An Integrated and Adaptive Ant Colony and Genetic Algorithm for Transport Network Design

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Background

Source: Vanegas, Aliaga, Benes, Waddell (2009, Procedural (2010))
Concern – network design

1. Order
   • Volume delay function
   • Wardrop Equilibrium

2. Order
   • Determination of a subset of candidate links and nodes
   • Determination of network element types
Preliminaries – objective functions

Costs:

\[ f = \left( \text{Generalized Costs, External Costs, …, Infrastructure Budget} \right) \]

Accessibility:

\[ f = \sum_{o=1}^{O} I_o \cdot \ln \left( \sum_{d=1}^{D} A_d \cdot \exp(-\beta \cdot t_{od}) \right) - \text{Infrastructure Budget} \]
Preliminaries – search space

Potential solutions:
- 100 nodes -> $10^{103}$
- 400 nodes -> $10^{446}$
- 625 nodes -> $10^{708}$

Potential links, connectors and intersections

Demand generating node

0 200m
Design – Genetic Algorithm vs. Ant Colony Optimization
Design - Integrated Ant Colony Genetic Algorithm

Initial population

Parent population

Individual 0 - 7

Individual 8-15

Individual

Recombination: Link definition according to
$p_{ij} = f(\text{Pheromone density } ij, \text{random term})$

New networks individuals, evaluation

Best individual

Parents of other individuals

Offspring

Pheromone update

Convergence reached

Final network
Design – recombination procedure

\[ p = f("\text{pheromone}", \text{random term}) \]
Design – path picking and pheromones update

\[
p_{ij}^{g} = \begin{cases} 
\frac{e^{\alpha \tau_{ij}^{g}} e^{\beta r}}{\sum_{l_{ij} \in L_{Parents}} e^{\alpha \tau_{ij}^{g}} e^{\beta r}}, & \text{when } l_{ij} \in L_{Parents} \\
0, & \text{otherwise}
\end{cases}
\]

\[
\tau_{ij}^{g} = (1 - \delta) \cdot \tau_{ij}^{g-1} + \max(\Delta \tau_{ij}^{g})
\]

\(\tau_{ij}^{g}\): Pheromone density in iteration \(g\) on link \(i - j\).

\(\delta\): Evaporation rate.

\(\max(\Delta \tau_{ij}^{g})\): Score of the best individual out of all processed network individual.
Results – pheromone development (generation 100)
Results – capacities (generation 100)
### Results – comparison of IACGA and GA (approximation)

<table>
<thead>
<tr>
<th>Network size [nodes]</th>
<th>Objective functions evaluated [numbers]</th>
<th>Total calculation time [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GA</td>
<td>IACGA</td>
</tr>
<tr>
<td>100</td>
<td>200’000</td>
<td>54’000</td>
</tr>
<tr>
<td>225</td>
<td>1.7⋅10^8</td>
<td>140’000</td>
</tr>
<tr>
<td>400</td>
<td>~1.1⋅10^9</td>
<td>700’000</td>
</tr>
</tbody>
</table>

Source: Vitins and Axhausen (2010)
### Results – quality (420 candidate links, n = 73)

<table>
<thead>
<tr>
<th>Without degraded initial population</th>
<th>With degraded initial population</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Best possible score</strong></td>
<td><strong>Share of optimal networks</strong></td>
</tr>
<tr>
<td>-2’432</td>
<td>51%</td>
</tr>
<tr>
<td>-2’432</td>
<td>55%</td>
</tr>
</tbody>
</table>
### Application – abstract shape grammars

<table>
<thead>
<tr>
<th>Network hierarchy</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>C</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td>D</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
</tbody>
</table>

- **Set of necessary connections, at least one for each row**
- **Set of possible connections**
Application – possible shape grammars

Necessary connection

Possible connection


Link types

Possible additional rule

Multiple level node
Roundabout
Light-signal system
T-junction
Crossing
Application – implemented shape grammars

<table>
<thead>
<tr>
<th>Shape grammar</th>
<th>Initial setting 1</th>
<th>Initial setting 2 (n = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average score</td>
<td>Relative difference</td>
</tr>
<tr>
<td>A</td>
<td>-143'200</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>-147'132</td>
<td>2.75%</td>
</tr>
<tr>
<td>C</td>
<td>-116'550</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>-129'297</td>
<td>10.94%</td>
</tr>
</tbody>
</table>
Outlook

Faster and more precise…

Implement other network elements and land use parameters

Include land use and variable demand

Visualization
References