Setting out Digital Transformations
- A supply chain perspective

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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

Connected communities, users, support specialists, firm networks

- e-Life Management (Monitoring and prevention)
- Wellbeing
- Digital Factory
  - Efficiency
- Monitored Product Usage
  - (smart products, devices, point of use)
- “Informed” logistics
- Availability

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Conceptualising the digital supply chain - Framing the literature

Connected communities, users, support specialists, firm networks

- e-Life Management (Monitoring and prevention)
- Wellbeing
- Monitored Product Usage (smart products, devices, point of use)
- Availability
- “Informed” logistics
- Connectivity, IoT
- Information (big data, small data, ICT)

Digital infrastructure
Digital Supply Chain
Digital Factory

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DIGITAL SUPPLY CHAINS – PHARMACEUTICALS

- Connected communities, patients, health professionals, firm networks
- Assisted living
- Digital-enabled prognosis
- Sensors
- Cloud
- Smart communities (sentiment, aware, active citizens)
- Monitored treatment (smart packs, devices, point of use)
- Informed patient (adherence and compliance)
- Digital-enabled diagnosis, Drug efficacy
- Data integration and standards
- Continuous processing and PAT
- Distributed production models
- Pack Integrity (Env'l compliance, authentication)
- Connectivity, IoT
- Information (big data, small data, ICT)
- Automated kitting, Digital pharmacy, Personalised delivery
- Digital data driven inventory reduction
- Automated kitting, Digital pharmacy, Personalised delivery
- DIGITAL SUPPLY CHAINS – PHARMACEUTICALS

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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)

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

**Understanding the Digital SC context – open access**
(to explore new opportunities, challenges facing industry)
Future digital supply chain scenarios

What types of firms could benefit from these digital transformations?

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)
Future digital supply chain scenarios

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<tbody>
<tr>
<td>Digital 3D modelling systems for factory layout design, process and material flow simulation</td>
<td>Advanced factory execution systems with sensor-enabled, smart devices, real-time data KPI monitoring, predictive maintenance</td>
<td>Advanced manufacturing plant/machine reconfiguration, scale flexibility, varied levels of human-robot-collaboration</td>
<td>Application of digital production processes (e.g. additive manufacturing, continuous processing) with advanced process analytics</td>
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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
Future digital supply chain scenarios

1. Automated e-Sourcing
2. Digital Factory Design
3. Real-time Factory Scheduling
4. Flexible Factory Automation
5. Digital Production Processes
6. e-Commerce Fulfilment
7. Extended Supply Chain (near) real-time Monitoring
8. Digital Product Quality
9. Digital Supply Network Design
10. Product Lifecycle Management
Classification of future digital supply chain scenarios

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

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

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Definition (and assessment) of Digital SC maturity

Maturity levels

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technologies¹, Processes &amp; organisational routines³</td>
<td>Basic technology principles, processes observed and reported</td>
<td>Technology concept piloted, Processes selectively applied</td>
<td>Technology validated/demonstrated Standardised processes</td>
<td>Technology/Processes routinely deployed with predictable outcomes</td>
</tr>
<tr>
<td>Skills &amp; attitudes²</td>
<td>Ad-hoc inconsistent practices / basic understanding, accidental implementation</td>
<td>Selective deployment of repeatable practices, nascent understanding, with product demonstrators</td>
<td>Well defined competency-based practices, emergent understanding, with multiple applications</td>
<td>Measured &amp; empowered practices / well understood capabilities, dependable &amp; routine implementation</td>
</tr>
</tbody>
</table>

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

**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.
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

<table>
<thead>
<tr>
<th></th>
<th>Personalization</th>
<th>Digitization</th>
<th>Localization</th>
<th>New production technologies</th>
<th>Multi-user participation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Virtual Enterprise</strong></td>
<td>No</td>
<td>Yes</td>
<td>Partly</td>
<td>Implied</td>
<td>No</td>
</tr>
<tr>
<td><strong>Industry 4.0</strong></td>
<td>Possible, but not at the individual level</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Partly, but not end user</td>
</tr>
<tr>
<td><strong>Grid Manufacturing</strong></td>
<td>No</td>
<td>Yes</td>
<td>Partly</td>
<td>Implied</td>
<td>No</td>
</tr>
<tr>
<td><strong>Concurrent Engineering</strong></td>
<td>No</td>
<td>Possible</td>
<td>No</td>
<td>New</td>
<td>Partly, but not end user</td>
</tr>
<tr>
<td><strong>Cloud based manufacturing</strong></td>
<td>No</td>
<td>Yes</td>
<td>Partly</td>
<td>Implied</td>
<td>No</td>
</tr>
<tr>
<td><strong>Smart manufacturing</strong></td>
<td>Possible, but not at the individual level</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Autonomous manufacturing, but does not involve end user</td>
</tr>
<tr>
<td><strong>Distributed Manufacturing</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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
TECHNOLOGY DRIVEN SUPPLY NETWORK DESIGN - DIGITAL TOOLSET

**Network Representation**
- Nodes: facilities; Arcs: sourcing policies
- Labour, transportation, Tax
- Carbon dioxide-constrained opt.
- Network direct cost
- Capacity-constrained optimisation
- Inventory policies; Time lags

**Data retrieval capability**
- e.g. Supply Chain Guru
- e.g. SuperPro Designer
- e.g. Umberto
- e.g. CIM IfM models

**Environmental assessment**
- Carbon dioxide-constrained opt.
- Equipment specs and cost, Labour, material properties
- Environmental aspects (emissions)
- Environmental aspects to impacts
- Material and energy cost flow assessment; Eco/efficiency
- Value creation/capture, product value structure

**Economic assessment**
- Network direct cost
- Cost of goods analysis
- Batch/Continuous ops modelling
- Production lead times
- N/A
- N/A

**Operations technology**
- Capacity-constrained optimisation
- Production lead times
- N/A

**Network Dynamics**
- Inventory policies; Time lags
- Production lead times
- N/A

**Technology driven supply network design**
- e.g. Supply Chain Guru
- e.g. SuperPro Designer
- e.g. Umberto
- e.g. CIM IfM models

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NETWORK DESIGN – connecting multiple layers of analysis

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

Meso-level:
Supply Network across firms & countries

Micro-level:
Unit operations modelling
Example - Pharmaceuticals

Network configuration design (simulation and optimisation)

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)

Demand & critical resources analysis

Manufacturing Operations modelling (process innovation)

Resource assessment - material and energy flow (Carbon footprint)
NETWORK DESIGN LAYERS OF ANALYSIS

MACRO: Aggregated phenomena observed at specific geographical areas over time

Meso-level

MESO: Supply Network across firms & countries

Micro-level

MICRO: Unit operations analysis

National data by location - prescription-centric

Ex-factory data – network-centric

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Digital SC Scenarios – workshop participants

Total respondents (complete forms)

By primary activity
- Aerospace
- Automotive
- Digital economy (incl. infrastructure, commun...)
- Rail
- Energy
- Medical
- Marine (incl. under sea)
- Nuclear
- Oil & Gas
- Built-Environment
- Pharmaceuticals
- Food
- Biotechnology
- Retail, entertainment and consumer goods
- Chemicals
- Mining

By industry
- Professional services and industry support
- Manufacturing industry
- Academic
- Other

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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 Scenarios
Skills gap vs Technology gap

Scenario Name
- Automated e-Sourcing
- Digital Factory Design
- Digital Product Quality
- Digital Production Processes
- Digital Supply Network Design
- e-Commerce Fulfilment
- Extended S-Chain (near) real-time Monitoring
- Flexible Factory Automation
- Real-time Factory Scheduling
- Product Lifecycle Management
- Technology gap [required maturity (avg)/current maturity (avg)]
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/
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

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?
CONTINUOUS DRUG MANUFACTURE

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

Smart Packaging

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

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

Electronic Leaflet

- DATAMATRIX SCAN (VIA CAMERA) OR NFC
- Using Apps to provide information, behaviour, adherence

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JUST IN TIME (JIT)
AUTOMATED CLINICAL PHARMACY

- Increase speed in supply chain (x16 -> 120)
- Increase **personalisation** capability
- Increase **quality** assurance
- More **efficient** operation
- Enabler for upstream dose-to-order innovation (**better medical outcomes**)
m-Health Demo App

Demo App (2017)
- Patient scans coded pack
- App queries
  - Product Information
  - Leaflet database
- PIL download (XML or PDF)

Near-term Extensions
- Alternative Languages
- Audio descriptions
- Video explanations
- 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

Simple accessibility aids:
- Zoom / large font 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/#.WG6bjVOLSp0](http://www.ifm.eng.cam.ac.uk/news/how-bright-is-your-digital-future/#.WG6bjVOLSp0)


- 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