Towards Modeling the Structure of Product Dependencies in Supply Networks to Identify Bottlenecks Among Suppliers

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Agenda

1. Motivation
2. Supply Network Graph Model
3. Ontology
4. Limitations and Conclusion
Motivation

- Global **chip shortage** in 2021 forced car manufacturers to halt production
- One reason were **bottlenecks in the supply networks** of microchips
- Bottlenecks are suppliers with the **highest loss contributions** in consequence of a **disruption**, resulting in a high **dependency**
- Disruptions in supply networks **increase(d)**
- Bottlenecks occur due to the **structure** of supply networks
  ➢ Provide a **graph model representing the structure of supply networks** as a basis for network metrics to identify bottlenecks

TSMC as a bottleneck in BMW's supply network.
Choice of Supply Network Graph Model 1/2

- One could model the graph of a supply network through **enterprises**
- The dependency relationships between enterprises are **not (entirely) transitive**
- Model graph of supply network through **products and their supply relation**
Choice of Supply Network Graph Model 2/2

- The relation between a product and its enterprise enables to identify suppliers
- Alternative products affect dependencies
  - Model knowledge graph of supply network with an ontology
Comparison with ontology with the greatest overlap of scope from related work (PRONTO [1])

- Make ontology **usable for a wider audience** beyond ontologists
- Reduce **amount and complexity of data** required
  - Particular focus on **conciseness** (minimal number of vocabulary terms and avoidance of redundancy)

Ontology Methodology 2/3

Competency questions

Support the identification of bottlenecks among suppliers by providing data on a supply network

- How many derivational dependency paths from a product to another certain product are there in a supply network?
- How many/much of a certain product does the creation of a product require across the supply network?
- Which enterprise sells a certain product in the supply network?
Ontology Methodology 3/3

Modeling requirements

▪ Provide a representation of products that are available for (potential) customers.

▪ Provide a representation of the enterprise that sells a product.

▪ Provide a representation of derivational dependencies between products of different enterprises, specifically all dependencies where a product is (partially) consumed in the process of creating another product.

▪ Provide a representation of the quantity of a dependency.

▪ Provide a representation of a derivational dependency being split between alternative products.
Ontology Considerations

Abstraction levels of the product class from related work

- Product model vs. product instance ("a BMW iX" vs. "that blue BMW iX over there in the corner")
- Product vs. product class ("BMW iX" vs. "car")
- Product vs. product group/family ("BMW iX, superior edition, 1.8 TDI, …" vs. "BMW iX")
Ontology Result

Resulting ontology after considering concepts from related work.

Instance data for a part of BMW's iX supply network.
## Ontology Evaluation 1/2

### Concise ontology

<table>
<thead>
<tr>
<th>Metric</th>
<th>Our ontology</th>
<th>PRONTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of classes</td>
<td>3</td>
<td>35</td>
</tr>
<tr>
<td>Number of relationships</td>
<td>3</td>
<td>43</td>
</tr>
<tr>
<td>Number of leaf classes</td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td>Number of root classes</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Relationship richness</td>
<td>( \frac{3}{3} = 1.0 )</td>
<td>( \frac{17}{43} = 0.4 )</td>
</tr>
<tr>
<td>Inheritance richness</td>
<td>( \frac{0}{3} = 0.0 )</td>
<td>( \frac{26}{35} = 0.74 )</td>
</tr>
<tr>
<td>Depth of subsumption hierarchy</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Attribute richness</td>
<td>( \frac{2}{3} = 0.67 )</td>
<td>( \frac{6}{35} = 0.17 )</td>
</tr>
</tbody>
</table>

Metrics regarding ontology complexity compared with PRONTO.
Ontology Evaluation 2/2

Competency questions

▪ How many derivational dependency paths from a product to another certain product are there in a supply network?

▪ How many/much of a certain product does the creation of a product require across the supply network?

▪ Which enterprise sells a certain product in the supply network?
Limitations

- The expressiveness of our concise ontology is naturally limited compared to heavyweight ontologies like PRONTO
- The paper does not answer which network metrics to use for identifying bottlenecks
  - How to execute the calculation of metrics (with queries)?
  - How to weight and aggregate weights regarding alternative products?
  - How to determine weights if a product is only occasionally required for a variant?
  - How to consider overlapping supply networks?
Conclusion

- Ontology representing supply networks of products with derivational dependencies between them to identify bottlenecks among suppliers
- The ontology is concise and considers various concepts and definitions from existing ontologies
- Compared the ontology to PRONTO, an ontology with a similar scope