From the Digital Internet to the Physical Internet: A conceptual framework with a simple network model

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What is the Physical Internet (PI)?
The PI was initiated to...

- The Information highway gets physical, the future of logistics (Mervis et al. 2014)
- ALICE, Horizontal 2020

Transport air, congestion in cities, pollutions, new IT technologies are not fully utilized, etc.

What is missing in the PI research

- How will PI contribute to improve sustainability? (Sternberg and Norrman, 2017)
- The implementation of PI remains a challenge (Cimon, 2014; Treiblmaier et al., 2016)
Our contribution

A simple network model as a first step to support the implementation of the PI

- A study of the PI on the basis of the Digital Internet (DI)
  - Similarities and differences between the DI and the PI
  - A simple network model of the PI
  - Analysis and simple heuristic of the model
  - Use the model to support PI implementation: a simple case study
Similarities in the network structure

The Digital Internet

- Modem/cable terminal system
- Router
- PC
- Mobile phone
- Fiber cable
- Ethernet cable
- Wireless/air

The Physical Internet

- Cargo
- Standardized box
- Mixing/distribution center
- Terminal
- Road connection
- Rail connection
- Local or regional LSP
- National or global LSP

End user
Differences between the DI and the PI

The Digital Internet
- Digital signals (0/1) in standardized packets
- Near-light transmission speed
- Trivial transmission cost
- *The reachability problem*: how to transmit from A to B

The Physical Internet
- Physical objects in standardized boxes
- Lead time of transport modes
- Substantial transportation cost
- *The reachability problem*: how to ship from A to B
- *The optimality problem*: how to optimize cost, lead time, etc. dynamically
A PI model should incorporate…

- A huge number of participants
- A network with a topology
- Each participant has its weight in cost, lead time, etc.
- Dynamic weights and topology
- Reachability and optimality problems can be analyzed
The simple network model of the PI

- A graph with nodes (logistics centers) and arcs (transport connections)
- Each node/arc is associated with a weight vector $w$. The elements of the vectors represent the cost, lead time, timing, etc.
- Cost/lead time minimization from $s$ to $r$, subject to (dynamic) constraints and topology
Model analysis and solution

- Only to minimize total logistics cost: the classical travelling salesman problem (TSP)
- Only to consider delays in the network flow due to capacity constraints: the classical traffic assignment problems (TAP)
- To combine both TSP and TAP in a time-dependent network, which is larger than any transportation problems studied so far?
- Our first heuristic
A simple case study

- Cargo
- Standardized box
- Mixing/distribution center
- Terminal
- Road connection
- Rail connection
Our PI model

- Walk 3 is the current cost-minimization route
- Walk 5 is the current lead-time-minimization route

Index | Walk from vertex $s$ to vertex $r$ | Total cost | Total lead time
--- | --- | --- | ---
1 | $s \rightarrow v_1 \rightarrow v_2 \rightarrow v_3 \rightarrow v_5 \rightarrow v_7 \rightarrow v_9 \rightarrow r$ | 38 | 36
2 | $s \rightarrow v_1 \rightarrow v_2 \rightarrow v_3 \rightarrow v_8 \rightarrow v_9 \rightarrow r$ | 41 | 31
3 | $s \rightarrow v_1 \rightarrow v_2 \rightarrow v_5 \rightarrow v_7 \rightarrow v_9 \rightarrow r$ | 23* | 33
4 | $s \rightarrow v_1 \rightarrow v_3 \rightarrow v_5 \rightarrow v_7 \rightarrow v_9 \rightarrow r$ | 32 | 31
5 | $s \rightarrow v_1 \rightarrow v_3 \rightarrow v_8 \rightarrow v_9 \rightarrow r$ | 35 | 26*
After a change of the PI structure

- The connection between $v_2$ and $v_5$ is broken when the shipment reaches $v_2$

<table>
<thead>
<tr>
<th>Index</th>
<th>Walk from $v_2$ to $r$</th>
<th>Total cost</th>
<th>Total lead time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$v_2 \rightarrow v_3 \rightarrow v_5 \rightarrow v_7 \rightarrow v_9 \rightarrow r$</td>
<td>38*</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>$v_2 \rightarrow v_3 \rightarrow v_8 \rightarrow v_9 \rightarrow r$</td>
<td>41</td>
<td>31*</td>
</tr>
</tbody>
</table>

- Walk 1 is the current cost-minimization route
- Walk 2 is the current lead-time-minimization route
Summary

- A model to support PI implementation
- Understand the Physical Internet from the Digital Internet
  - Reachability problem
  - Optimality problem
- A simple PI model
  - Graph theory
  - Solution heuristics
- A simple case study
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- Sustainable Operations and Supply Chain Management
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