An iterated local search technique for water distribution network design optimisation

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ORBEL- January 30, 2014
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Overview

WDN
- Definitions
- Problem formulation

Test networks
- Benchmark networks
- HydroGen networks

ILS
- Sort
- Local Search
- Acceptance
- Perturbation
- Stopping criterion

Visuals

Conclusion
Water distribution network (WDN) is a network that consists of different components that transport drinking water from one or more resource nodes to multiple demand nodes.
## Optimisation of WDN

<table>
<thead>
<tr>
<th>Phase</th>
<th>Decision level</th>
<th>Decision variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layout</td>
<td>Strategic</td>
<td>System connectivity, Topology, Pump and valve placement</td>
</tr>
<tr>
<td>Design</td>
<td>Tactical</td>
<td>Pipe diameter, Pipe roughness, Pump type</td>
</tr>
<tr>
<td>Programming</td>
<td>Tactical/Operational</td>
<td>Priority order users, Pump and valve control</td>
</tr>
<tr>
<td>Planning</td>
<td>Operational</td>
<td></td>
</tr>
</tbody>
</table>

→ Use OR techniques to create decision support tools
→ Focus WDN design optimisation
Problem formulation

**WDN design optimisation**

Finding optimal pipe-configuration out of a set of discrete pipe types in terms of investment cost, with respect to hydraulic principles, energy conservation laws and customer requirements.
Problem formulation

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Finding optimal pipe-configuration out of a set of discrete pipe types in terms of investment cost, with respect to hydraulic principles, energy conservation laws and customer requirements.
Mathematical formulation

Objective:

\[
\text{minimize } \sum_{p \in P} \sum_{t \in T} L_p \ IC_t \ x_{p,t} \quad x_{p,t} \in \{0, 1\}
\]

Subject to: Mass conservation law

\[
\forall n \in N : \quad \sum_{i \in N/n} Q_{in} - \sum_{j \in N/n} Q_{nj} = D_n - S_n
\]

Energy conservation law

\[
\forall l \in L : \quad \sum_{p \in l} \Delta H_p = \sum_{p \in l} \frac{10.6668 \ y_p \ Q_p^{1.852}}{\sum_{t \in T} (x_{p,t} \ C_t^{1.852} D_t^{4.871})} = 0 \quad y_p \in \{-1, 1\}
\]

Minimal head requirement

\[
\forall n \in N : \quad H_n \geq H_n^{\text{min}}
\]
Dimensions not comparable to those of real networks.

Only very few benchmark networks available.
### Test networks: NY city tunnels problem

<table>
<thead>
<tr>
<th>Method</th>
<th>authors</th>
<th>$w$</th>
<th>total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scatter Search</td>
<td>Lin et al., 2007</td>
<td>10.5</td>
<td>36.68</td>
</tr>
<tr>
<td>Simulated Annealing 1</td>
<td>Cunha et al., 2001</td>
<td>10.5</td>
<td>37.10</td>
</tr>
<tr>
<td>Tabu Search 1</td>
<td>Cunha et al., 2004</td>
<td>10.5</td>
<td>37.13</td>
</tr>
<tr>
<td>Tabu Search 2</td>
<td>Cunha et al., 2004</td>
<td>10.5</td>
<td>37.13</td>
</tr>
<tr>
<td>Immune Algorithm</td>
<td>Chu et al., 2008</td>
<td>10.5</td>
<td>37.13</td>
</tr>
<tr>
<td>Modified Immune Algorithm</td>
<td>Chu et al., 2008</td>
<td>10.5</td>
<td>37.13</td>
</tr>
<tr>
<td>Genetic Algorithm</td>
<td>Savic et al., 1997</td>
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<tr>
<td>Genetic Algorithm</td>
<td>Lippai et al., 1999</td>
<td>10.5</td>
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<tr>
<td>Shuffled Frog Leaping Algorithm</td>
<td>Eusuff et al., 2003</td>
<td>10.7</td>
<td>38.13</td>
</tr>
<tr>
<td>Scatter Search</td>
<td>Lin et al., 2007</td>
<td>10.7</td>
<td>38.13</td>
</tr>
<tr>
<td>Ant Colony Optimisation</td>
<td>Maier et al., 2003</td>
<td>10.7</td>
<td>38.64</td>
</tr>
<tr>
<td>Ant System</td>
<td>Zecchin et al., 2005</td>
<td>10.7</td>
<td>38.64</td>
</tr>
<tr>
<td>Max-Min Ant System</td>
<td>Zecchin et al., 2006</td>
<td>10.7</td>
<td>38.64</td>
</tr>
<tr>
<td>Harmony Search</td>
<td>Geem et al., 2006</td>
<td>10.7</td>
<td>38.64</td>
</tr>
<tr>
<td>Particle Swarm Harmony Search</td>
<td>Geem et al., 2009</td>
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<td>38.64</td>
</tr>
<tr>
<td>Differential Evolution</td>
<td>Vasan et al., 2010</td>
<td>10.7</td>
<td>38.64</td>
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<tr>
<td>Scatter Search</td>
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<tr>
<td>Simulated Annealing 2</td>
<td>Cunha et al., 2001</td>
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<tr>
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<tr>
<td>Genetic Algorithm</td>
<td>Savic et al., 1997</td>
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<td>40.42</td>
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$w = \text{hydraulic coefficient}$

⇒ Benchmarks are fit to demonstrate developed techniques, not for complex algorithm testing...
Test networks: HydroGen

HydroGen algorithmically generates realistic WDNs of arbitrary size and varying characteristics.
Metaheuristics

Water distribution network design optimisation:
- Mixed-integer, non-linear optimisation problem
- NP-hard

⇒ Use metaheuristic techniques to find satisfying solution in reasonable time.

Iterated Local Search

Iteratively applies a large random change (perturbation) to the current solution, on which the local search algorithm is applied afterwards.
Algorithm 1: Iterated Local Search

\( s_0 = \text{GenerateInitialSolution}; \)
\( \text{Sort;} \)
\( s = \text{LocalSearch}(s_0); \)
\( \text{while stopping criterion not met do} \)
\( \quad s' = \text{Perturbation}(s); \)
\( \quad s^* = \text{LocalSearch}(s'); \)
\( \quad s = \text{Evaluation}(s, s^*, \text{history}); \)
WDN
Test networks

ILS
Sort
Local Search
Acceptance
Perturbation
Stopping criterion

Visuals
Conclusion

**SORT = 1**
- sort according to decreasing pipe length

**SORT = 2**
- random pipe sort

**SORT = ?**
- LS = 1
- A = 2
- PR = 20%
- iterations = 70
Local Search

LS = 1
- move: decrease diameter
- strategy: first improving
- +/- 300 seconds

LS = 2
- move: decrease diameter
- strategy: first improving
- memory
- +/- 40 sec

SORT = 1
LS = ?
A = 2
PR = 20%
iterations = 70
Acceptance criterion

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Effect of perturbation rate

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Effect of perturbation rate

LS = 1

LS = 2

PR = 20 %
PR = 40 %
PR = 60 %
PR = 80 %

SORT = 1
LS = 1 or 2
A = 2
PR = ?
iterations = 70
Stopping criterion

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LS = 1
LS = 2

SORT = 1
LS = 1 or 2
A = 2
PR = 20%
iterations = ?
Conclusion

- WDN design optimisation is a mixed integer non-linear, NP-hard problem → use metaheuristics.

- Benchmark networks are easy for demonstration, HydroGen networks for algorithm testing.

- Analysis of sort, local search, acceptance, perturbation and stopping criterion mechanisms.

- Further testing of ILS for robustness.
ILS for WDN design optimisation

Slides available at http://webhost.ua.ac.be/antor/.

Partially supported by the Research Foundation - Flanders (FWO) and the Interuniversity Attraction Poles (IAP) Programme initiated by the Belgian Science Policy Office (COMEX project).