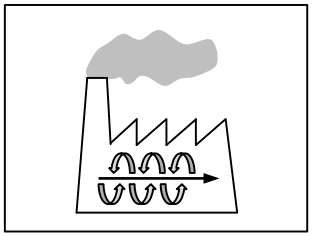

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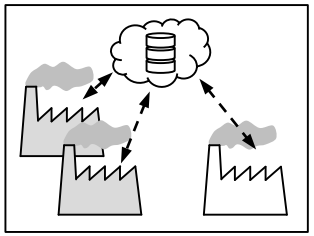

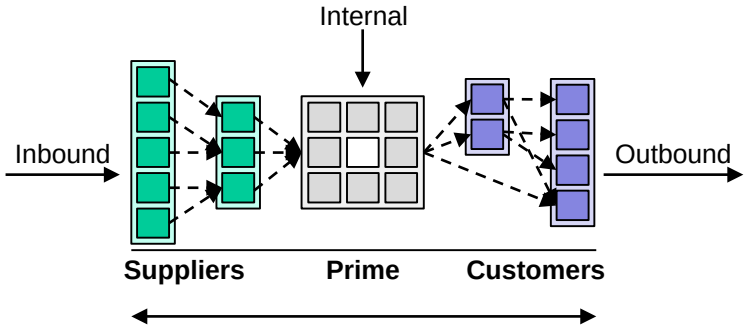

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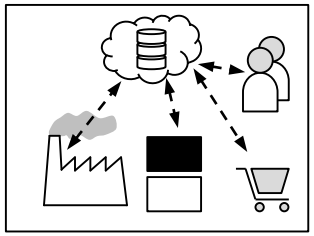

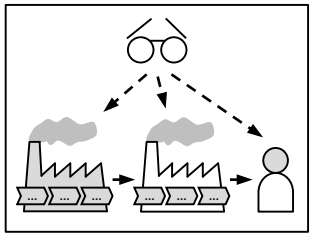

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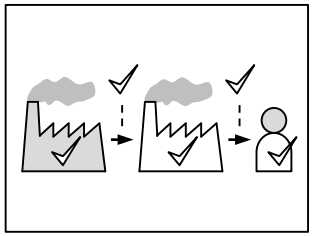

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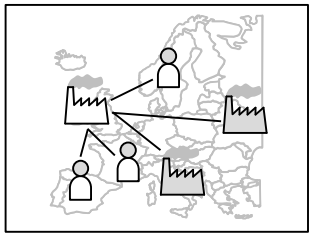

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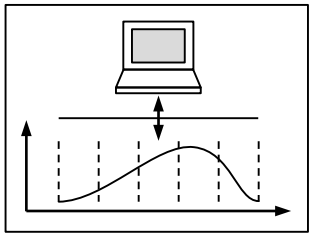

10. Product Lifecycle Management

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Classification of future digital supply chain scenarios

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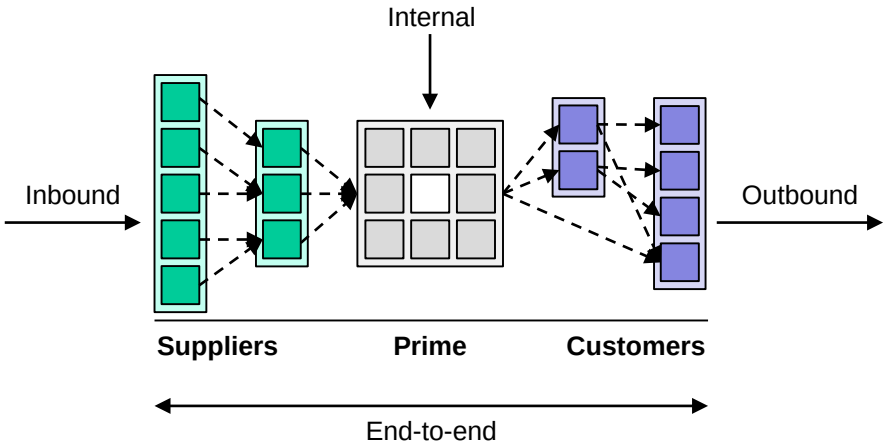

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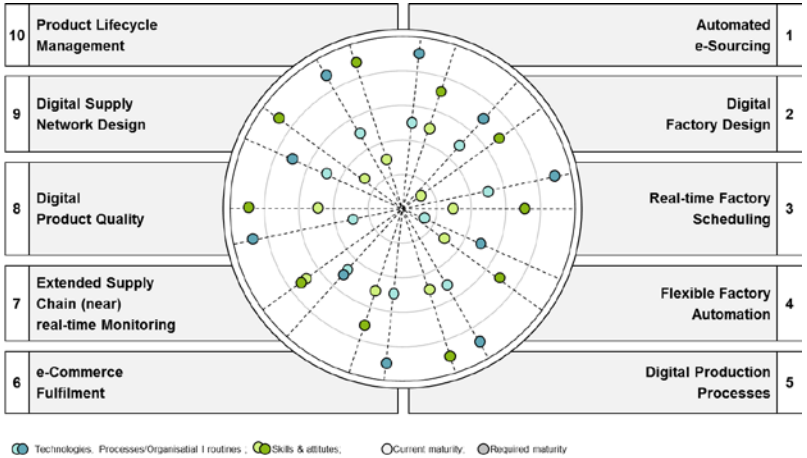
Definition (and assessment) of Digital SC maturity



	Maturity levels				
	1	2	3	4	5
Technologies[1], **Processes & organisational routines**[3]	Basic technology principles, processes observed and reported	Technology concept piloted, Processess selectively applied	Technology validated/ demonstrated Standardised processes	Technology/ Processes routinely deployed with predictable outcomes	Technology/ Processes optimised to full performance limits
Skills & attitudes[2]	Ad-hoc inconsistent practices / basic understanding, accidental implementation	Selective deployment of repeatable practices, nascent understanding, with product demonstrators	Well defined competency-based practices, emergent understanding, with multiple applications	Measured & empowered practices / well understandood capabilities, dependable & routine implementation	Expert facilitated digital practices & innovation / leading understanding, proactive implementation

[1] based on Ford & Ryan 1981, Krubasik 1982, Sommerlatte & Deschamps 1985, Höft 1992, Mankins 1995 and Reinhart et al. 2011;
[2] Curtis et al. 2009; [3] based on Paulk et al. 1992, Fisher 2004, Srai & Gregory 2005 and Srai 2009

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Initial learnings from the Digital Supply Chains Consortium

- Requires holistic view of digital technology in the context of business systems, data, analytics, skills and attitudes
- Skills gaps often bigger than technology gaps – education!
- Major business opportunities are in:

FLEXIBLE SUPPLY CAPABILITY	Designing a new, flexible configuration utilising nextgen factory automation, factory modelling and strategic design of a responsive supply network to support customisation.
REAL-TIME SUPPLY VISIBILITY	Developing a 'single watchtower' approach that links factory scheduling and extended supply chain monitoring, and that supports a new vision for omni-channel fulfilment.
END-TO-END QUALITY ASSURANCE	Creating a fully integrated quality assurance repository across E2E supply to meet the customer promise on provenance and to eradicate root causes of quality non-conformance

Shaping the Future of Production - Six drivers on how production will play out through to 2030

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

Disrupted

Exponential takeoff of new technologies, early breakthroughs propelling artificial and machine intelligence to unimaginable levels. Hyperconvergence of key technologies already happening.

Damaged

Populism and unbridled protectionism translate into a profoundly uneven landscape for global production – widespread "islandization" of both economies and production systems.

Deterred

Advancement of production curtailed by pervasive cyber conflict between states and their proxies, owing to critical infrastructure being compromised and production processes being interrupted.

Devolved

Sharp deterioration in the physical environment prompts urgent action to mitigate the consequences, leading to production becoming more localised.

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*input to WEF 2017 – **Shaping the Future of Production***

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Distributed Manufacturing

'the ability to personalize product manufacturing at multiple scales and locations, be it at the point of consumption, sale, or within production sites that exploit local resources, exemplified by enhanced user participation across product design, fabrication and supply, and typically enabled by digitalisation and new production technologies'. *(Srai et al, 2015)*

- **Digitalisation** of product design, production control, demand and supply integration, that enable effective quality control at multiple and remote locations
- **Localisation** of products, point of manufacture, material use enabling quick response, just-in-time production
- **Personalisation** of products tailored for individual users to support mass product customisation and user-friendly enhanced product functionality
- **New production technologies** that enable product variety at multiple scales of production, and as they mature, promise resource efficiency and improved environmental sustainability
- **Enhanced designer/producer/user participation,** unlike the world of the artisan, enabling democratisation across the manufacturing value chain

Manufacturing Paradigms and Distributed Manufacturing

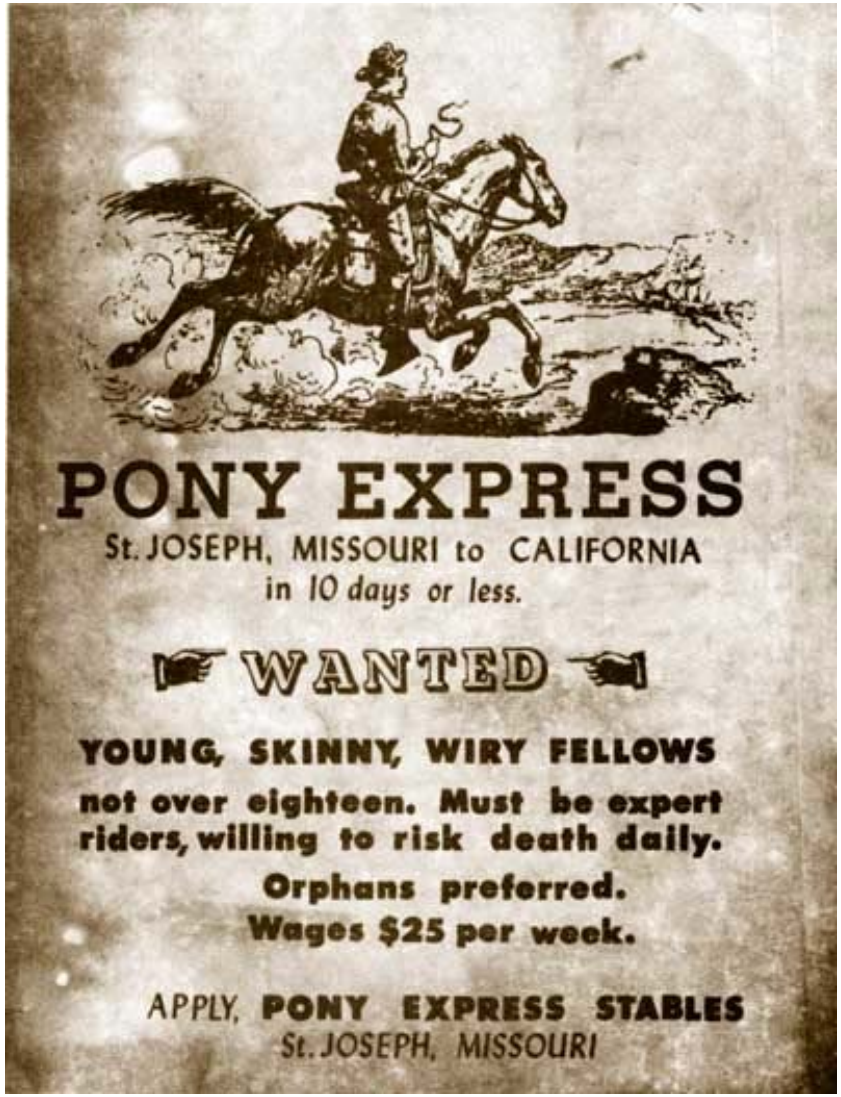
	Personalization	Digitization	Localization	New production technologies	Multi-user participation
Virtual Enterprise	No	Yes	Partly	Implied	No
Industry 4.0	Possible, but not at the individual level	Yes	No	Yes	Partly, but not end user
Grid Manufacturing	No	Yes	Partly	Implied	No
Concurrent Engineering	No	Possible	No	New	Partly, but not end user
Cloud based manufacturing	No	Yes	Partly	Implied	No
Smart manufacturing	Possible, but not at the individual level	Yes	No	Yes	Autonomous manufacturing, but does not involve end user
Distributed Manufacturing	Yes	Yes	Yes	Yes	Yes

Sources: Kohtala (2015), Matt, *et al* (2015), Kostakis *et al*, (2015), Ren *et al,* (2014), Srai et al 2016

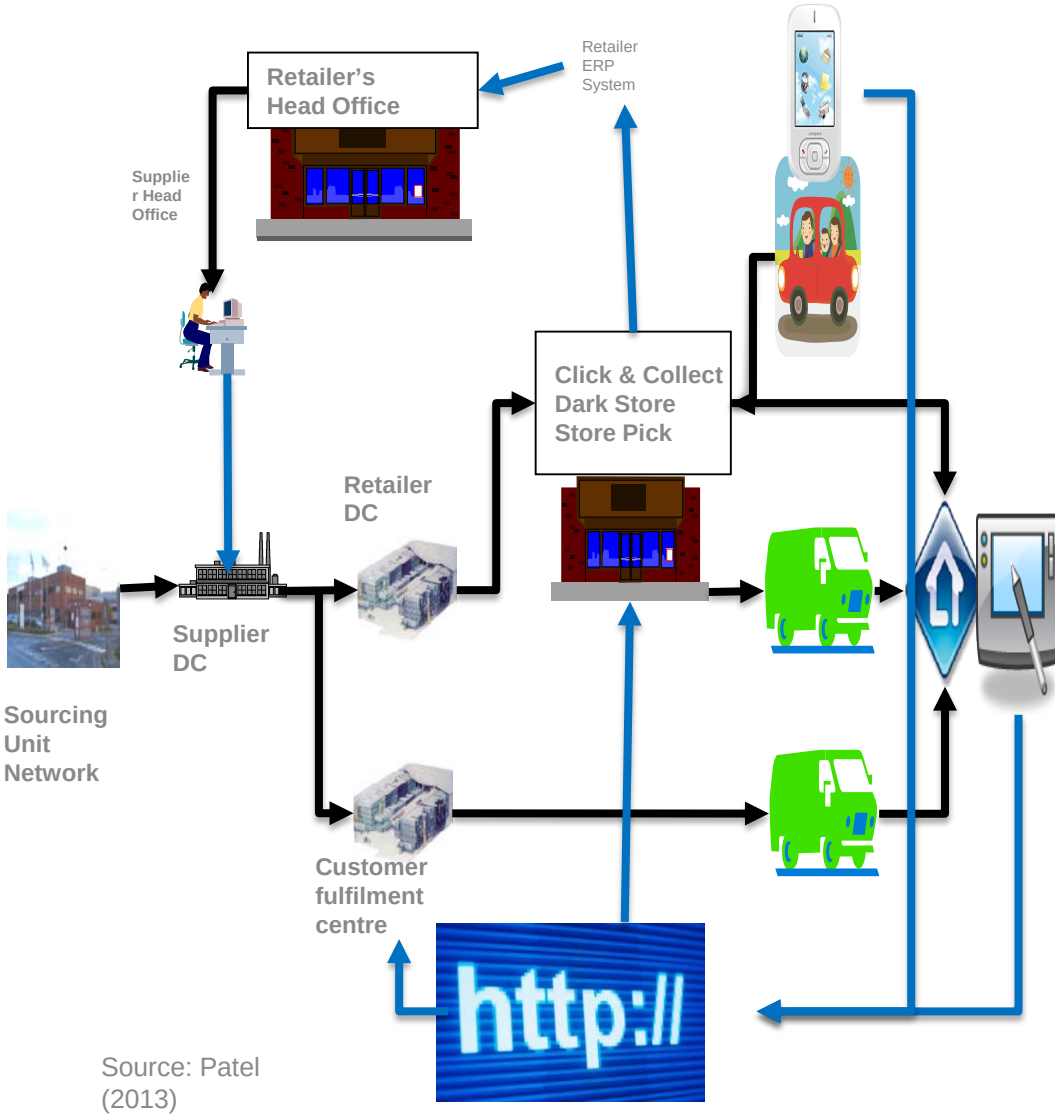
E-Commerce and Last mile logistics

- In retail consumer goods, LM costs > manufacturing & primary distribution
- Major retailers operating ‘dark stores’ in high population density areas
- Patient-centric healthcare – future of specialized medicine delivery
- Continued rapid growth in B2C delivery
- Mass customisation - lot size of one - future C2B models and ‘zero’ inventory

Last Mile Configurations

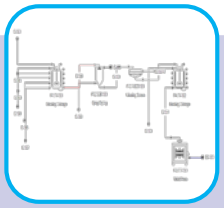


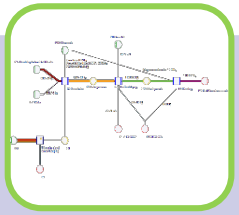
21C Last Mile Configurations

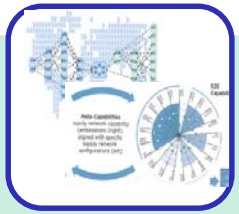


Source: Patel (2013)

TECHNOLOGY DRIVEN SUPPLY NETWORK DESIGN - DIGITAL TOOLSET







	e.g. Supply Chain Guru	e.g. SuperPro Designer	e.g. Umberto	e.g. CIM IfM models
Network Representation	Nodes: facilities; Arcs: sourcing policies	Nodes: equipment; Arcs: materials	Nodes: transformation Arcs: physical/cost flows	Nodes: tiers, markets; Arcs: SN relationships
Data retrieval capability	Labour, transportation, Tax	Equipment specs and cost, Labour, material properties	Substance flows; unit processes; some prices	Case studies data collection templates
Environmental assessment	Carbon dioxide-constrained opt.	Environmental aspects (emissions)	Environmental. aspects to impacts	E2E 'green' capability assessment
Economic assessment	Network direct cost	Cost of goods analysis	Material and energy cost flow assessment; Eco/efficiency	Value creation/ capture, product value structure
Operations technology	Capacity-constrained optimisation	Batch/Continuous ops modelling	N/A	Technology interventions; Practice
Network Dynamics	Inventory policies; Time lags	Production lead times	N/A	Current state/Future state SC analysis

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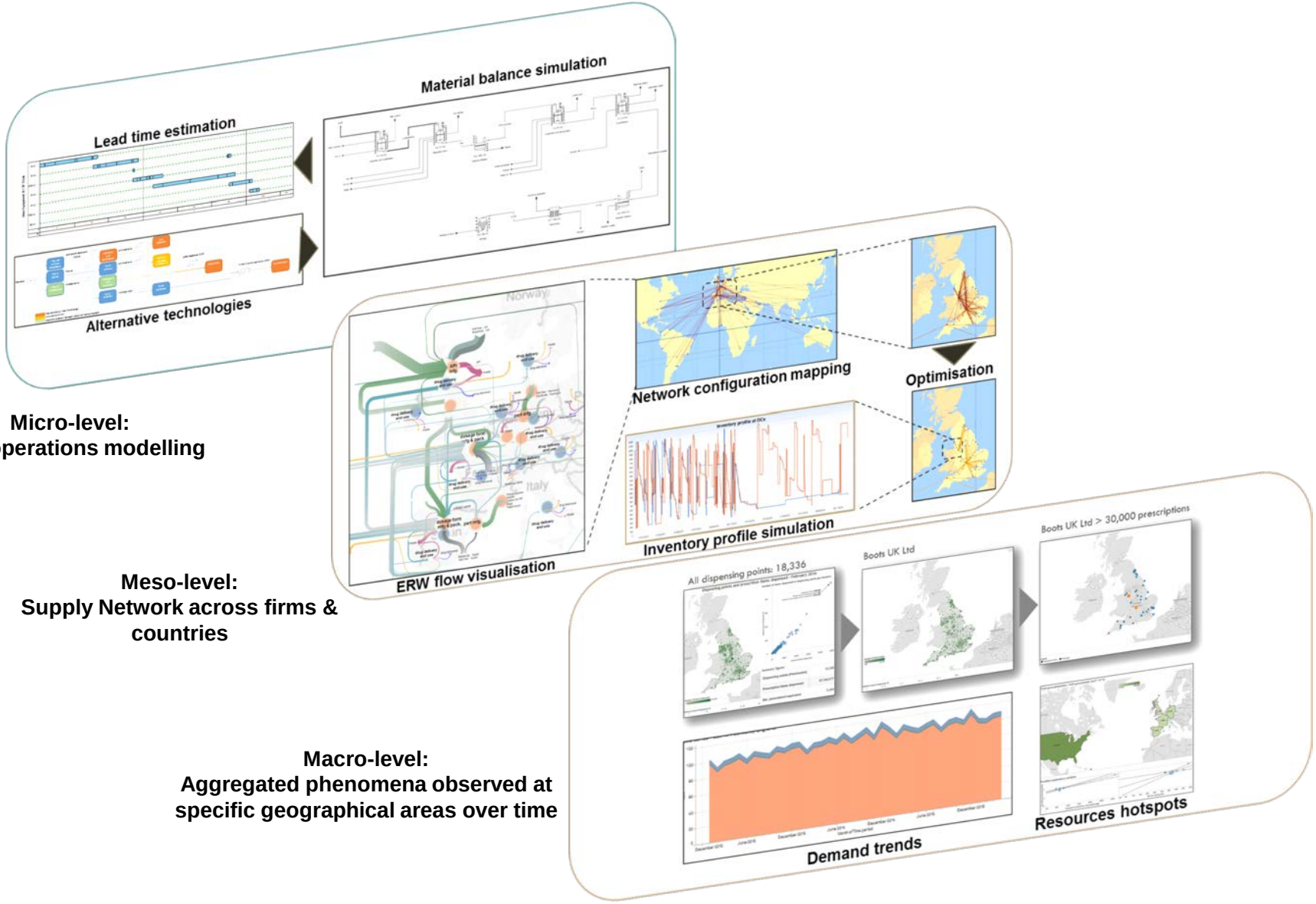
NETWORK DESIGN – connecting multiple layers of analysis



Micro-level:
Unit operations modelling

Meso-level:
Supply Network across firms & countries

Macro-level:
Aggregated phenomena observed at specific geographical areas over time

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Example - Pharmaceuticals

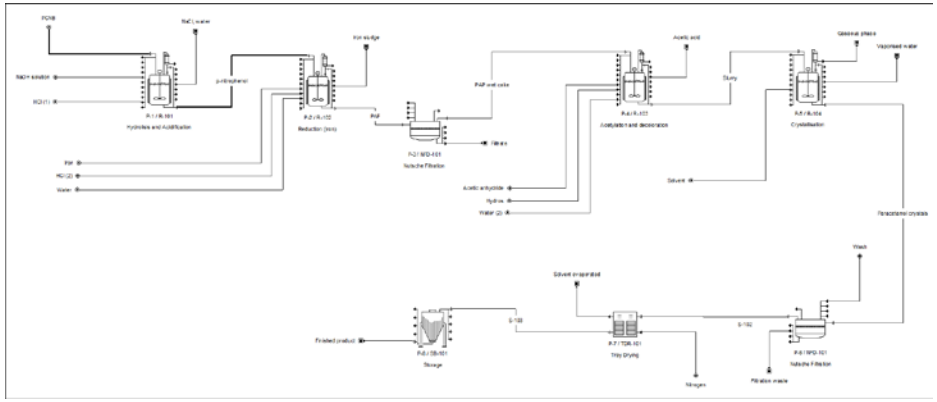
Current state map & policy declaration (Make, Source, Inventory, Transportation)

Scenario building (Demand projections; locations alternatives; technology interventions; Environmental constraints)

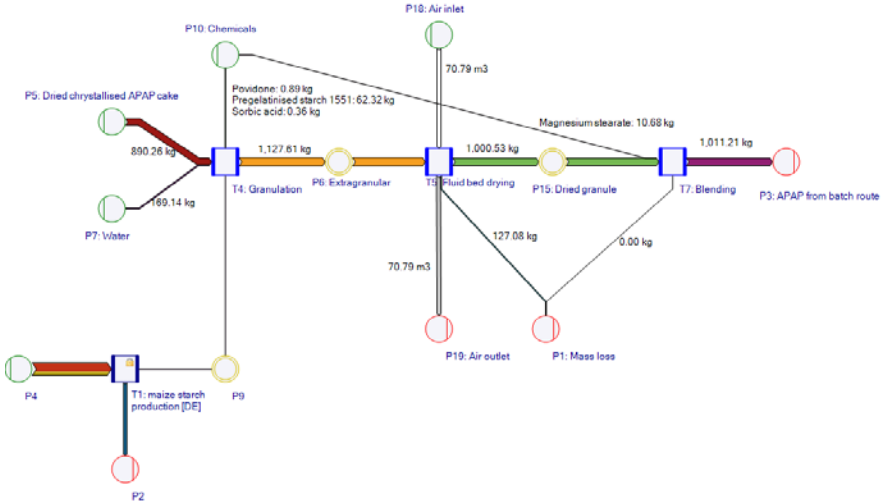
Configuration options evaluation (Economic flows; Resource intensity; Inventory dynamics)

Network configuration design (simulation and optimisation)

Demand & critical resources analysis



Manufacturing Operations modelling (process innovation)



Resource assessment - material and energy flow (Carbon footprint)

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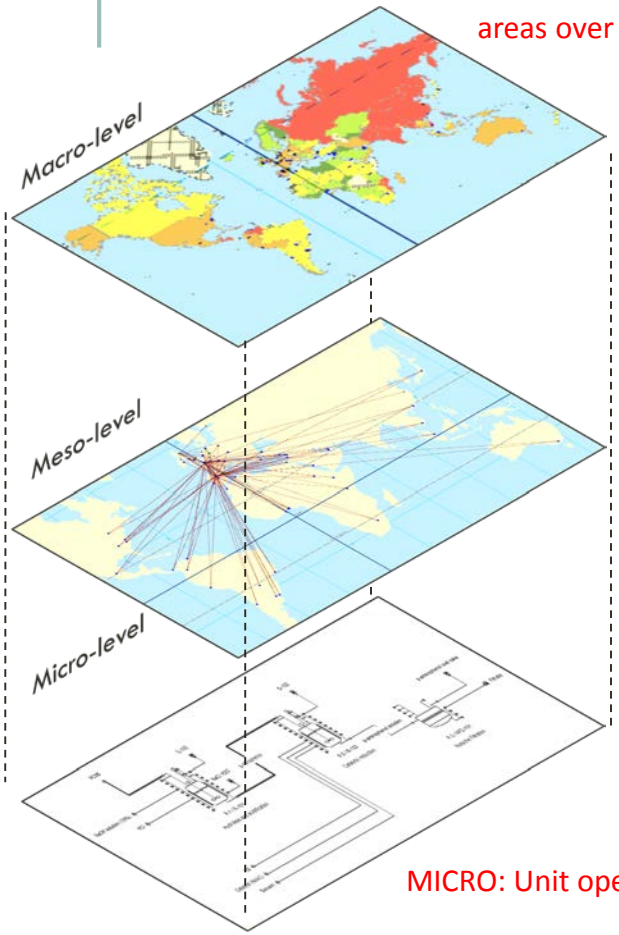
NETWORK DESIGN LAYERS OF ANALYSIS

ReMediES
RE-configuring MEDIcines End-to-end Supply

MACRO: Aggregated phenomena observed at specific geographical areas over time

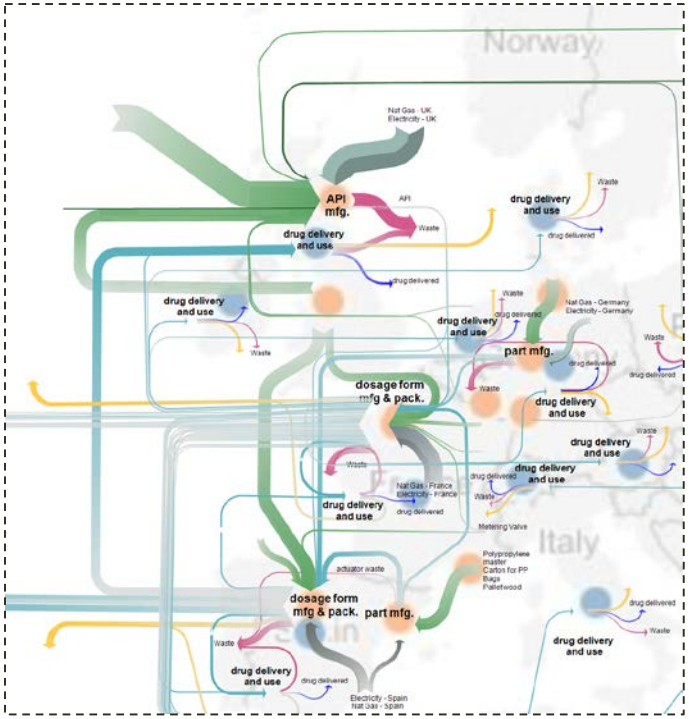


MESO: Supply Network across firms & countries

MICRO: Unit operations analysis

National data by location - prescription-centric

Ex-factory data – network-centric

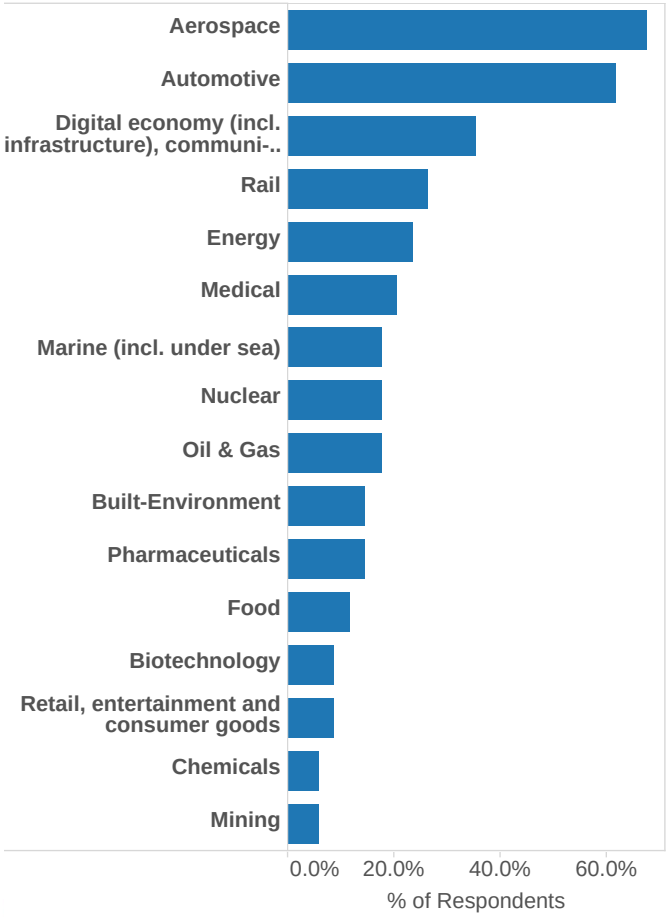


Digital SC Scenarios – workshop participants

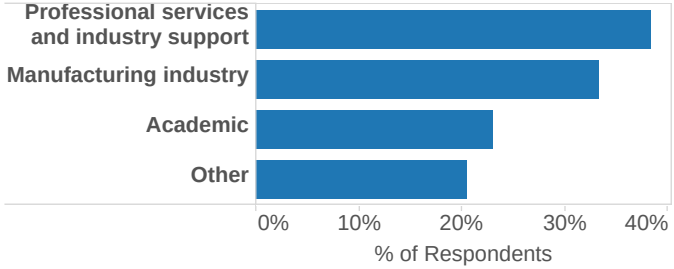
Total respondents (complete forms)

41

By primary activity

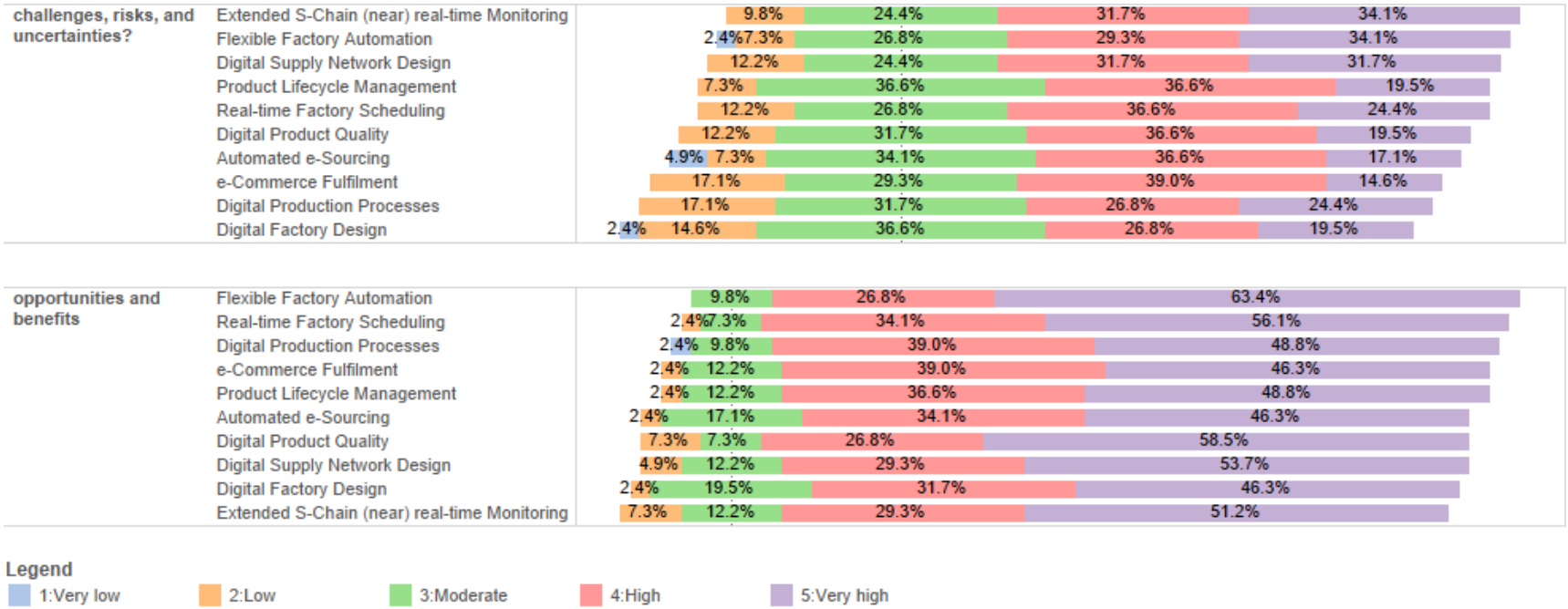


By industry



Initial workshop results – Opportunites and risks

Scoring (1-5) of opportunities and benefits & challenges, risks, and uncertainties (n=41)



- Promising scenarios have significant delivery challenges
- Intra-Factory Digital : Flexible Factory Automation/Scheduling/Production processes most promising
- Gap between opportunities and challenges/risks greatest in Digital Production Processes
- Opportunities & Benefits greater than Challenges & Risks - across the 10 Digital SC Secnraios

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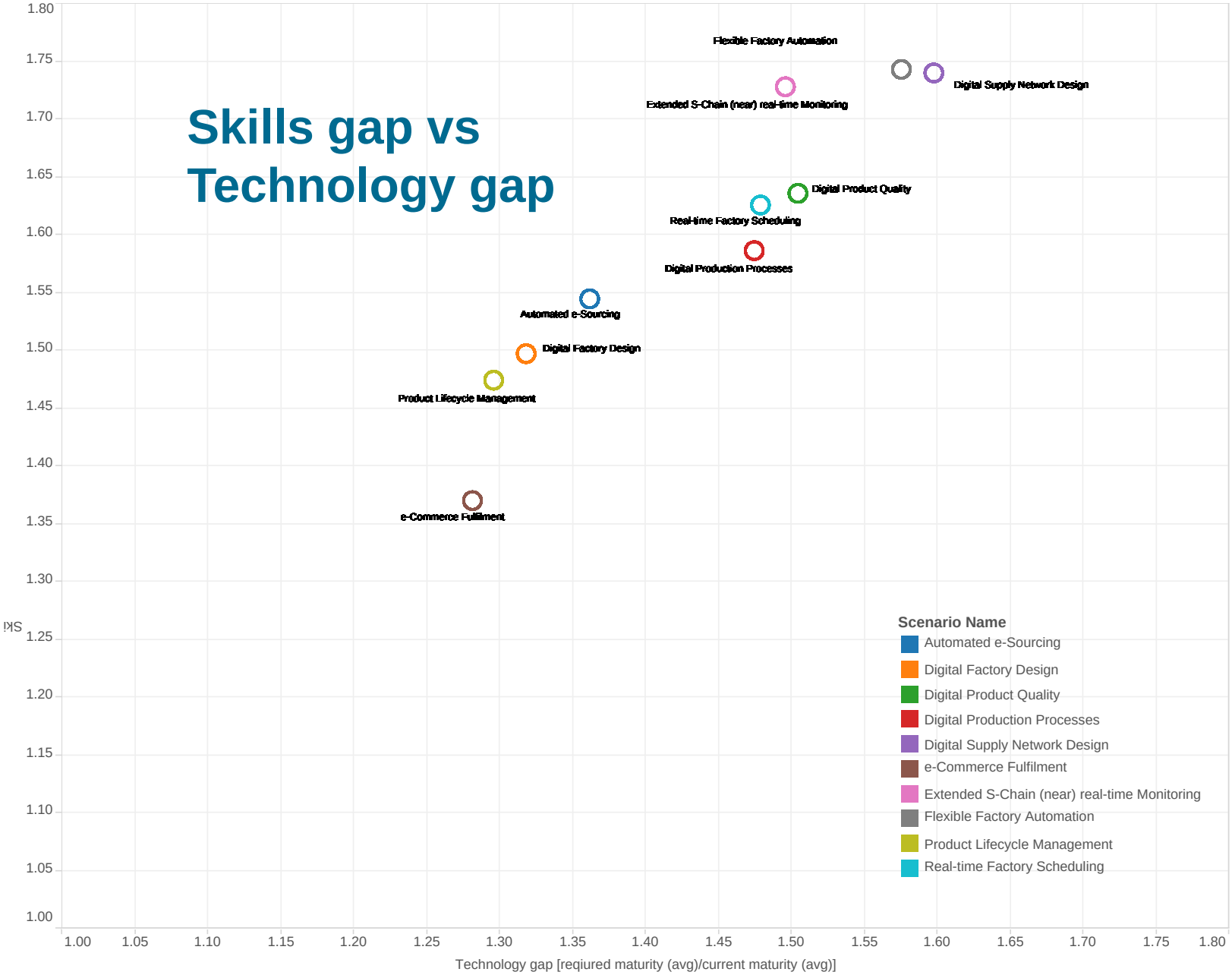
Skills gap vs Technology gap



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EXPERIMENTATION IN PHARMACEUTICALS – PROJECT REMEDIES

Headed up by GlaxoSmithKline (GSK)

Research led by the University of Cambridge's Institute for Manufacturing (IfM)

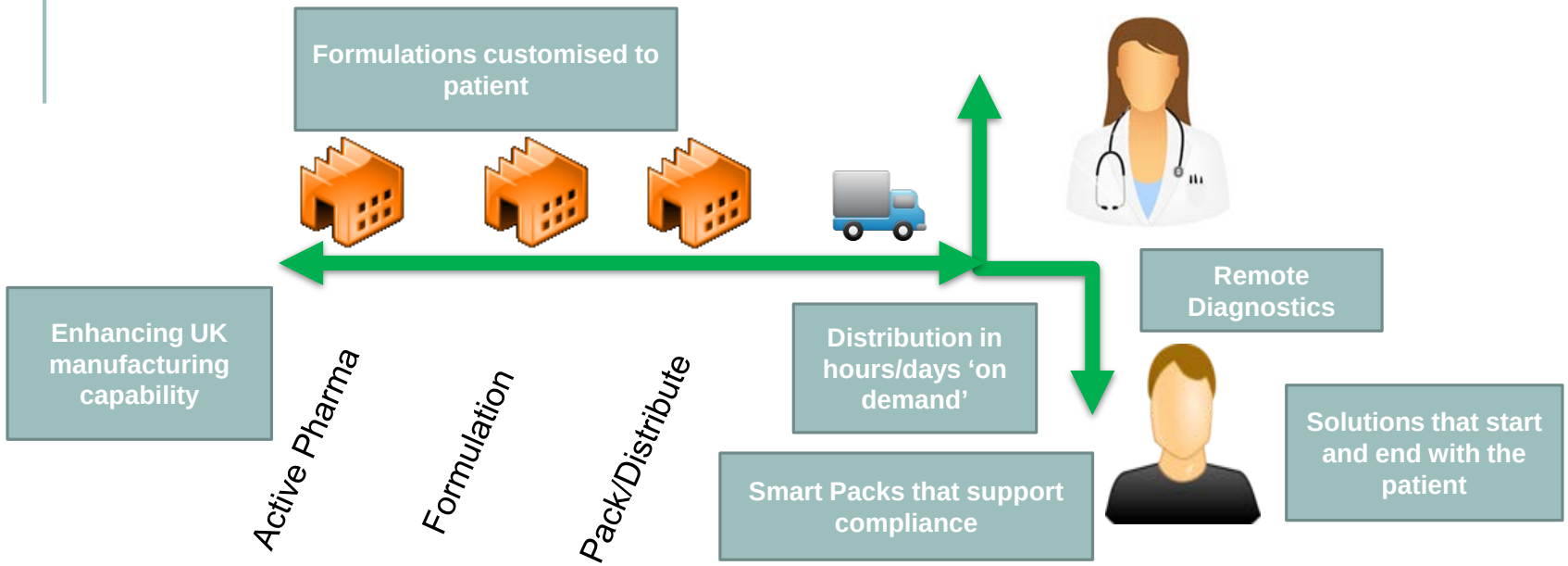
Brings together key players in the medicines end-to-end supply chain

£11.5 m contribution from industry, £11.5 m of government funding through The Advanced Manufacturing Supply Chain Initiative (AMSCI) and the Scottish Funding Council

http://remediesproject.com/

PATIENT-DRIVEN RESPONSIVE SUPPLY MODEL

ReMediES
RE-configuring MEDIcines End-to-end Supply



Processes and Technologies developed:

- Continuous Manufacturing techniques that shrink factory scale, provide speed, lower cost
- Smart Packaging technologies that enable product tracking, monitoring and patient engagement
- Technologies that support right-first time quality and yield improvements
- Improved Process Analytical Technologies for in-line monitoring and quality assurance
- Supportive Regulatory Regimes for these emerging technologies
- Developing new End-to-End SC Clinical & Commercial platforms that support patient-centric agile supply models

Digital Supply Chain - Pharmaceuticals

ReMediES
RE-configuring MEDIcines End-to-end Supply

Value Propositions

1) How to enable data integration across the supply chain for more responsive or adaptive supply?
2) How to improve E2E inventory management, and reduce levels of inventory?
3) How do we monitor product quality and delivery performance, ensuring high product visibility, traceability, and environmental compliance?
4) How do we monitor product efficacy in-use to support improved patient outcomes?
5) What are the opportunities and benefits of more personalised services to patients?
6) How do we achieve better segmentation? (patient focused?)
7) How do we capture patient/customer feedback?
8) What is the role of regulators and standards agencies to facilitate the benefits that digital supply chains might offer?
9) How might we utilise digital design tools for future state supply chain design?

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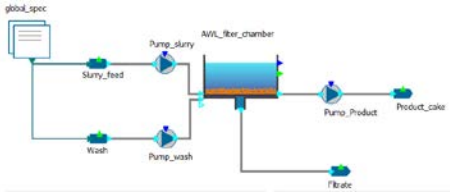
CONTINUOUS DRUG MANUFACTURE

ReMediES
RE-configuring MEDIcines End-to-end Supply

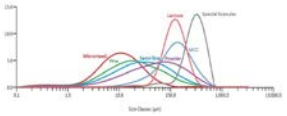
Continuous drug substance filtration

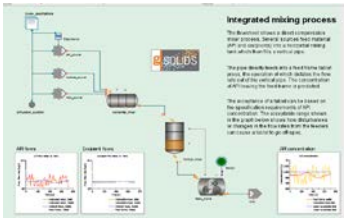
- AWL lab scale prototype
- Continuous washing, filtration and drying



Continuous direct compression

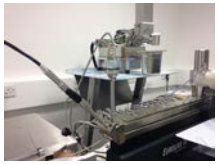
- GEA CDC50 test rig, PAT enabled
- Continuous feeding, blending and compression

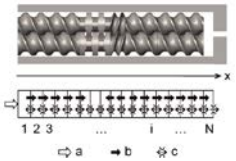


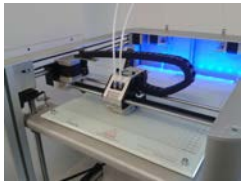


Hot melt extrusion / 3D printing

- 16mm twin screw extruder at Univ of Strathclyde, PAT enabled
- Potential to direct couple HME and 3DP



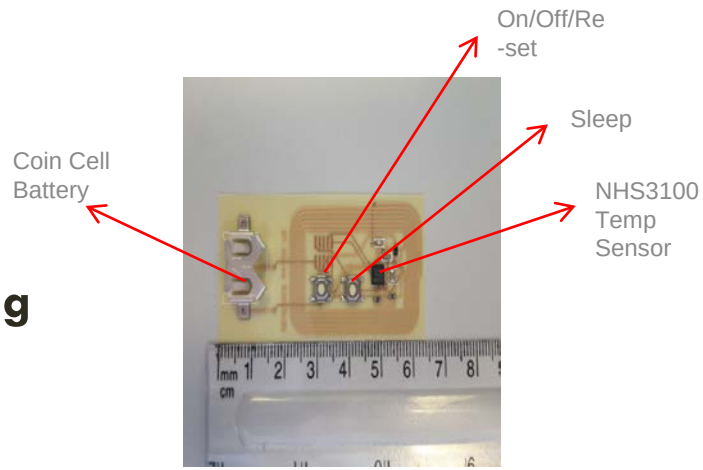


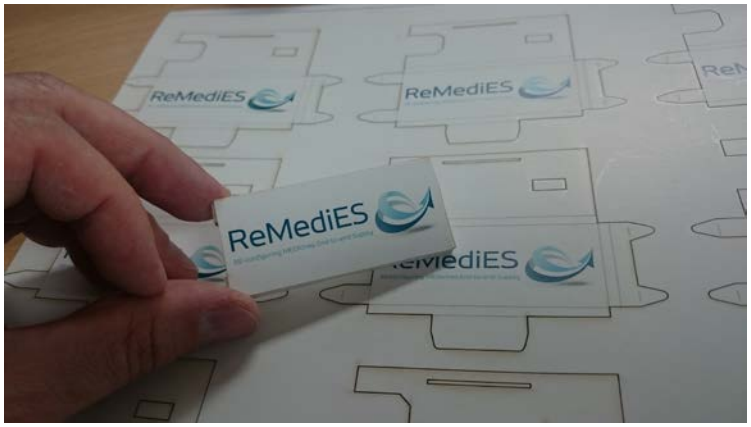


INFORMED LOGISTICS, CONNECTED PATIENTS

ReMediES
Re-configuring MEDIcines End-to-end Supply

Smart Packaging





- Each chip has a Unique Identifier (UID) built in, and a 'real time clock'
- Temperature monitor with 0.3c accuracy between -20c & +65c
- Moving to NFC-based technology; Additional functionality can be added

On-going design iterations, ….. power management, alarm, GPS & measurement of shock

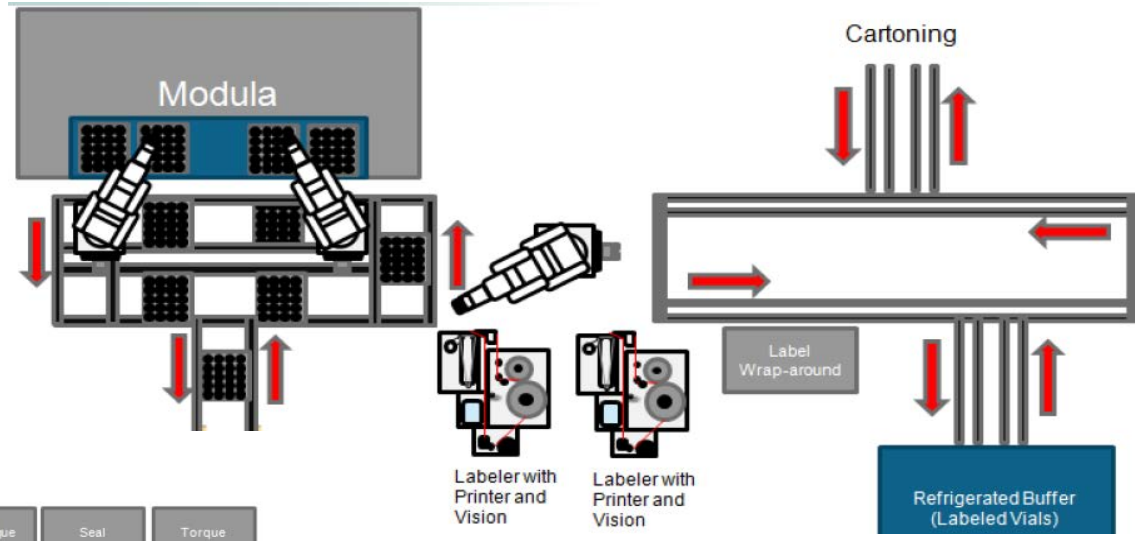
Electronic Leaflet

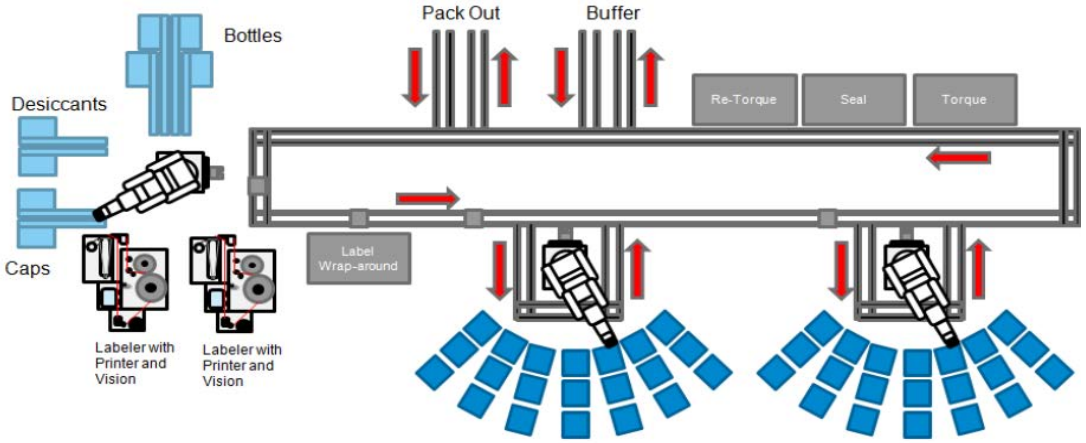
IfM/GSK
……Electronic leaflet from Datapharm's database

DATAMATRIX SCAN
(VIA CAMERA) OR NFC

Using Apps to provide information, behaviour, adherence

JUST IN TIME (JIT) AUTOMATED CLINICAL PHARMACY





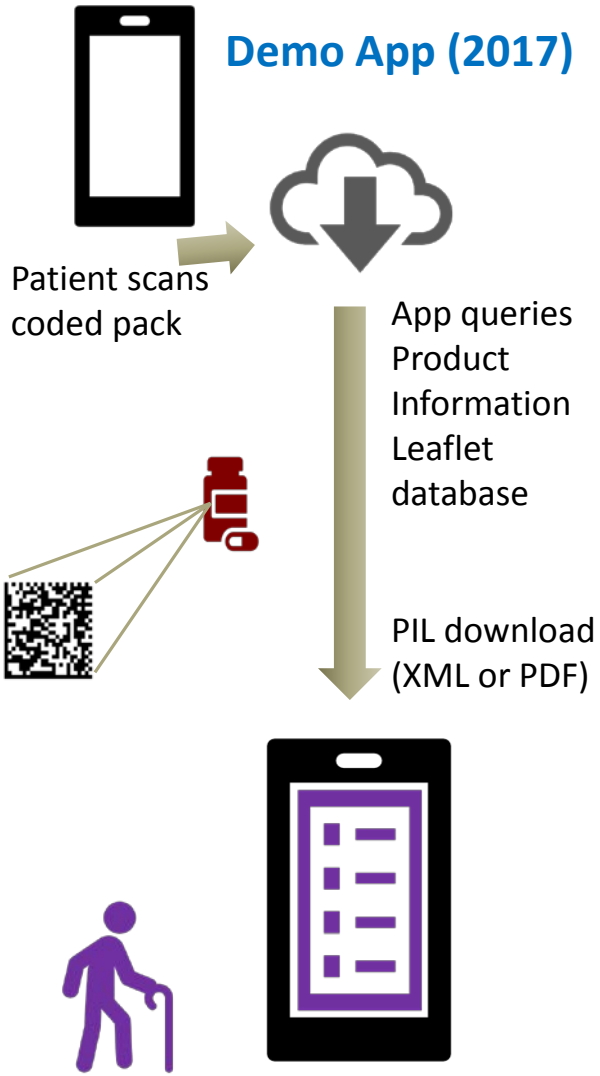
- Increase speed in supply chain (x**16 -> 120**)
- Increase **personalisation** capability
- Increase **quality** assurance
- More **efficient** operation
- Enabler for upstream dose-to-order innovation (**better medical outcomes**)

- Reduce Patient Kit Wastage (**£10M's – £100M+** per annum per company; equates to 25% - 70% of total)
- Reduce lead time from 4-6 months to **<1 week**
- Reduce **investments at risk** via delayed decision requirements (i.e. development & manufacture)

m-Health Demo App

ReMediES
RE-configuring MEDIcines End-to-end Supply

Demo App (2017)



Near-term Extensions

Alternative Languages

Audio descriptions

Video explanations

YellowCard

Link to AE reporting

Possible future

Drug-Drug Interaction warnings if incompatible drugs scanned

Disease info, patient forums, etc

Link to user-generated data (Activity, Wellness etc)

Automatic reminder to return unused medicines

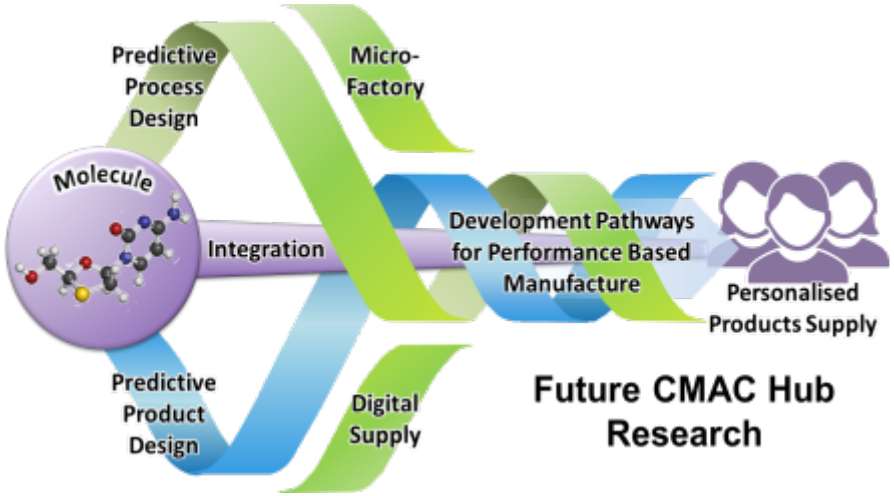
Dialogue with Health Care Professional

Blinded feedback on outcomes, inventory etc

Future Digital SC research agendas

- Digital Pharma
  - Project Remedies field experiments
  - Manufacturing Research Hub on Continuous Manufacturing -> personalised medicines
- Food Security through digital SC
  - SC Integration, resource efficiency, localisation/choice
- Theoretical developments
  - Enablers of Distributed Manufacturing
  - Technology driven supply chain design ‘laboratory’
- Developing digital SC scenarios – observations from industry
  - Maturity models for developing digital attitudes
  - Standards – necessary enabling activity?

Future Research in Continuous Manufacturing, 2017 - 2023



Vision: **Rapid Performance Based Design and Continuous Manufacture**

WP1 **Integrated Development Pathways**

WP2 **Future MicroFactory Demonstrators**

WP3 Future Digital Supply of Personalised Products and Medicines

- New 7 year £50M Programme
- 2023 Manufacturing vision: research and skills
- Substantial industry engagement and support
- Key Innovation partners include

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Summary

- Sector opportunities can be very different – upstream, intra-factory, downstream supply chain; value-add combinations need teasing out and not easily delivered
- Emerging 'transformation hotspots', e.g.
  - Production intensity B2B firms seek reconfigurable plant automation
  - Consumer driven firms extend firm boundaries for vol/var flexibility
  - Service organisations building end-to-end supply visibility
- Digital innovations can be transformative – novel products and services, new industry players, alternative business models
- Technology is a crucial enabler – product, production process, infrastructure and change often not incremental

References and Resources

- **How bright is your digital future?** http://www.ifm.eng.cam.ac.uk/news/how-bright-is-your-digital-future/#.WG6bjVOLSpo

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- Srai, J. S., Badman, C., Krumme, M., Futran, M., & Johnston, C. **2015**. **Future supply chains enabled by continuous processing–opportunities and challenges**. May 20-21, 2014 Continuous Manufacturing Symposium. Journal of Pharmaceutical Sciences, 104(3), 840–849.

- Srai, J. S.; Alinaghian, L. S., **Value Chain Reconfiguration in Highly Disaggregated Industrial Systems: Examining the Emergence of Health Care Diagnostics**. *Global Strategy Journal* **2013,** *3* (1), 88-108

Questions