Building a Digital Twin:
Testing the Effectiveness of Telecommunication Policies in a Virtual World

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Summary

1. Decisions

2. Currently poor transparency and reproducibility

3. Digital Twin: Holds promise...

(...if produced in the right way)
Digital infrastructure **decisions** are hard
Operators *don’t* want to share data
We have few existing open-source models
Model code isn’t shared, so *can’t* be independently validated
Existing models *don’t* have a GUI and are hard for non-technical users.
Disagreement on FTTP Targets

‘...I will set a target to see full-fibre connections being available to 15 million premises, that’s the majority of homes and businesses, by 2025.’

‘We want to reach 10m premises by the mid-2020s, and believe we can ultimately fully-fibre the majority of the UK under the right conditions.’

Hammond, P. MP, Chancellor of the Exchequer (CBI Speech)

Clive Selley, CEO Openreach (Response to CBI Speech)
What is a Digital Twin?
The Digital Twin Concept

‘an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin.’

(NASA, 2010)

Schleich et al. 2017
Method

Scenarios

- Individuals
- Households
- Willingness To Pay
- Adoption Rate
Method

Scenarios

Household allocation

Individuals → Households

Willingness To Pay

Premises

Adoption Rate
Method

Scenarios

Household allocation

Network synthesis

Individuals → Households

Willingness To Pay

Premises

Multi-level Network

Adoption Rate
Method

Scenarios

Household allocation

Network synthesis

Strategies

- Individuals
- Households
- Willingness To Pay
- Premises
- Multi-level Network
- FTTdp
- FTTP
- Adoption Rate
- Asset Costs
- Market Subsidies
Method

Scenarios
Individuals → Households

Household allocation

Network synthesis
Premises → Multi-level Network

Strategies

FTTdp, FTTP

Decisions
Revenue → Cost

Adoption Rate

Willingness To Pay

Market Constraints
Asset Costs
Market Subsidies

Revenue Decisions
Cost

Network synthesis
Method
Method

Scenarios
- Individuals
- Households
- Willingness To Pay
- Adoption Rate

Household allocation
- Premises
- Multi-level Network

Network synthesis
- FTTdp
- FTTP

Strategies
- Revenue
- Cost

Decisions
- Asset Costs
- Market Subsidies
- Market Constraints

Cost-Benefit Ratio
Individuals → Households → Willingness To Pay → Adoption Rate

Scenarios

Household allocation

Network synthesis

Strategies

Decisions

Results

Premises → Multi-level Network

FTTdp → FTTP

Revenue → Cost

Cost-Benefit Ratio

Premises Passed → Premises Connected

Asset Costs → Market Subsidies → Market Constraints
Method: High-Resolution Demand Data

\[
\text{Propensity to adopt } (p_i) = a_i \cdot b_i \cdot c_i \cdot d_i \cdot e_i
\]

Probabilities taken from the Ofcom (2017) Technology Tracker for propensity to adopt >30 Mbps
Method: Scenario Adoption
## Method: Synthetic Network Structure

<table>
<thead>
<tr>
<th>Data category</th>
<th>Data</th>
<th>Source</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply-side</td>
<td>Postcode to exchange data</td>
<td>Openreach</td>
<td>2011, 2013</td>
</tr>
<tr>
<td>Supply-side</td>
<td>Postcode to cabinet data</td>
<td>Openreach</td>
<td>2011, 2013</td>
</tr>
<tr>
<td>Boundaries</td>
<td>Postcode polygons</td>
<td>Ordinance Survey</td>
<td>2012 (October)</td>
</tr>
<tr>
<td>Supply-side</td>
<td>Broadband technology by postcode</td>
<td>Ofcom</td>
<td>2017</td>
</tr>
<tr>
<td>Boundaries</td>
<td>Local Authority District polygons</td>
<td>ONS</td>
<td>2016</td>
</tr>
<tr>
<td>Supply-side</td>
<td>Urban Local Authority Districts by city and size</td>
<td>Analysys Mason</td>
<td>2008</td>
</tr>
<tr>
<td>Demand-side</td>
<td>Premises points data</td>
<td>Ordinance Survey</td>
<td>2016</td>
</tr>
<tr>
<td>Supply-side</td>
<td>Exchange points</td>
<td>SamKnows</td>
<td>2017</td>
</tr>
</tbody>
</table>
# Method: Synthetic Network Structure

<table>
<thead>
<tr>
<th>Geotype</th>
<th>Classification</th>
<th>Exchanges</th>
<th>Average lines per exchange</th>
<th>Cabinets</th>
<th>Average lines per cabinet</th>
<th>Distribution points</th>
<th>Average lines per distribution point</th>
<th>Average line length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner London</td>
<td>Inner London</td>
<td>86</td>
<td>16,812</td>
<td>2,892</td>
<td>500</td>
<td>172,118</td>
<td>8.4</td>
<td>1.24</td>
</tr>
<tr>
<td>&gt;500k pop</td>
<td>Major City (pop = 500k+)</td>
<td>204</td>
<td>15,512</td>
<td>6329</td>
<td>500</td>
<td>376,721</td>
<td>8.4</td>
<td>1.78</td>
</tr>
<tr>
<td>&gt;200k pop</td>
<td>City (pop = 200k+)</td>
<td>180</td>
<td>15,527</td>
<td>5,590</td>
<td>500</td>
<td>332,713</td>
<td>8.4</td>
<td>1.8</td>
</tr>
<tr>
<td>&gt;20k lines (a)</td>
<td>&gt;20,000 lines, &lt;2km from the exchange</td>
<td>167</td>
<td>17,089</td>
<td>6,008</td>
<td>475</td>
<td>365,886</td>
<td>7.8</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt;20k lines (b)</td>
<td>&gt;20,000 lines, &gt;2km from the exchange</td>
<td>167</td>
<td>10,449</td>
<td>4,362</td>
<td>400</td>
<td>223,708</td>
<td>7.8</td>
<td>4.83</td>
</tr>
<tr>
<td>&gt;10k lines (a)</td>
<td>&gt;10,000 lines, &lt;2km from the exchange</td>
<td>406</td>
<td>10,728</td>
<td>9,679</td>
<td>450</td>
<td>604,925</td>
<td>7.2</td>
<td>1.4</td>
</tr>
<tr>
<td>&gt;10k lines (b)</td>
<td>&gt;10,000 lines, &gt;2km from the exchange</td>
<td>406</td>
<td>3,826</td>
<td>4,142</td>
<td>375</td>
<td>215,740</td>
<td>7.2</td>
<td>4.0</td>
</tr>
<tr>
<td>&gt;3k lines (a)</td>
<td>&gt;3,000 lines, &lt;1km from the exchange</td>
<td>1,003</td>
<td>2,751</td>
<td>13,455</td>
<td>205</td>
<td>493,569</td>
<td>5.6</td>
<td>0.73</td>
</tr>
<tr>
<td>&gt;3k lines (b)</td>
<td>&gt;3,000 lines, &gt;1km from the exchange</td>
<td>1,003</td>
<td>3,181</td>
<td>22,227</td>
<td>144</td>
<td>570,745</td>
<td>5.6</td>
<td>4.83</td>
</tr>
<tr>
<td>&gt;1k lines (a)</td>
<td>&gt;1,000 lines, &lt;1km from the exchange</td>
<td>1,230</td>
<td>897</td>
<td>5,974</td>
<td>185</td>
<td>246,555</td>
<td>4.5</td>
<td>0.62</td>
</tr>
<tr>
<td>&gt;1k lines (b)</td>
<td>&gt;1,000 lines, &gt;1km from the exchange</td>
<td>1,230</td>
<td>935</td>
<td>9,343</td>
<td>123</td>
<td>257,043</td>
<td>4.5</td>
<td>4.09</td>
</tr>
<tr>
<td>&lt;1k lines (a)</td>
<td>&lt;1,000 lines, &lt;1km from exchange</td>
<td>2,302</td>
<td>190</td>
<td>0</td>
<td>0</td>
<td>130,706</td>
<td>3.4</td>
<td>0.52</td>
</tr>
<tr>
<td>&lt;1k lines (b)</td>
<td>&lt;1,000 lines, &gt;1km from exchange</td>
<td>2,302</td>
<td>305</td>
<td>0</td>
<td>0</td>
<td>209,571</td>
<td>3.4</td>
<td>4.26</td>
</tr>
<tr>
<td><strong>National Figure:</strong></td>
<td></td>
<td>5,578</td>
<td>4,886</td>
<td>90,000</td>
<td>303</td>
<td>4,200,000</td>
<td>6.5</td>
<td>2.33</td>
</tr>
</tbody>
</table>
Let’s use a subset for Cambridgeshire as an example.
Method: Objects
Method: FTTC, FTTdp and FTTP

Point of Presence (Exchange)

Primary Connection Point (Cabinet)

Distribution Point

Premises

<table>
<thead>
<tr>
<th>Asset</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre per metre</td>
<td>£10</td>
</tr>
<tr>
<td>Optical Connection Point</td>
<td>£45</td>
</tr>
<tr>
<td>G. Fast distribution point</td>
<td>£200</td>
</tr>
<tr>
<td>FTTP Customer Premises Equipment</td>
<td>£74</td>
</tr>
<tr>
<td>FTTdp Customer Premises Equipment</td>
<td>£37</td>
</tr>
</tbody>
</table>

(All capex costs taken from Tactis and Prism, 2018 for HM Treasury)

(Tactis and Prism, 2018 for HM Treasury)
Technology Rollout by Scenario and Strategy

Expected Investment Return Period: 4 Years

- Low Adoption
- Baseline Adoption
- High Adoption

Exogenously specified adoption
Technology Rollout by Scenario and Strategy

Expected Investment Return Period: 4 Years

- Low Adoption
- Baseline Adoption
- High Adoption

Percentage of Premises (%)

Year

Adoption Desirability, FTTdp Passed, FTTdp Connected

Marked Rollout, Targeted Subsidy
Want to adopt but haven’t been passed

FTTdp Passed
FTTdp Connected
FTTP Passed
FTTP Connected
Want to adopt but haven’t been passed
Want to adopt but haven't been passed

Premises passed exceeds demand
Software Architecture

1. **Portal**
   - JS
   - Job submit/status/results

2. **REST**
   - Get Results
   - Send the job to queue

3. **Job Queue**
4. **Results Store**
   - Store Results
5. **Application DB**
   - Store Job parameters

6. **Model**
   - python

The diagram illustrates the flow of a job submission, status, and results through a portal, REST API, job queue, results store, and application database.
An Application as a Service is in development which allows non-technical users to run the model from a browser.
Obtain model results

Option to run sensitivity analysis

Results mapped spatially using OpenStreetMap

Users can interrogate individual areas if desired
The Cambridge Communications Assessment Model

(click on the 'docs' button to get directed to the full model documentation)

The Cambridge Communications Assessment Model currently focuses on the mobile sector to provide analytics for decision-makers on (i) capacity-demand and (ii) risk, vulnerability and resilience. The fixed, wireless and satellite sectors are currently under development.

Setup and configuration

All code is written in Python (Python>=3.5), avoiding external dependencies.

A word from our sponsors

The Cambridge Communications Assessment Model was written and developed at the Judge Business School, University of Cambridge and at the Environmental Change Institute, University of Oxford within the EPSRC-sponsored MISTRAL programme, as part of the Infrastructure Transition Research Consortium.

Install

For development purposes:

Run this command once per machine:

www.github.com/nismod/digital_comms
How may the Digital Twin concept enhance our existing approach to testing policy options?
What characteristics does a Digital Twin require?
Why may a Digital Twin help support better decisions?
Contribution:

Development of an **open-source** fixed broadband assessment framework
Building a Digital Twin:
Testing the Effectiveness of Telecommunication Policies in a Virtual World

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