Circular Manufacturing Systems

An essential paradigm shift for the manufacturing industry

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Research motivation

• Linear manufacturing paradigm of today’s ‘take-make-use-dispose’ economy
  – An inherently wasteful system in terms of both resource efficiency and effectiveness.

Flows of material resources
(in Gt - billion tons) EU27, 2017
Research motivation

• Manufacturing industry is a major consumer of energy and material resources generating significant amount of waste
  – In 2018, manufacturing generated 10.6% of the total waste in EU-27, being the 3rd biggest contributor

• Conventional closed loop systems
  – The products are neither designed nor manufactured for closing the loop (closing the loop by chance)
  – Limits in capturing the full economic and environmental potential

Source: Eurostat (online data code: env_wasgen)
Circular Manufacturing Systems (CMS)

- CMS refer to systems that are **designed intentionally for closing the loop** of components or products preferably in their original form, through **multiple lifecycles**

- It is a **value management** approach that includes the phases of **value creation, delivery, use, recovery** and **reuse** in a systemic perspective
A **systemic** and **systematic** approach integrating BMs, PD, SCs, and ICT

- Innovative **business models** that enable economically viable ways to continuously reuse products and materials
- Products need to be **designed intentionally for closing the loop** (e.g., design for value retention through multiple lifecycles)
- Integrated forward & reverse **supply chains** solutions that can handle the dynamics of multiple lifecycles
- **ICT** as a system enabler that aim at tracing and tracking the products over their multiple lifecycles
A stepwise transition approach

- Transition from **product-oriented** to **service-oriented** business models
  - Increased circularity potential
  - Reduced leakage in the system
  - Increased complexity
## Relevant industrial practices

<table>
<thead>
<tr>
<th>Company</th>
<th>Business Model</th>
<th>Product Design</th>
<th>Supply Chain</th>
<th>ICT</th>
<th>Regenerative approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caterpillar</td>
<td>Buy back and reselling</td>
<td>Design for multiple lifecycles</td>
<td>Caterpillar parts distribution network</td>
<td>Monitor the condition of key components and intercept products before they break</td>
<td>Repair, Reuse, Refurbishing, Remanufacturing, Recycling</td>
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<tr>
<td>Xerox</td>
<td>Take-back and reselling</td>
<td>Design for the future (reduce-reuse-recycle strategy)</td>
<td>Optimized global reverse logistics systems</td>
<td>Connectivity, Tracing and tracking</td>
<td>Repair, Reuse, Refurbishing, Remanufacturing, Recycling</td>
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<td></td>
<td>Leasing/Renting</td>
<td>Modular design</td>
<td>Partnership at every stage</td>
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<td></td>
<td>Pay-per-copy</td>
<td>Longevity &amp; durability</td>
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<td><strong>Michelin</strong></td>
<td>Michelin Fleet Solution</td>
<td>Design products and services with sustainable mobility in mind&lt;br&gt;Long-lasting performance</td>
<td>Collaborative partnerships&lt;br&gt;Sustainable logistics (e.g. expand the use of direct factory-to-customer deliveries)</td>
<td>Cloud B2B Integration Connected mobility</td>
<td>4Rs strategy: Reduce/ Reuse/ Recycle/ Renew</td>
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<td>Pay-per-kilometre</td>
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<td><strong>Ricoh</strong></td>
<td>Leasing/Renting</td>
<td>Design for resource conservation and recycling&lt;br&gt;Modular design to support upgradeability&lt;br&gt;Lifecycle design</td>
<td>Network of collection centres, recovery centres and recycling centres&lt;br&gt;Partnership at every stage</td>
<td>Remote diagnostics and monitoring software to track usage data</td>
<td>Repair Maintenance Upgrading Refurbishing Remanufacturing Recycling</td>
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<td>Other service contracts</td>
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CMS modelling and simulation

- Capture the complex and dynamic nature of CMS by connecting the aspects of BMs, PD, and SCs to evaluate the **economic**, **environmental**, and **technical** performance of the system.

- Evaluate economic and environmental performance of new CBMs (e.g., cost streams, revenue streams, profit margins).

- Quantify design efforts for different CBM configurations (e.g., assign value recovery strategies over multiple lifecycles).

- Optimize circular supply chain to ensure product returns and redistribution (e.g., centralized vs. decentralized refurbishment).

Physical, information, and financial flows
Analytical vs. Simulation modelling

**Analytical models**

- Static modelling
- Linear behaviour
- Number of parameters is ‘manageable’
- Dependencies are clear, easy to build a mental model

**Simulation models**

- Designed for analysing dynamic systems
- Non-linear behaviour
- Time and causal dependencies
- Large number of parameters
- Uncertainty (stochastic system)
Why multi-method simulation modelling for CMS design and analysis?

- Simulation modelling techniques
- Framework for CMS implementation

Different levels of abstraction are needed to model the complex and systemic nature of CMS

Source: Borshchev (2013)

Source: Rashid et al., (2020).
Simulation modelling outcomes

Economic performance

Environmental performance

Technical performance
EU funded H2020 ReCiPSS project

ReCiPSS
Resource-efficient Circular Products-Service Systems

Large-Scale Demonstrations of Circular Manufacturing Systems

White goods

System approach

Automotive parts

System enablers

www.recipss.eu
Social value of the research

To ensure sustainable consumption and production patterns
References

