Algorithmic generation of water distribution networks

University of Antwerp – ANT/OR
ORBEL - February 8, 2012
Annelies De Corte & Kenneth Sörensen
Table of contents

Introduction
Definition
Optimisation of WDN
Availability test data

State of the art

Our method
Requirements
Procedure
Examples
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</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Topology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pump and valve placement</td>
</tr>
<tr>
<td>Design</td>
<td>Tactical</td>
<td>Pipe diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pipe roughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pump type</td>
</tr>
<tr>
<td>Programming</td>
<td>Tactical/Operational</td>
<td>Priority order users</td>
</tr>
<tr>
<td>Planning</td>
<td>Operational</td>
<td>Pump and valve control</td>
</tr>
</tbody>
</table>

*WDN* refers to Water Distribution Networks.
→ Use OR techniques as decision support tools
→ Test developed methods on realistic WDN

But...lack of available, realistic WDN due to:

• time consuming and expensive process of:
  • data collection
  • data conversion
  • digitalisation
  • data calibration
  • data validation

• confidentiality reasons
Limited data availability leads to inability to:

- perform sensitivity analysis
- compare techniques
- make profound conclusions
- test robustness

→ need for wide range of realistic test networks...
→ generate them!
WDN generation: first attempts

New York city tunnels network \cite{Schaake&Lai1969}

Two Loop network \cite{Alperovits&Shamir1977}

14 pipe problem \cite{Gessler1985}

Hanoi network \cite{Fujiwara&Khang1990}

+ simple networks $\rightarrow$ easy-to-use for demonstration
- no pumps, tanks, valves $\rightarrow$ no realistic setting
- very few nodes and pipes $\rightarrow$ no realistic setting

Networks are fit to demonstrate, not for complex algorithm testing...
New York city tunnels network

Hanoi network

14 pipes network

Two Loop network
WDN generation: more advanced attempts

**EXNET** (Farmani et al., 2004)

**Micro- and Mesopolis** (Brumbelow, 2007)

+ based on city evolution → realistic setting

- manual construction → time consuming generation
WDN generation: more advanced attempts

Modular Design System (Sitzenfrei, 2010)
- systematic generation → extensive library
- no pumps, tanks, valves → not so realistic setting
- junctions are rectangular grid points → equal pipe lengths → no realistic setting

WaterNetGen (Muranho et al., 2012)
- systematic generation → extensive library
- varying input parameters → more realistic setting
- ex-post insertion of certain elements
Example: MDS & WaterNetGen
**Goal:** Develop a method to generate realistic WDN

**Characteristics of WDN generator tool:**
- algorithmic generation
- free adjustment of parameter settings
- free and online available
- EPANET input format
Network analysis

Water distribution network can be represented as a graph $G = (N, E)$ with set $N$ of $n$ nodes and set $E$ of $m$ edges.

$\Rightarrow$ (nearly) planar, connected, undirected graph

Analysis of 11 realistic WDN using graph theory indices:

- average degree
- maximal degree
- $\alpha$-index (meshedness coefficient)
- $\beta$-index (link-node ratio)
- $\gamma$-index (sparseness index)
Network analysis: indices

\[
0 < l \\
2 \leq k_{avg} \leq 3 \\
k_{i,\text{max}} \leq 4 \\
0.3 \leq \gamma \leq 0.5 \ll 1 \\
10^{-2} \leq \alpha \leq 10^{-1} \ll 1 \\
\beta_{avg,\text{region}} < \beta_{avg,\text{town}} \\
\gamma_{avg,\text{region}} < \gamma_{avg,\text{town}} \\
\alpha_{avg,\text{region}} < \alpha_{avg,\text{town}}
\]

(number of loops)  
(average degree)  
(maximal degree)  
(link-node ratio)  
(sparseness, link density)  
(meshedness)  
(link-node ratio)  
(sparseness, link density)  
(meshedness)

Observations:

- all networks are looped (\(l\))
- rather sparse networks (\(\gamma\))
- low connectivity (\(\gamma\))
- junctions with more than 4 pipes are exceptional (\(k_{\text{max}}\))
- small towns tend to be more clustered than regions (\(\alpha, \gamma\))
Generation steps

1. Generation of clusters
2. Generation of intra-cluster pipes
3. Addition of reservoirs, tanks and pumps
4. Generation of loops
5. Addition of inter-cluster pipes
6. Assignment of load patterns
1: Generation of clusters
2: Generation of intra-cluster pipes
3: Addition of reservoirs, tanks and pumps
4: Generation of loops
5: Addition of inter-cluster pipes
6: Assignment of load patterns
## Input parameters

<table>
<thead>
<tr>
<th>parameter</th>
<th>type</th>
<th>range</th>
<th>unit</th>
<th>standard value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>cluster characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of clusters</td>
<td>integer</td>
<td>1 – 1,000</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>clustertype*</td>
<td>integer</td>
<td>1 – 3</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td><strong>demand node characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of demand points</td>
<td>integer</td>
<td>5 – 10,000</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>elevation of demand points</td>
<td>float</td>
<td>0 – 300</td>
<td>m</td>
<td>0</td>
</tr>
<tr>
<td>base loads*</td>
<td>float</td>
<td>0 – 100</td>
<td>m³/h</td>
<td>0.00997</td>
</tr>
<tr>
<td>demand patterns*</td>
<td>float</td>
<td>0 – 50</td>
<td>-</td>
<td>0.15 - 1.5</td>
</tr>
<tr>
<td><strong>reservoir characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of reservoirs</td>
<td>integer</td>
<td>1 – 10,000</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>reservoir hydraulic head</td>
<td>float</td>
<td>1 – 50</td>
<td>m</td>
<td>30</td>
</tr>
<tr>
<td><strong>pump characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of pumps</td>
<td>integer</td>
<td>0 – 20,000</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>pump curve: data points*</td>
<td>(float, float)</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>pipe characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of loops</td>
<td>integer</td>
<td>0 – 10,000</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>pipe roughness coefficient</td>
<td>integer</td>
<td>80 – 150</td>
<td>-</td>
<td>130</td>
</tr>
<tr>
<td>demand point distance</td>
<td>integer</td>
<td>5 – 100</td>
<td>m</td>
<td>15</td>
</tr>
<tr>
<td>pipe diameter</td>
<td>float</td>
<td>10 – 500</td>
<td>mm</td>
<td>150 - 200</td>
</tr>
<tr>
<td><strong>tank characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of tanks</td>
<td>integer</td>
<td>1 – 10,000</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>bottom elevation</td>
<td>float</td>
<td>0 – 300</td>
<td>m</td>
<td>0</td>
</tr>
<tr>
<td>diameter</td>
<td>float</td>
<td>0 – 100</td>
<td>m</td>
<td>4</td>
</tr>
<tr>
<td>initial water level</td>
<td>float</td>
<td>0 – 200</td>
<td>m</td>
<td>10</td>
</tr>
<tr>
<td>minimum water level</td>
<td>float</td>
<td>0 – 200</td>
<td>m</td>
<td>0</td>
</tr>
<tr>
<td>maximum water level</td>
<td>float</td>
<td>0 – 200</td>
<td>m</td>
<td>20</td>
</tr>
</tbody>
</table>
Examples: 15 clusters
Examples: 15 clusters
Algorithmic generation of water distribution networks

Thank you for your attention