Towards circular economy implementation using a multi-method simulation approach to link design and business strategy

PDT Europe
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Agenda

ResCoM overview, scope and objectives

Multi-method model (agent-based & discrete event)

Washing machine case example
The ResCoM project has received funding from the European Union’s Seventh Programmes for research, technological development and demonstration under grant agreement No 603843.
ResCoM
Resource Conservative Manufacturing
ResCoM and Collaborative PLM platform
ResCoM and Collaborative PLM platform

Collaboration tools

Data Bases & Analyses

System Performance

Methodologies

Dynamic Modelling

Collaboration tools

PLM

Decision making

Browse & search

Analysis

Material Database

System Performance

Environmental
demand

Process-centric
(Discrete-Centric)

Agent-Based Modeling

ResCoM and Collaborative PLM platform

Collaboration tools

Data Bases & Analyses

System Performance

Methodologies

Dynamic Modelling

Supply chain

ICT

Product design

Business model
One of the main challenges...

How can economic and environmental impact of different circular manufacturing systems be quantified and assessed considering different business models, design strategies and supply chains?
Exploring and optimizing circular manufacturing systems

Explorative approach

How to design for any circular business model?
- Reuse?
- Remanufacturing?
- Recycling?

Which EoL strategy for which component?

How much additional design effort?
- Cost?
- CO2?

For which business model?
- Pay-per-use?
- Leasing?
- Buy-back?
- ...

Systematic exploration of different design and business model potentials

Optimization approach

Best fitting design strategy for the selected circular business model
- Reuse?
- Remanufacturing?
- Recycling?

...considering all possibilities of EoL strategies on component level?

...with a given level of additional design effort?
- Cost?
- CO2?

...for one particular business model?
- Pay-per-use?
- Leasing?
- Buy-back?
- ...

What is the best circular design strategy...

(Lieder et al., 2017)
Multi-Method Model (agent-based & discrete event)

- Design decisions and data on component level
- Component agent carrying all component data
- Discrete event circular supply chain including relevant business settings
Multi-Method Model (agent-based & discrete event)

Product disassembly

Component A
- Part number: 18
- Part name: ABC
- Material name: ABS (extrusion)
- Mass: 0.24 kg
- Manufacturing/purchasing cost: 3.33 €
- LCA & LCC data …

Component B
- Part number: 19
- Part name: XYZ
- Material name: Borosilicate - 2405
- Mass: 1.28 kg
- Manufacturing/purchasing cost: 17.76 €
- LCA & LCC data …

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Part Name</th>
<th>Material Name</th>
<th>Mass (kg)</th>
<th>Cost (€)</th>
<th>CO2 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>ABC</td>
<td>ABS (extrusion)</td>
<td>0.24</td>
<td>3.33</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>XYZ</td>
<td>Borosilicate - 2405</td>
<td>1.28</td>
<td>17.76</td>
<td></td>
</tr>
</tbody>
</table>
Multi-Method Model (agent-based & discrete event)

Design decisions and data on component level

1) manufactured
2) reused
3) assembled in product
4) after use
5) disassembled after use
6) recycle
7) material recovered

Component agent carrying all component data

Component A
Component
...

Discrete event circular supply chain including relevant business settings

Manufacturing, transport, use phase

Reuse & Remanufacturing

Recycling

End of use phase

Buy-back
Leasing
Pay-per-use

Part Number (1) | Part Name (2) | Material Name (3) | Mass (kg) (4) | Cost (€) (5) | CO2 (kg) (7)
---|---|---|---|---|---

P

EoL Strategy [1]
Reuse
Number [int]
18

P

Mass [double]
0.24

P

Material [string]
ABS (extrusion)

## Design options washing machine

<table>
<thead>
<tr>
<th>End-of-Life strategy</th>
<th>Design option 1</th>
<th>Design option 2</th>
<th>Design option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reuse ((r_{\text{reuse}}))</td>
<td>0.70</td>
<td>0.48</td>
<td>0.24</td>
</tr>
<tr>
<td>Remanufacturing ((r_{\text{reman}}))</td>
<td>0.24</td>
<td>0.39</td>
<td>0.58</td>
</tr>
<tr>
<td>Recycling ((r_{\text{recycling}}))</td>
<td>0.06</td>
<td>0.12</td>
<td>0.18</td>
</tr>
</tbody>
</table>

(Lieder et al., 2017)
Explorative circular design and business study (washing machine, 33 components)

In a defined time period (15 years in this case) **1,70** customers have been served with the components of one single washing machine.

Most costly business scenario due to highest operational cost!

Optimize end-of-life strategies of components in pay-per-use setting to decrease lifecycle cost!

(Lieder et al., 2017)
Optimization run for washing machine pay-per-use model

Screen shot optimization experiment

| Component number | Material name | Manufacturing cost (euro), $\Delta D = 0.249$ | Design option 1 (before optimization) $\Delta D = 0.249$ | Optimized Pay-per-use design (after optimization) $\Delta D = 0.2391$
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Material A</td>
<td>12.76</td>
<td>Reuse</td>
<td>Reuse</td>
</tr>
<tr>
<td>2</td>
<td>Material B</td>
<td>1.53</td>
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<td>Reuse</td>
</tr>
<tr>
<td>3</td>
<td>Material C</td>
<td>2.77</td>
<td>Reuse</td>
<td>Reuse</td>
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<tr>
<td>4</td>
<td>Material D</td>
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<tr>
<td>5</td>
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<td>Reuse</td>
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<tr>
<td>6</td>
<td>Material D</td>
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<td>Reuse</td>
</tr>
<tr>
<td>7</td>
<td>Material D</td>
<td>13.87</td>
<td>Reuse</td>
<td>Reuse</td>
</tr>
<tr>
<td>8</td>
<td>Material E</td>
<td>74.79</td>
<td>Reuse</td>
<td>Reuse</td>
</tr>
</tbody>
</table>

Best (cost minimum) design strategy for a given pay-per-use setting, which should be adopted from the beginning!

(Lieder et al., 2017)
Lifecyle cost saving overview

Aggregated lifecycle cost (Euro) (without service activities)

Component number

Cost effects of chosen end-of-life strategies:

- REUSE: -28.49%
- REMAN: -25.47%
- RECYCLING: +38.03%

(Lieder et al., 2017)
Lifecycle material savings compared to linear scenario (15 years)

Roughly 326 tons of washing machine materials could be saved in 15 years for a given number of customers served!

(Lieder et al., 2017)
Benefits and lessons learned

- Breakdown of circular business scenarios to operational level
- Press several years into a few minutes through simulation to significantly reduce uncertainty at early design stage
- Cost, CO$_2$ and material savings over time can be quantified, explored and optimized (sustainability reporting!)
- Get a reference point if and which circular design approach may be the best choice for your business
- Get a steady-state result of your circular manufacturing system to identify suitable investments and pay-off periods for implementing the necessary infrastructure
Original article (open access)

"Towards circular economy implementation in manufacturing systems using a multimethod simulation approach to link design and business strategy"

Lieder M. et al., International Journal of Advanced Manufacturing Technology, 2017 (online)

DOI: http://dx.doi.org/10.1007/s00170-017-0610-9
CirBES is a spin-off from KTH Royal Institute of Technology

Founded by engineering professionals having backgrounds in manufacturing and sustainability

Operating as a ‘change agent’ supporting manufacturing industry to facilitate transitions from linear to circular systems

www.cirbes.se
CirBES approach

Awareness & knowledge building

→ CE learning experiences & workshops

- Focus on industrial needs
- In-depth understanding on CE
- Customized training sessions
- All formats: Lectures, workshops, seminars

Assessment & potential analysis

→ Circularity analysis

- Objective analysis and documentation
- Systematic identification of circular system potentials
- Focus on organizational capabilities
- Concrete strategic recommendations

Implementation support

→ Advisory & end-to-end support

- Clear guidance towards implementation of circular systems
- Customized arrangements in implementation projects
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