BU LRIC model methodology

A REPORT PREPARED FOR THE ILR

April 2014

Contents

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Contents

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1 Introduction

This document forms part of the call for inputs by the Institut Luxembourgeois de Régulation (ILR) on the development of a bottom-up long run incremental cost model (BU-LRIC) to ensure the SMP operator's compliance with its cost orientation obligations.

The purpose of this document is to provide greater transparency over the structure of the BU LRIC model and the calculations in general. This is to enable stakeholders to comment on the methodology used.

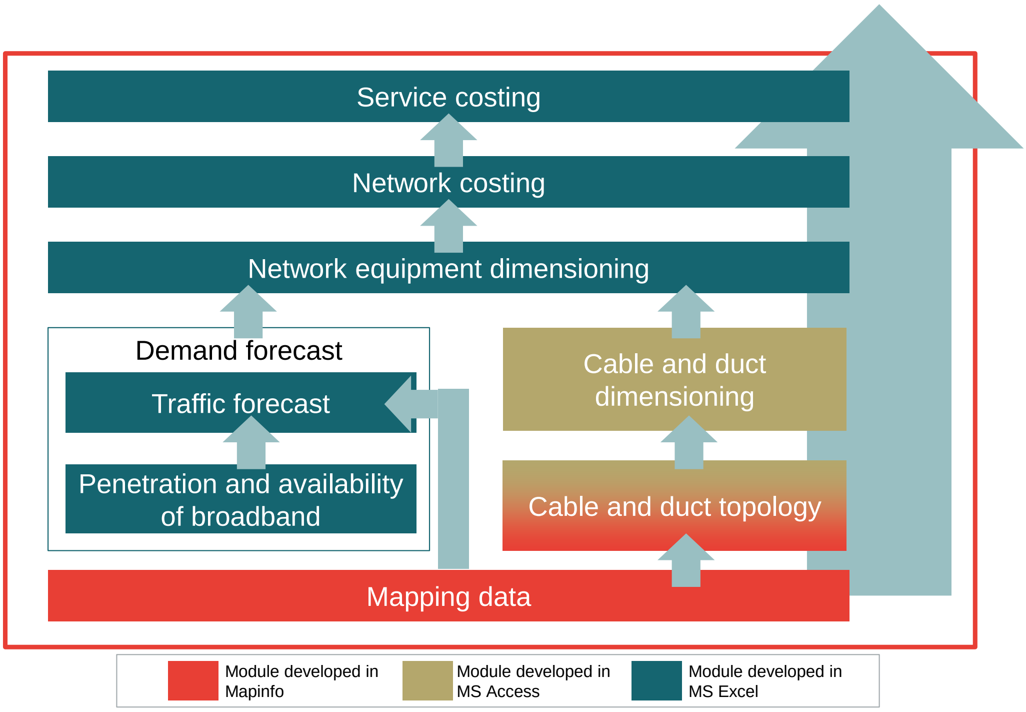
1.1 Structure of the model

As described in Section 2 of the Model Specification document, the bottom-up modelling process consists of three main stages:

- Development of demand forecast;
- Calculation of network requirements; and
- Costing.

The model is therefore structured in three modules, each of which corresponds to one of these stages. As described in further detail below, the ILR model is developed using Microsoft Office 2010 and using MapInfo software to analyse the geographic information system (GIS) data. The colour coding in the figure below indicates the software used for each calculation step. For efficiency reasons, the parts of the model conducted in Excel have been consolidated in a single file. Due to the volume of geographic data used, the MS-Access model consists of a number of linked databases.

Figure 1. Modules, calculation steps, and software used in the bottom-up model



1.2 Structure of methodology document

The rest of this document sets out how the approach described in the model specification document is implemented in practice. This document follows the structure used in the models. In particular:

- Section 2 describes the scenario manager and results section of model;
- Section 3 describes the demand calculations;
- Section 4 describes the GIS based modelling of the cable and duct network implemented in MS Access;
- Section 5 describes the POP data copied from the MS Access model into the Excel file.
- Section 6 describes the other network dimensioning calculations; and
- Section 7 describes the costing calculations.

2 Results and sensitivity analysis

The first section of the model summarises the model results and presents the results of the sensitivity analysis. This is outlined in the table below. These are described in further detail in this section.

Table 1. Results and sensitivity analysis

Worksheet	Description
Results	This worksheet presents a summary of the costs of the services modelled under the model settings as they are defined in the sensitivity input sheet.
Sensitivity input	This worksheet presents a list of all the key input assumptions that feed into the model. The default setting is the model 'base case'. However, for each setting alternative options are provided and the model settings can be changed here. The settings that are selected in this worksheet define the 'current' model settings.
Sensitivity output	This worksheet presents the output of the sensitivity analysis. This lists the costs of key services modelled under alternative model settings. This is to observe how sensitive the overall results are to changes to the model settings.

Source: BU LRIC model

The results and sensitivity analysis section appears at the beginning of the model. This is to ensure that the model inputs are used consistently throughout the rest of the model. This also allows the model user to consider how the results change following a change to the input assumptions.

2.1 Results

The main output of the model is the cost of various services. The services fall under the following categories:

- Voice calls;
- Wholesale line rental;
- Wholesale infrastructure access;
- Wholesale broadband access; and
- Data transmission services.

The model reports the cost of services for each year in the period 2013-2017 inclusive.

2.2 Sensitivity inputs

The key input assumptions used are summarised in the table below. These can be found in the worksheet 'Sensitivity_input'. The settings that are defined in this worksheet feed into the model and impact the overall results. This enables the user to consider how the overall model results change following a change to the input assumptions.

Table 2. Key inputs to the model

Input assumption	Description
WACC[1]	Weighted average cost of capital
Traffic	Expected annual increase in traffic per subscriber
Access network technology	Mix of access network technology used (Copper to MDF/ FTTC/ FTTH – GPON/ FTTH - P2P)
Trench sharing	Proportion of trench shared with other utility providers
Opex	Operational expenditure (opex) split between the access network and the core network
Working life of asset	Asset lives used for different categories of network equipment
MEA price trend	Forecast annual change in price for modern equivalent assets for different categories of network equipment
Common cost mark-ups	Level of common costs
Trenching costs	Cost of trenching per metre in different morphology types
Jointing chambers	Cost of jointing chambers in different morphology types
Distance between jointing chambers	Distance between jointing chambers in different morphology types
Number of POPs	Number of points of presence (POPs) in the modelled network

BU LRIC model

The scenario manager contains a defined base case for each of the key input assumptions. This allows the user to return to the base case input assumptions following any user defined changes to the current model assumptions.

The scenario manager also contains a number of pre-defined alternative scenarios. These are set so that one input assumption is changed relative to the base case. For example, the model user can select an alternative input for the WACC. The pre-defined alternative scenarios include a 'high WACC' scenario and 'low WACC' scenario.

2.3 Sensitivity outputs

The pre-defined scenarios described above are used to run the sensitivity analysis macro. In particular, the sensitivity analysis macro runs the model under each of the pre-defined scenarios in turn in order to test how sensitive the model results are to changes in the key input assumptions. The results of the sensitivity analysis are pasted into the 'Sensitivity output' worksheet. For example the 'Sensitivity outputs' sheet contains the main model results under the 'high WACC' scenario, 'low WACC scenario', etc.

[1] The NGA risk premium is also defined here although no pre-defined sensitivity alternative scenario for this is built into the model for sensitivity analysis.

3 Demand module (DEM)

The table below summarises the sheets in the demand module. The type of input data used in these sheets and the calculations are described in further detail in the rest of this section.[2]

[2] The actual data used in the model is described in a separate document

Table 3. Demand module calculations –sheets (Demand module - DEM)

Section heading	Sub-section heading	Description of input data/calculations
DEM - Assumptions and inputs		
	DEM - Assumptions	Assumptions for FTTH coverage
DEM - Calculations		
DEM - Voice	DEM - Voice by tech	Calculation of network voice subscribers and network voice traffic
DEM - Broadband	DEM - Broadband by tech	Calculation of network broadband subscribers and broadband traffic
DEM - Corporate	DEM - Corporate by tech	Calculation of network leased lines and data traffic per subscriber
DEM - Outputs	DEM - National by Tech	Summary of relevant demand forecasts at the national level (takes inputs from the preceding sheets)
	DEM – Customers by POP	List of POPs in the network with information on the number of buildings, businesses and households per POP
	DEM – Customers by DP	List of distribution points (DPs) in the network with information on the number of buildings, businesses and households per DP
	DEM - Cu to rem agg node (FTTC)	Estimation of how national FTTC demand is spread over remote nodes (subscribers and traffic)
	DEM - Cu to PoP (legacy)	Estimation of how national copper demand is spread over POPs (subscribers and traffic)
	DEM - FTTH-GPON to PoP	Estimation of how national FTTH GPON demand is spread over POPs (subscribers and traffic)
	DEM - FTTH-P2P to PoP	Estimation of how national FTTH P2P demand is spread over POPs (subscribers and traffic)

3.1 DEM – Assumptions and inputs

3.1.1 DEM – Assumptions

This sheet contains input assumptions relating to FTTH coverage, and its growth over time. This is split between:

- GPON coverage (measured as a percentage of premises covered); and
- P2P coverage (measured as a percentage of premises covered)

3.2 DEM – Calculations

This section of the model consists of three sheets, which contain demand calculations. This is split between the following types of traffic:

- Voice;
- Broadband; and
- Corporate

These are described in further detail below.

3.2.1 DEM – Voice by tech

Summary

The output of this sheet is:

- Network subscribers by access technology;
- Traffic per subscriber in bhkbps (busy hour kilobits per second); and
- Total voice traffic (calculated by multiplying voice traffic per subscriber by the number of subscribers).

Market voice lines

This sheet estimates the total number of voice lines.

This estimate is technology neutral and therefore includes voice lines provided over PSTN, ISDN and VOIP.

Assumptions

This section contains input assumptions relating to:

- Percentage of broadband subscribers purchasing voice lines;
- Voice only technology mix (i.e. the technology that voice lines are provided over – copper to MDF/ FTTC/ FTTH);

- Conversion of minutes to bandwidth (minutes per year per Erlang and voice codec rate); and
- Conversion of minutes to busy hour call attempts – BHCA (average call duration, call attempts per call, average call duration).

Voice lines by technology

This section calculates the total number of voice subscribers on the network by access technology type (copper to MDF, FTTC, FTTH GPON, FTTH P2P). This starts with an estimate of the total number of broadband lines by technology (from the 'DEM - Broadband by tech' sheet).

This is then multiplied by the percentage of broadband subscribers purchasing voice (as set out in the assumptions section above) to estimate the number of voice lines provided with a broadband line.

The remaining voice lines (as estimated in the market voice lines section above) are provided without broadband.

Voice traffic

The estimated voice traffic per subscriber in bhkbps is calculated in this sheet by:

- Taking the forecast voice traffic per subscriber in minutes; and
- Using the conversion of minutes to bandwidth (this uses input data on the minutes per year per Erlang and the voice codec rate).

3.2.2 DEM –Broadband by tech

Summary

The output of this sheet consists of:

- Network subscribers by access technology type (copper to MDF, FTTC, FTTH- GPON, FTTH P2P); and
- Traffic per subscriber in bhkbps.

Market broadband lines

This section contains assumptions relating to:

- Growth of the broadband line market (percentage change per year); and
- Split of broadband lines between retail and wholesale. That is, the split of lines that are provided by the modelled operator at the retail level directly to end users, and those provided by alternative operators buying wholesale access to the modelled network.

These assumptions are used to estimate the forecast of broadband lines provided at the market level and then the number of retail and wholesale broadband lines provided by the modelled operator.

Assumptions

This section contains assumptions relating to:

- Broadband mix, in other words, the proportion of total modelled lines that offer different speeds – standard (up to 24 Mbps), superfast (24-30 Mbps and ultrafast (50 Mbps and faster);
- Standard broadband technology mix (i.e. the access technology standard broadband lines are provided over – copper to MDF/ FTTC/ FTTH);
- Superfast broadband technology mix (i.e. the access technology superfast broadband lines are provided over – FTTC and FTTH);
- Forecast growth in bandwidth per subscriber; and
- Broadband bandwidth per subscriber for different speeds of broadband (standard/superfast/ ultrafast).

Broadband lines by speed and technology

This section estimates the year end number of broadband lines by speed (standard/superfast/ultrafast). This takes the estimate of the total number of lines (as calculated in the 'Market broadband lines' section above) and multiplies by the broadband mix (as set out in the 'Assumptions' section above).

The number of broadband lines by speed is then multiplied by the technology mix for each speed category (as set out in the 'Assumptions' section above).

The final table in this section calculates the number of GPON lines as a percentage of the number of FTTH lines. These are used in the 'DEM-National by Tech' worksheet of the model.

Broadband bandwidth by speed and technology

This section takes the bandwidth in bhkbps for different speeds of broadband (standard/superfast/ultrafast) calculated in the 'Assumptions' section of this sheet. This is then used to calculate the bandwidth by access technology (copper to MDF, FTTC, FTTH) by calculating an average by speed weighted by number of lines provided over each access technology.

Raw data

This section contains raw data provided used to derive the assumptions used in this worksheet. The data here relates to:

- Historic and forecast total retail/wholesale/full LLU broadband subscribers;
- Historic and forecast broadband subscribers by speed (standard/superfast/ultrafast); and
- Historic and forecast broadband subscribers by access technology (FTTC/FTTH GPON).

3.2.3 DEM – Corporate by tech

Summary

The output of this sheet is:

- The number of corporate subscribers by access technology (copper to MDF/ FTTC/ FTTH GPON/ FTHH P2P); and
- The traffic per line in bhkbps by access technology.

Corporate lines

The model forecasts the number of corporate lines by speed:

- Low speed traditional (less than 2Mbit/s);
- High speed traditional (2 Mbit/s and over);
- Gigabit Ethernet; and
- 10G Ethernet.

This is calculated by taking the number of lines in the previous year and applying the forecast annual change in the number of lines.

Assumptions

The model uses assumptions relating to the access technology mix (copper to MDF/ FTTC/ FTTH GPON/FTTH P2P) for each speed of leased line.

This section also contains input assumptions relating to bandwidth per line for each speed of leased line. This is based on raw data which is inputted the bottom section of this sheet.

Corporate lines by speed and technology

This section forecasts the number of corporate lines by speed and by technology. This is calculated by taking the forecast of the corporate lines by speed (from the 'Corporate lines' section of this sheet) and multiplying by the assumed technology mix (as set out in the 'Assumptions' section of this worksheet).

Corporate bandwidth by technology

This section forecasts the total bandwidth for each access network technology in bhkbps. This takes the number of lines (from the 'Corporate lines by speed and technology' above) and multiplies by the bandwidth per line by speed (as set out in the 'Assumptions' section above).

This is then used to estimate the bandwidth per line by access network technology.

Raw data – lines

This section sets out the raw data relating to the number of leased lines. This contains both actual and forecast data. This is used to determine the forecasts in this worksheet.

Raw data – bandwidth

This section contains raw data relating to bandwidth on leased lines by access network technology and speed. This relates to both actual and forecast data. This is used to estimate the bandwidth per line.

3.3 DEM – Outputs

This section of the model summarises the outputs of the calculations relating to demand that are set out in the preceding sheets. This is then used to estimate how demand is spread geographically. This in turn is used in the network dimensioning sheets to determine the amount and type of network equipment required to meet this demand.

3.3.1 DEM - National by Tech

This worksheet summarises all relevant demand forecasts on a national basis.

National summary

This section summarises the main results from the previous sheets. It takes the outputs from the following sheets (all of which are described above):

- 'DEM – Voice by tech' – total voice subscribers, voice traffic per subscriber, and the total number of 'voice only' subscribers;
- 'DEM – Broadband by tech' – total broadband subscribers and broadband traffic per subscribers; and
- 'DEM – Corporate by tech' – total leased lines and corporate traffic per line.

This section also summarises the total number of accesses across the following subscribers types:

- Voice only;
- Voice and broadband;
- Broadband only; and
- Corporate.

This is to avoid the double-counting of subscribers across the different services.

Copper to MDF

This section summarises the demand, at the national level, served over copper to the MDF access technology. This takes the relevant information from the following sheets:

- 'DEM – Voice by tech' – voice subscribers served over copper to the MDF access technology and the associated voice traffic per subscriber;
- 'DEM – Broadband by tech' – broadband subscribers served by copper to the MDF access technology and the associated broadband traffic per subscribers; and
- 'DEM – Corporate by tech' – leased lines served by copper to the MDF access technology and the associated corporate traffic per line

FTTC

This section is similar to the 'Copper to MDF' section described above but for the demand served over FTTC access technology only.

FTTH GPON

This section is similar to the 'Copper to MDF' section described above but for the demand served over FTTH GPON access technology only.

FTTH P2P

This section is similar to the 'Copper to MDF' section described above but for the demand served over FTTH P2P access technology only

Summary – across technologies

This section summarises the total level of demand served over different access technologies.

- Total traffic across services (split between voice, broadband, corporate, VOD)
  - This is calculated by taking data on traffic per subscriber and the total number of subscribers from the sections above.

- Proportion of total traffic accounted for by the different services (voice, broadband, corporate, VOD)
  - This is calculated by taking data on total traffic from the section directly above.
- Accesses by technology type
  - This is the total number of lines (voice only, voice and broadband, broadband only, and corporate) served over each access network technology (copper to MDF/FTTC/ FTTH GPON/ FTTH P2P).

3.3.2 DEM – Customers by POP

This worksheet lists every POP in the network. For each POP, there is raw data on:

- The number of buildings served by the PoP;
- The number of the buildings that are vacant;
- The number of businesses in these premises; and
- The number of households in these premises.

This data comes from the MS Access module, and it is used in order to map national demand to individual POPs.

Depending on the model setting, the relevant information is drawn from the section on 'POP inputs' described in Section 7.

3.3.3 DEM – Customers by DP

This worksheet is similar to the worksheet 'DEM – Customers by POP'. Every distribution point (DP) in the network is listed, along with raw data on:

- The number of buildings;
- The number of vacant buildings;
- The number of businesses; and
- The number of households.

3.3.4 DEM - Copper to remote aggregation node (FTTC)

This sheet takes the national demand from subscribers served over FTTC access technology and allocates it to the DPs listed in the worksheet 'DEM – Customers by DP'.

The allocation is based on the sum of households and businesses in each node area. For example, if one DP has 5% of all households and businesses in Luxembourg, then 5% of all FTTC subscribers are allocated to that particular DP.

3.3.5 DEM - Copper to PoP (legacy)

This sheet performs the same calculations described above, but for subscribers using legacy copper access technology, and their associated traffic. This demand is allocated across the POPs listed in the worksheet 'DEM – Customers by POP'

3.3.6 DEM - FTTH-GPON to PoP

This sheet performs the same calculations described above, but for subscribers using GPON fibre access technology, and their associated traffic.

3.3.7 DEM - FTTH-P2P to PoP

This sheet performs the same calculations described above, but for subscribers using P2P fibre access technology, and their associated traffic

4 Cable and duct module

The cable and duct module was developed in MS Access and is made up of eight databases which are summarised in the table below. The input data used in these databases and the calculations are described in further detail in the rest of this section.

Table 4. Network topology module – databases

Database file name	Description of input data/calculations
GIS data	Includes input data on the road network, customer premises an d the distance between network nodes and road intersections ('GIS nodes')
Nodes	Includes input assumptions on distribution points (DPs), points of presence (PoPs), aggregation points and core nodes in the modelled network
Houses to roads	Calculates the number of customer premises per road section and per side of the road section
LCR – DPs	Calculates the routes from road intersections (GIS nodes) to their closest distribution point along the road network
LCR – PoPs	Calculates the routes from distribution points to the PoP sites
LCR – Core	Calculates the routes from Core sites to establish Voronoi polygons around each core site which are then used as inputs to the calculation of routes between core sites
Cable and duct	Generates a list of all street segments with installed duct and calculates the total capacity requirement for copper pairs and fibres
Core routes	Calculates the core duct routes between the collection of PoP sites and aggregation node sites which make up the core sites

All databases include tables, which store inputs, assumptions, intermediate results and outputs and queries, which process the data through a series of intermediate calculations. Except for 'GIS-data' and 'Nodes', all databases also include Visual Basic (VB) modules that run the queries in a specific order. In general, VB code is not used for calculations, with the exception of some custom functions in 'Houses to roads'.

The rest of this section is structured as follows.

- Sections 4.1, 4.3 and 4.3 describe 'GIS data', 'Nodes' and 'Houses to roads' respectively. These descriptions follow the order of the output tables in the database (this includes a description of the queries used to generate these output tables).

- The databases 'LCR-DPs', 'LCR-Pops' and LCR Core calculate the least cost routing at different levels of hierarchy in the network. These are described in Section 4.4, 4.5 and 4.6 following the structure of the respective VB module that runs the queries and generates output tables. Both least cost routing databases follow a similar structure, therefore only one is described in full detail in Section 4.4.

- The database 'Core routes' described in Section 4.7 calculates the least cost routing for the core network, which provides for physical route redundancy (i.e. the network is built up from rings).

- 'The cable to duct' module is described in Section 4.8 following the structure of the VB module that runs the queries and generates output tables.

4.1 GIS data

This database includes input data on the road network, customer premises and the distance between network nodes and road intersections ('GIS nodes').

This database provides a common set of input data to the other databases and contains no model calculations or queries.

The 'GIS data' database consists of seven tables and, the sub-headings below provide more detail on each table.

4.1.1 Matched addresses

This table contains input data on buildings and potential customers in Luxembourg. The geographic location of the buildings is defined in the LUREF format (Luxembourg 1930 / Gauss projection). It also contains information on the number of business and residential occupants and the number of estimated households in each building. The number of households is estimated applying a mapping from the number of resident persons to the number of households, with the number of households increasing as the number of resident persons increase (e.g. where there are up to four residents, it is assumed that this is a single household, 5 to 6 there are two households etc.). This means that in each premise there is an integer number of estimated households. The mapping has been calibrated such that the sum of the estimated households across all premises is similar to the estimated number of households for Luxembourg as a whole.

4.1.2 GIS nodes

This table contains data on road intersections ('GIS nodes') in the road network of Luxembourg. A road intersection is defined as either a junction between two or more roads, or the end-point of a road. The geographic location of the GIS nodes is defined in the LUREF format (Luxembourg 1930 / Gauss projection).

4.1.3 GIS lines

This table contains information on road sections in the road network of Luxembourg. A road section is defined as a part of a road between two GIS nodes. The table includes information on the length of each road section and the corresponding GIS nodes ('From_node', 'To_node').

4.1.4 Addresses with nearest nodes

For each potential customer building in the table 'Matched addresses', this table contains data on the closest GIS node from the table 'GIS nodes' (measured along the road network). The table includes the distance between the potential customer building and the closest GIS node as the crow flies.

4.1.5 Nearest_PoP_Cu_roadintersection

This table contains information on the location of the MDF sites in the modelled network and the closest GIS node from the table 'GIS nodes' for each PoP. The distance is measured as the crow flies.

4.1.6 PoP_ftth_nodes

This table contains information on the location of FTTH sites in the modelled network and the closest GIS node from the table 'GIS nodes' for each PoP. The distance is measured as the crow flies.

4.1.7 Nearest_PoP_VDSL_roadintersection

This table contains information on the location of distribution points (DPs; or sites of a node in the FTTC network) in the modelled network and the closest GIS node from the table 'GIS nodes' for each PoP. The distance is measured as the crow flies.

4.2 Nodes

This database includes input assumptions on the distribution points, PoPs, aggregation points and core nodes used to define the network structure. It allows the calculation of alternative scenarios of the number of PoP locations.

The 'Nodes' database consists of two tables (and three additional input tables that are linked to the database 'GIS data' described above) and three queries. The queries in this database are used to create the input tables. The sub-headings below provide more detail on each table. The relevant queries for each table are highlighted in bold in the respective sections.

4.2.1 DP nodes

This table contains information on the location of distribution points (DPs; or sites of a node in the FTTC network) in the modelled network and the closest GIS node for each PoP.

The query **'Create DPs from VDSL sites'** inserts data from the table 'Nearest_PoP_VDSL_roadintersection' (from the database 'GIS data') into the table.

4.2.2 PoP nodes

This table contains information on the location of PoPs in the modelled network and the closest GIS node for each PoP.

This table can be populated by the queries **'Create PoPs from FTTH sites'** and **'Create PoPs from MDF sites'** which insert data from the tables 'Nearest_PoP_VDSL_roadintersection' and 'PoP_ftth_nodes' (both from the database 'GIS data') respectively.

4.2.3 Aggregation nodes

This table contains information on the location of aggregation nodes in the modelled network and the closest GIS node for each node. The locations are based on the location of the Copper-DLU sites.

The query **'Create Agg nodes from DLU sites'** inserts data from the table 'Nearest_PoP_Cu_roadintersection' (from the database 'GIS data') into the table.

4.2.4 Core nodes

This table contains information on the location of core nodes in the modelled network and the closest GIS node for each node.

The query **'Create Core nodes from PoP sites'** inserts data from the table 'PoP nodes' into the table. The query **'Add Agg nodes to Core'** adds any additional aggregation node sites (sites that are not already included as they are not a PoP site) to the table 'Core nodes'.

4.3 Houses to roads

This database calculates the number of potential customer premises per GIS line (road section) and whether premises are located on one or both sides of the GIS line for each road section in the network.

The database consists of seven tables (and four additional input tables that are linked to the database 'GIS data' described above), nine queries and three VB modules. The sub-headings below provide more detail on each of the output tables.

The relevant queries and VB functions for each table are highlighted in bold in the respective sections. The VB module 'Macros' runs the queries in the database in consecutive order and is not described in more detail below.

4.3.1 C1 Lines from nodes

This table assigns each road segment to one of its two GIS nodes.

The table includes information on the angle (calculated as ratio of two sides of a right triangle) between each GIS node and all of the corresponding GIS lines which have one end terminating in the node using the VB function **'atan2'**. The angle is calculated using the two queries **'1 Create lines from nodes 1'** and **'2 Create lines from nodes 2'** to map the two ends of each road segment to the corresponding node.

4.3.2 C2 House angle from node

For each potential customer premise in the table 'Addresses with nearest nodes', this table includes information on the angle between the premise and the nearest GIS node. This is calculated using the query **'3 Create house angle from node'**. To calculate the angle, the query uses the VB function **'atan2'**.

4.3.3 C3 Compare lines and houses

For each potential customer premise in the table 'Addresses with nearest nodes', this table includes information on the difference in the angle between the premise and all the GIS lines measured from the corresponding GIS nodes.

This is calculated as a comparison between the information in tables 'C1 lines from nodes' and 'C2 house angle from node' using the query **'Create compare lines and houses'**. To calculate the difference between the angles, the query uses the VB function **'angle_diff'**.

4.3.4 C4 Minimum angle

Using the information from the table 'C3 Compare lines and houses', the query **'5 Create minimum angle'** chooses for each premise the smallest difference in angles between the premises and GIS lines measured from the GIS nodes. This information is then used in the following calculations to determine which road section each potential customer building should be assigned to as when the difference in angles is at a minimum the (perpendicular) distance from the premises to the road should be at a minimum.

4.3.5 C5 Houses to lines

This table links each potential customer building to a road section.

The table links each potential customer building from the table 'addresses with nearest nodes' to the GIS line it is closest to as calculated in the steps above using the query **'6 Create houses to lines'**.

4.3.6 C6 Houses to lines and sides

This table links each potential customer premise to a side of the road section it is linked to.

For each potential customer building from the table 'addresses with nearest nodes', this table includes information on the nearest GIS line as in the table 'C5 Houses to lines' and also includes information on which side of the GIS line the building is located using the query **'7 Create houses to line and side'**. The side of the GIS line each building is on is indicated by a dummy variable based on the sign of the difference in angle between the GIS Line and the buildings from the GIS node.

4.3.7 Summary connections per line per side

This table shows the number of potential customer buildings per side of each road section. It summarises the output of the database 'Houses to roads' using the query **'8 Create connections per line per side'**.

For each GIS line to which buildings have been mapped, there is a record, or two records if there are buildings on both sides of the road corresponding to each side of the road section. For each record, this table includes information on the number of potential customer premises, the number of business occupants and the number of households (residential occupants) and vacant premises that neither have business nor residential occupants.

4.4 LCR – DPs

This database calculates the shortest route from each road intersection (GIS nodes) to the closest DP along the road network. These routes are used to model the installed local access cable.

The database consists of eight tables (and three additional input tables that are linked to the databases 'GIS data' and 'Nodes' described above), 23 queries, two VB modules and two macros.

The description below follows the structure of the VB module 'Algorithm Code' which is split into three sections:

1. Initialise (clears intermediate result tables and puts in initial values for intermediate tables);
2. Addline (iteratively adds GIS lines to the total set of routes); and

3. LCR (repeats the queries in 1 and 2 in a loop until there are no more lines to be added. i.e. the total route network is calculated).

The sub-headings within those three sections below correspond to the queries in the database. The output tables created from the queries are highlighted in bold in the respective sections.

4.4.1 Initialise

Clear Nodes

This query deletes the data from the table **'Nodes'** whilst maintaining the structure and variables.

Clear Lines

This query deletes the data from the table **'Lines'** whilst maintaining the structure and variables.

Clear Parent Nodes

This query deletes the data from the table **'Parent nodes'** whilst maintaining the structure and variables.

Update Nodes with GIS data

This query updates the table **'Nodes'** with the data on GIS nodes (from the table 'GIS nodes' in the database 'GIS data' which is linked in the database).

Update Lines with GIS data

This query updates the table **'Lines'** with the data on GIS lines (road sections) (from the table 'GIS lines' in the database 'GIS data' which is linked in the database).

Update Parent nodes with DPs

This query defines the parent nodes for the database as the GIS nodes that are closest to each DP (as given in the input table 'DP nodes' from the database 'Nodes' which is linked in the database). The table **'Parent nodes'** is updated with the IDs for those GIS nodes. These are the 'seeds' for the network of routes.

Clear Lines to Excluded Nodes

This query deletes the data from the table **'Lines to Excluded Nodes'** whilst maintaining the structure and variables.

Clear Line Added

This query deletes the data from the table **'Line Added'** whilst maintaining the structure and variables.

Clear Node Added

This query deletes the data from the table **'Node Added'** whilst maintaining the structure and variables.

Clear Routes

This query deletes the data from the table **'Routes'** whilst maintaining the structure and variables.

Clear Route Added

This query deletes the data from the table **'Route Added'** whilst maintaining the structure and variables.

Add Parent nodes to Node Added

This query inserts the parent nodes (from the table **'Parent_Nodes')** into the table **'Node Added'**. The 'Node Added' table is used to temporarily store the GIS nodes added to the root network in each iteration step. For the first iteration these are the parent nodes: the GIS nodes that are assigned to each DP based on the smallest road distance.

The nearest node (i.e. the GIS node nearest the corresponding DP) for each parent node is defined as the parent node itself.

Update Nodes with Node Added

This query updates the information in the table **'Nodes'**. The '**Nodes'** table stores the information for each GIS node on the closest DP (actually the corresponding GIS node) the distance also the road network to the DP. Initially the table is empty (as it is cleared in the query above). This query then adds data from the table **'Node Added'**.

4.4.2 Addline

Add Lines to Excluded Nodes 1

This query adds data to the table **'Lines to Excluded Nodes'**. This table temporarily stores a list of all GIS lines which have one end (GIS node) connected to the calculated route network and the other end is not connected. This list forms the set of potential lines which can be added to the route network in this iteration[3].

For each line, the distance to the GIS node not included in the current route network is calculated as the sum of the distance to the GIS node in the road network and the length of the GIS line.

As each GIS Line has two ends, two separate queries are run. This query uses the line where the 'From node' is one of the 'Nodes Added' (i.e. is in the current route network).

Add Lines to Excluded Nodes 2

This query repeats the calculations above for each line where the 'To node' is one of the 'Nodes Added' in the route network.

Clear Line Added

This query deletes the data from the table **'Line Added'** whilst maintaining the structure and variables.

Clear Node Added

This query deletes the data from the table **'Node Added'** whilst maintaining the structure and variables.

Clear Route Added

This query deletes the data from the table **'Route Added'** whilst maintaining the structure and variables.

Minimum to distance

This query is a Select which is run dynamically in response to the 'Add Line Added' query being run below. It calculates the minimum distance to the GIS node not included in the current route network across the GIS lines included in the table **'Lines to Excluded Nodes'.**

Add Line Added

This query adds those GIS lines from the table **'Add Lines to Excluded Nodes'** where the distance to the end of the line not in the current route network is at a minimum to the table **'Line Added'**. The **'Line Added'** table temporarily stores all of the GIS lines to be added to the route network

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[3] For example in the first iteration step, all GIS lines which connect to one of the Parent nodes are added.

Add node to Node Added

This query adds the corresponding GIS nodes which are not in the current route network for the lines in the table **'Line Added'** to the table **'Node Added'**. These GIS nodes are the additional nodes for which a least cost route has been calculated.

Update Nodes with Node Added

This query updates the information in the table **'Nodes'** with the nodes in the table **'Node Added'** including which is the nearest DP (the GIS node corresponding to the DP) and the distance to this nearest node and the final GIS line connecting this node to the existing route network from the 'Line Added' table.

Add final segment to Route added

The table '**Route added'** temporarily stores the new routes from the Parent nodes to the new nodes included in the route network.

This query inserts the final line connecting the new node from the table **'Node Added'** into the table '**Route added'**.

Add preceding segments to Route added

For each node that was inserted into the table 'Route added' in the step above, this query adds the data on the existing route from the Parent node to the end of the final line already in the Route network from the table **'Routes'**.

Add Route Added to Routes

This query inserts the new route data from the table **'Route Added'** into the table **'Routes',** expanding the route network.

Remove lines to Node Added

This query deletes the data entries in those rows of the table '**Lines to excluded Nodes'** where the corresponding GIS line connects to one of the nodes in the table **'Node Added'** as these lines now connect two nodes in the route network.

4.4.3 LCR

Loop

The queries described under 4.4.1 (Initialise) and 4.4.2 (Addline) are repeated in a loop. The loop ends when there are no more GIS lines connecting between GIS nodes in the route network and GIS nodes which are not in the route network.

4.5 LCR - PoPs

Calculations in this database are similar to those performed in 'LCR-DPs' described above with the Parent Nodes being the PoPs.

For output to the 'Cable and Duct' database, the set of least cost routes from all road nodes to the PoPs is filtered so that only those routes from road nodes nearest to DPs are included in the calculation.

4.6 LCR - Core

Calculations in this database are similar to those performed in 'LCR-DPs' described above with the Parent Nodes being the sites of the core nodes (PoPs and any aggregation nodes sited at locations which are not PoPs). The resulting routings are not used directly in the 'Cable and Duct' database but form an input to the calculation of core routes below.

4.7 Core routes

This database calculates a network with redundancy that connects all of the core nodes (PoP sites and aggregation sites) with links being the shortest route along the road network.

The database consists of 15 tables (and four additional input tables that are linked to the database 'LCR Core' described above), 23 queries, two VB modules and two macros.

The methodology consists of two principal steps:

1. Creation of shortest ("least cost") routes between pairs of core nodes where the Voronoi polygons defined around these nodes share a border;
2. "Thinning" of the resulting network by removing routes which are not necessary to maintain route redundancy between core nodes.

The description below follows the structure of the VB module 'Routing and Optimisation Code'.

The sub-headings within those three sections below correspond to the queries and functions in the database. The output tables created from the queries are highlighted in bold in the respective sections.

4.7.1 Routing

1 Make table Border Lines

This query creates the table **'Border Lines'** which includes all road sections (GIS lines) where the shortest road distance between the GIS nodes at each end are to different core node, i.e. those road segments that span the border between the Voronoi polygons defined around each core node.

2 Create All Routes

This query creates the table **'All Routes'** which consists of a collection of the routes between the core nodes sharing a border. It stores the least costs routes from each core node to the end of the road segments at the border (GIS node) from the table 'Border Lines'.

3 Add Reverse Routes to All Routes

This query repeats the calculation in the above query 'Create All Routes' but stores the routes in the reverse order in the table **'All Routes**' so that the shortest route selected below includes all routes.

4 Create Shortest Routes

This query uses the information on routes from the table 'All Routes' and selects the shortest route between each pair of neighbouring core node which share a border. This will generally be the shortest route over the road network between the two nodes (i.e. the "Least Cost Route"). It creates the table **'Shortest Routes'**.

This collection of routes will from a dense network of routes between the core nodes with a high degree of redundancy.

5a Copy Shortest Routes to Optimised Routes

This query inserts the information from the table 'Shortest Routes' into the table **'Optimised Routes'**. The optimised network will then be calculated by removing routes from this set, thinning the network, while maintaining route redundancy.

4.7.2 DeleteLines1

This subroutine iteratively deletes routes from the table 'Optimised Routes' while there is a direct route in the optimised route set with two alternative routes. A direct route is a route between two neighbouring core nodes which does not pass a third node. An alternative route is defined as a route between two neighbouring core nodes that passes through at least one other core node (two hop route).

5b1 Create Alternative route inputs 1

This query creates a table with all routes which connect neighbouring core nodes in the set of optimised routes.

5b2 Create Alternative route inputs 2

This query creates the reverse of the routes defined in query '5b1' above.

5c Create Alternative Routes

This query creates the table **'Alternative Routes'** which stores all alternative indirect routes between two core nodes.

5d Create Alternative Routes by Line

This query calculates how many alternative indirect routes are in place for each direct route between neighbouring core nodes. It creates the table **'Alternative Routes by Line'**.

5f Create Line to Delete

This query selects the longest direct route for which there are at least the two alternative indirect routes (along the road network) for those routes which have at least two alternative routes.

5g Delete Route

This query deletes the route selected in the query '5f' above from the table 'Optimised Routes'.

4.7.3 DeleteLines2

The queries in this loop repeat the calculations described above under 'DeleteLines1' (4.7.2) for routes with alternative routes that pass at least two other core nodes (three hop routes).

6 Create core routes 1

For the optimised set of routes this query adds the route from each core node to the "From" node (which is a dedicated end of the GIS line) in the border road segment to the set of routes in the table **'Core Routes'**.

7 Create core routes 2

This query adds the route from each core node to the "To" node (which is a dedicated end of the GIS line) in the border road segment to the set of routes in the table **'Core Routes'**.

8 Create core routes 3

This query adds the road segment on the border between the two core node areas to complete the route connecting two core node to the table **'Core Routes'**.

9 Create Core Routes Consolidated

This query calculates how often a road section is used in the core routes to calculate how many routes ("Cables") use each road segment. It creates the table **'Core**

Routes Consolidated'. This table is used as the input to the 'Cable and Duct' dimensioning.

4.8 Cable and duct

This database calculates the total inventory for the passive network structure. It generates a list of all street segments with installed duct and calculates the total capacity requirement for copper pairs and fibres.

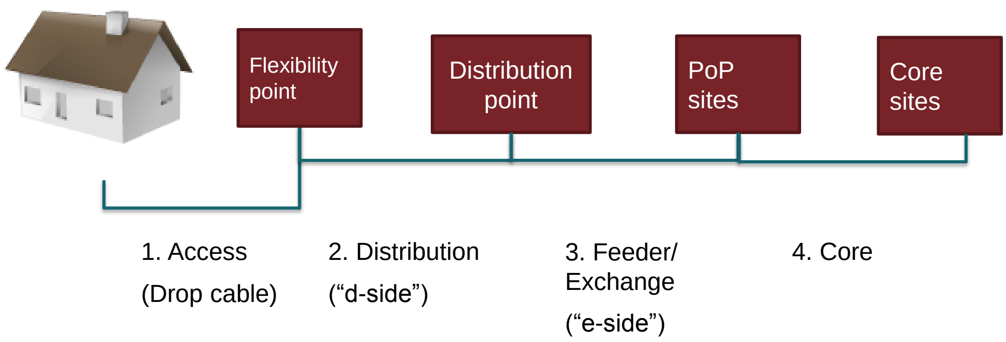
The database consists of 35 tables (and 9 additional input tables that are linked to the databases 'Nodes', 'Houses to roads', 'LCR DPs', 'LCR PoPs' and 'Core Routes' described above), 48 queries, two VB modules and two macros.

The queries in this database are split into five main sections:

1. Access network (queries starting with 'A')
2. Distribution network ('D')
3. Exchange-side (E-side) network ('E')
4. Infrastructure ('I')
5. Inventory.

The first three sections calculate fibre and copper cable requirements in the access network, distribution network and E-side network and the resulting duct requirements on each road section (GIS line). The requirements for the core network are calculated based on the results from the 'Core Routes' database. The split into these four levels of hierarchy is shown in the figure below. The queries in the infrastructure section combine the results from all levels of the model hierarchy to calculate the total duct and fibre and cable length in the network. The queries in the inventory section create the output tables from the calculation results that feed into the costing module of the model described in Section 5 of this document.

Figure 2. Passive network structure



The description below follows this structure. The sub-headings within the five sections below correspond to the queries in the database. The output tables created from the queries are highlighted in bold in the respective sections.

4.8.1 Access ('A')

A1 Create Fibres and pairs per line per side

For each side of each GIS line this query calculates the number of fibres and copper pairs required at each hierarchy level for each technology.

The query uses the data on the number of customer premises and potential customers mapped to each GIS line (from the table 'Summary connections per line per side' calculated in the database 'Houses to roads'). Using the dimensioning assumptions in the input table 'I9 Connections' this query creates the table **'Fibre and pairs per line per side'**.

A2 Create Access Copper per line per side

This query chooses the available cable type with the smallest number of copper pairs that can serve the number of connections required on each GIS line and side.

It uses the number of connections from the table 'Fibre and pairs per line per side' calculated above and an assumption on the available cable sizes from the input table 'I4 Copper_distribution_cable' to create the table **'Access copper per line per side'**.

A3 Create access fibre per line

This query chooses the available cable type with the smallest number of fibre pairs available that can serve the number of connections required on each GIS line and side.

It uses the number of connections from the table 'Fibre and pairs per line per side' calculated above and an assumption on the available cable sizes from the input table 'I6 Fibre_distribution_cable' to create the table **'Access fibre per line'**.

A4 Create Duct sides per line

This query calculates whether duct is needed to access houses on one or both sides of each road segment.

It uses the information in the table 'Fibre and pairs per line per side' and counts whether access copper connections are installed on one or both sides of the road segment. If there are no access copper connections on a road, the query does not calculate a duct for that segment. It creates the table **'Duct sides per line'**.

A5 Create houses per line - secondary side

This query calculates the number of customer premises on the secondary side (the side with fewer premises) for those road segments that have premises on both sides.

It uses the information on the number of buildings along each road segment from the table 'Summary connections per line per side' and identifies the road segments with duct on both sides from the table 'Duct sides per line' to create the table **'Houses per line – secondary side'**.

4.8.2 Distribution ('D')

D1 Create Lines to Nodes

For each GIS line this query calculates the end of the line which is closest to a DP by comparing the distances given in the 'Nodes' table of the 'LCR-DPs' database for the node at each end of the line. It creates the table **'Line to node'**.

D2 Create D-side copper pairs per line

This query calculates the number of copper pairs in the distribution network for each road section.

For each road section the query calculates all of the routes from road sections containing buildings to the nearest DP which use the road section based on the input table 'Routes' (from the database 'LCR – DPs'). The query then sums the number of D-side copper pairs required to serve each of the corresponding road segment containing building from the table 'Fibre and pairs per line per side' to give the total requirement for copper pairs on this road segment and creates the table **'D-side copper pairs per line'**.

D3 Create D-side copper per line

This query chooses the available cable type with the smallest number of copper pairs that can serve the number of connections required on each GIS line in the distribution network.

It uses the number of connections from the table 'D-side copper pairs per line' and an assumption on the available cable sizes from the input table 'I4 Copper_distribution_cable' to create the table **'D-side copper per line'**.

D4 Create D-side fibre cable per line

This query calculates the fibre cables needed on each road section in the distribution network.

For each road section, the query calculates all of the routes from road sections containing buildings to the nearest DP which use the road section based on the input table 'Routes' (from the database 'LCR – DPs'). The query then aggregates the fibre cables from the table 'Access fibre per line' to give the total requirement for fibre cable on this road segment to create the table **'D-side fibre cable per line'**.

D5 Create D-Side total fibre cables per line

This query calculates the total number of fibre cables in the D-side network summing across all sizes of cables.

It creates the table **'D-side total fibre cables per line'**.

D6 Create D-side fibre duct number

This query calculates the number of ducts required for fibre cables in the distribution network in each road segment.

This is based on the number of D-side fibre cables per line from the table 'D-side total fibre cables per line' and an assumption on the number of fibre cables per duct from the input table 'I1 Assumptions' as it assumes there is a fixed capacity in terms of the numerb fo cables within the micro-ducts within a duct. It creates the table **'D-side fibre duct number'**.

D7 Create D-side copper duct area

This query calculates the cross-sectional area needed for the copper cables in the distribution network in each road segment.

It uses data on the road segments from the table 'D-side copper cable per line' and assumption on the diameter sizes available from the input table 'I6 Copper_distribution_cable' to create the table **'D-side copper duct area'**.

D8 Create D-side copper duct number

This query calculates the number of ducts required for copper cables in the distribution network in each road segment.

This is based on the cross-sectional area of copper cables in the table 'D-side Copper Duct Area' and assumptions on the degree to which ducts are filled and the cross section of the ducts from the input table 'I1 Assumptions'. It creates the table 'D-side copper duct number'.

4.8.3 Exchange-side (E-side) ('E')

E1 Create Fibres and Pairs per DP

For each DP, this query calculates the number of fibre and copper pairs that arrive from the D-side network and the number of fibre and copper pairs into which these are aggregated and leave the DP into the E-side network.

The query uses the number of fibre and copper pairs from the table 'Fibre and pairs per line per side' and the information on the DPs from the input table 'Nodes' (from the database 'LCR-DPs') to create the table **'Fibres and pairs per DP'**.

E2 Create E-side copper per DP

This query calculates the available cable type with the smallest number of copper pairs that can serve the number of connections required at each DP.

For each DP in the table 'Fibres and pairs per DP', it uses an assumption on the available cable sizes from the input table 'I5 Copper Feeder Cable' to calculate the table **'E-side copper per DP'**.

E3 Create E-side copper per line

This query calculates the number of copper cables per road segment in the E-side network.

It uses data on the road segments on the routes leading from the DP to the PoP sites from the table 'Routes DP to PoP' (from the database 'LCR PoPs') and the number of copper cables from each DP from the table 'E side copper per DP' to create the table **'E-side copper per line'**.

E4 Create E-side copper duct area

This query calculates the cross-sectional area needed for the copper cables in the E-side network for each road section.

It uses data on the road segments from the table 'E-side copper cable per line' and an assumption on the diameter sizes available from the input table 'I5 Copper feeder cable' to calculate the cross sectional area and create the table **'E-side copper duct area'**.

E5 Create E-side copper duct number

This query calculates the number of ducts required for copper cables in the E-side network for each road section.

This is based on the cross-sectional area of copper cables in the table 'E-side copper duct area' and assumptions on the degree to which ducts are filled and the cross section of the ducts from the input table 'I1 Assumptions' to create the table 'E-side copper duct number'.

E6 Create E-side Fibre per DP

This query calculates the number or E-side fibre required at each DP.

For each DP in the table 'Fibres and pairs per DP', it sums the fibre cables for VDSL (FTTC), P2P and GPON in the E-side network and creates the table **'E-side fibre per DP'**.

E7 Create E-side fibre cable per DP

This query calculates the number of E-side fibre cables at each DP.

For each DP in the table 'E-side fibre per DP', it calculates the number of cables using an input assumption from the table 'I1 Assumptions' to create the table **'E-side fibre cable per DP'**.

E8 Create E-side fibre cable per line

This query calculates the number of fibre cables per road segment in the E-side network.

It uses data on the road segments leading from the DP to the PoP sites from the table 'Routes DP to PoP' (from the database 'LCR PoPs') and the number of fibre cables at each DP from the table 'E side fibre cable per DP' to create the table **'E-side fibre cable per line'**.

E9 Create E-side fibre duct number

This query calculates the number of ducts required for fibre cables in the E-side network.

For each road segment in the table 'E-side fibre cable per line', this uses an assumption on the number of fibre cable per duct from the input table 'I1 Assumptions' to create the table 'E-side fibre duct number'.

4.8.4 Infrastructure ('I')

I1 Create Ducts per line per component

For each road section, this query consolidates the number of ducts required, for each level of network hierarchy.

For every road section in the table 'Lines', it creates a record with the number of ducts from the tables 'Ducts per side per line', 'D side Copper duct number', 'D side Fibre duct number'; 'E side Copper duct number', 'E side Fibre duct number' and 'Core Routes consolidated' and counts the number of ducts required. It creates the table **'Ducts per line per component'**.

I2 Create Ducts per line total

This query calculates the total number of ducts at each road section across all levels of network hierarchy.

It sums the number of ducts per component from the table 'Ducts per line per component' to create the table **'Ducts per line total'**.

I3 Create duct allocation per line

Where a road section is used for routes in multiple levels of the network hierarchy, the cost of the trench housing the ducts is split in proportion to the number of ducts. This query calculates an allocation of the share of the total number of ducts at each road section split into E-side, D-side and Core.

It uses the number of ducts from the tables 'Ducts per line total' and 'Ducts per line per component' to create the table **'Duct allocation per line'**.

I4 Create Houses per line

This query calculates the number of houses at each road intersection.

It uses the number of buildings from the table 'Summary connections per line per side' (from the database 'Houses to roads') to create the table **'Houses per line'**.

I5 Create House density per line

This query calculates the density of houses along each road section based on the length of the road section and the number of houses.

It uses the number of houses from the table 'Houses per line' and calculates the density of houses based on the number of houses along the road section for each kilometre to create the table **'House density per line'**.

I6 Create Line geotype

This query determines the geotype of each road section based on the house density.

It uses the house density from the table 'House density per line' and assumptions for the different geotypes in the input table 'I2 Geotype' to create the table **'Line geotype'**.

I7 Create secondary duct per line

This query calculates the length of duct on the secondary side (the side with fewer houses) of each road section for those road sections that have duct on both sides.

It uses the number of houses on the secondary side from the table 'Houses per line – secondary side' and an assumption on the trench distance per building from the input table 'I1 Assumptions' to create the table **'Duct length – secondary side'**.

4.8.5 Inventory

These queries produce output for export to the Excel costing model. They summarise the data in existing tables for input into the model. They are all Select queries which output the data but do not store the results in a new table.

Inventory Access Copper Cable

This query calculates the total length of access copper cables in the network.

It uses the number and types of copper cable per road section from the table 'Access copper per line per side' and the length of the road sections from the table 'Lines'.

Inventory Access Fibre Cable

This query calculates the total length of access fibre cable in the network.

It uses the number of and type of fibre cables from the table 'Access fibres per line' and the length of the road sections from the table 'Lines'.

Inventory Average Access Fibre Length

This query calculates the average length of fibre runs in the access network from customer premises to DPs ("D-side" + "access") which is used to estimate splicing costs for fibre cables.

Inventory Core Fibre Cable

This query calculates the total length of core fibre cable in the network.

It uses the number of fibre cables from the table 'Core routes consolidated' and the length of the road sections from the table 'Lines'.

Inventory D-side Copper Cable

This query calculates the total length of D-side copper cables in the network.

It uses the number of and types of copper cable from the table 'D-side copper cable per line' and the length of the road sections from the table 'Lines'.

Inventory D-side Fibre Cable

This query calculates the total length of D-side fibre cable in the network.

It uses the number of and types of fibre cables from the table 'D-side fibre cables per line' and the length of the road sections from the table 'Lines'.

Inventory Duct

This query calculates the total duct length in the network required in the access, E-side, D-side and core parts of the network.

It uses the required duct from the table 'Ducts per line per component' and the length of the road sections from the table 'Lines'.

Inventory E-Side Copper Cable

This query calculates the total length of E-side copper cable in the network.

It uses the number and types of copper cables from the table 'E-side copper cable per line' and the length of the road sections from the table 'Lines'.

Inventory E-Side Fibres

This query calculates the total number of E-side fibres in the network by using the number of fibre cables for VDSL, GPON and P2P feeder fibre from the table 'Fibres and pairs per DP'.

Inventory E-Side Fibre Cable

This query calculates the total length of trench on the primary side of each road section per geotype and an allocation to the level of hierarchy in the model.

Inventory Primary Road Segments

This query calculates the total number of road segments per geotype and an allocation to the level of hierarchy in the model. This is used to calculate the number of jointing chambers required in the access network and the uplift to duct costs to take account of the higher cost of crossing roads at the end of road segments

Inventory Primary Trench

This query calculates the total length of trench on the primary side of each road section per geotype and an allocation to the level of hierarchy in the model.

It uses the information from the tables 'Ducts per line total', 'Duct allocation by line', 'Line geotype', 'Lines' and from the input table 'I1 Assumptions'.

Inventory Secondary Trench

This query calculates the total length of trench on the secondary side of each road section per geotype.

It uses the tables 'Line geotype' and 'Duct length secondary side'.

Mapping customers to DP

This query calculates the number of customers connected to each DP in the network.

It uses the tables 'DP nodes', 'Summary connections per line per side', 'Line to Node' and 'Nodes'.

Mapping customers to PoP

This query calculates the number of customers connected to each PoP in the network.

It uses the tables 'DP nodes', 'PoP nodes', 'Mapping DP to PoP', 'Summary connections per line per side', 'Line to Node' and 'Nodes' .

Route length

This query calculates the average route length in the access network from customer premises to DPs ("D-side" + "access") which is used as an input to the query "Inventory Average Access Fibre Length".

5 POP inputs (POP)

The model contains different pre-defined scenarios for the number of POPs based on outputs from the MS Access module. There are six sheets in total, each prefixed with 'POP'. The contents of these sheets are summarised in the table below. These sheets do not contain any calculations.

Table 5. POP input sheets

Sheet name	Description of input data
POP - Customers by POP	Number of POPs that are assumed under each scenario. For each POP, the worksheet contains information on: ▫ The number of buildings; ▫ The number of vacant buildings; ▫ The number of businesses; and ▫ The number of households.
POP - Customers by DP	Number of DPs that are assumed under each scenario. For each DP, the worksheet contains information on: ▫ The number of buildings; ▫ The number of vacant buildings; ▫ The number of businesses; and ▫ The number of households.
POP - GPON splitters	POPs that are assumed under each scenario and number of GPON fibres that are required for each POP
POP - Cable and duct requirements	Cable and duct requirements that are needed under the different scenarios. The equipment covers: ▫ D-side cables (split across different technology types, and different cable sizes); ▫ E-side cables (split across different technology types, and different cable sizes); and ▫ Duct and trench (split across Access, D-side, and E-side)
POP - Node mappings	Remote nodes in the modelled network. For each of the different scenarios, each remote node is mapped to the closest POP.
POP - Distance for joints	For each of the modelled scenarios, this sheet lists information on the length of copper cables. This information is used to determine the average distance between jointing chambers in the trench network.

6 Network dimensioning module (ND)

The table below summarises the sheets in the network dimensioning module. The input data used in these sheets and the calculations are described in further detail in the rest of this section.

Table 6. Network dimensioning module calculations –sheets (ND)

Section heading	Sub-section heading	Description of input data/calculations
ND – Inputs and Settings		
	ND – Settings	Assumption on the network dimensioning modelling year
	ND – Technical assumptions	Equipment specification and utilisation information
	ND – Access equipment input	Interface with cable and duct requirements module
	ND – GPON splitters	Interface with cable and duct requirements module (fibres by site)
	Quality of service factors	Calculations to determine quality of service (QoS) factors used to model real time services, etc.
ND – Network Dimensioning		
	ND – Node Mapping	Geographic location of nodes in the network
	ND – Remote equipment	Calculation of equipment required for subscribers served by FTTC
	ND – GPON P2P remote node aggregation	Calculation of equipment required for subscribers served by FTTH, and aggregation of fibre uplinks from remote nodes
	ND – MSAN CU	Calculation of equipment required for subscribers using copper to the MDF
	ND – Aggregation Equipment	Calculation of aggregation equipment required
	ND – IP Edge equipment	Calculation of IP Edge aggregation equipment required
	ND – IP Core equipment	Calculation of IP core equipment required

	ND – BRAS equipment	Calculation of BRAS equipment required
	ND – Core transmission	Calculation of transmission equipment required
	ND – Other equipment	Calculation of other core network equipment required
ND – Output		
	ND – Equipment summary	Summary of equipment modelled

6.1 ND – Inputs and settings

The model dimensions network equipment requirements for one year in the period 2013-2017 (the model automatically cycles through the years when calculating costs). This sheet defines the network dimensioning modelling year. This allows the model user to select a given year and investigate how the demand inputs from that year feed into the network dimensioning sheets.

The sheet does not contain any calculations.

6.1.1 ND – Technical assumptions

This sheet contains key technical assumptions for the modelled network equipment. For each level of the network hierarchy, the sheet lists which type of equipment is used in the dimensioning process. For each type of equipment there is information on:

- Modularity (e.g. ports per module, slots per chassis, etc.);
- Utilisation rates;
- Space requirements; and
- Power consumption.

6.1.2 ND – Access equipment input

This sheet summarises the outputs from the cable and duct requirements module. It lists the total length of:

- D-side cables (split across different technology types, and different cable sizes);

- E-side cables (split across different technology types, and different cable sizes); and
- Duct and trench (split across access, D-side, and E-side).

This is based on information from the 'POP inputs' section of the model.

The sheet also includes some calculations relating to the model setting on the mixture of access technologies. For example, in a scenario with no copper, all copper requirements are set to zero.

6.1.3 ND – GPON splitters

This sheet lists the number of GPON fibres that terminate at each POP in the modelled network. This is based on information from the 'POP inputs' section of the model.

The sheet also contains some calculations to reflect the chosen access technology-mix as selected in the scenario manager. For example, under a scenario with no GPON access technology, the GPON fibres to be dimensioned in the model are set to zero.

6.1.4 Quality of service factors

This sheet calculates quality of service (QoS) factors. These are applied to the traffic volumes used in the dimensioning process at each level of the network. The calculations take account of how some services are delivered in 'real time' (such as voice calls) while others are more tolerant of delay and are therefore delivered on a 'best effort' basis.

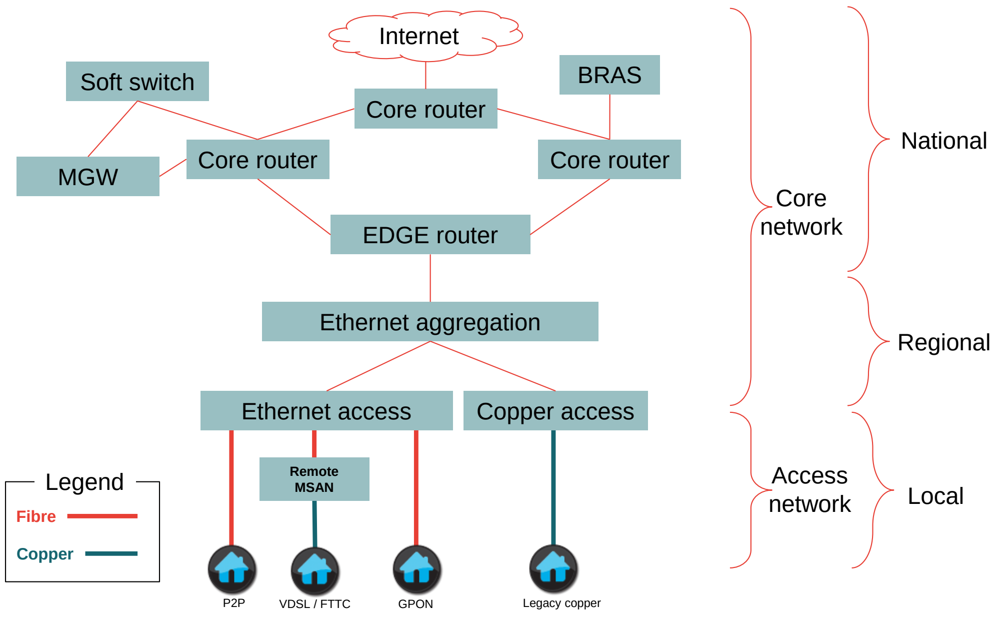
In practice, this means that the modelled network needs to be able to deal with peaks of traffic during the 'busy hour'. 'Real time' traffic, like voice, requires an uplift factor to ensure that it can be delivered in 'real time' even during the busy hour. The output of this sheet is a list of QoS uplift factors for different levels of the network that feed into the dimensioning sheets.

6.2 ND – Network Dimensioning

This section of the model is used to calculate the amount of equipment required at each node in the network, and the type of equipment required. There is a separate sheet for each level of the network (and separate sheets for different access technologies).

The first sheets deal with dimensioning at access nodes – which depends on the type of access technology. The subsequent sheets deal with dimensioning higher up the network. The figure below provides an illustration of the network.

Figure 3. Illustration of modelled network



For the different access technologies (i.e. P2P, FTTC, GPON and legacy copper) there is no path resilience. This means that each subscriber premises is only connected to one cabinet / POP, and each cabinet is only connected to one POP. However, within the core network every node is connected to two nodes higher up the network. For example, each access node is connected to two aggregation nodes, each aggregation node is connected to at least two IP Edge nodes, and so on. Core routers are fully meshed. This means that are all directly connected with each other.

For the access node sheets ('ND – Remote equipment', 'ND – GPON P2P remote node aggregation' and 'ND – MSAN CU'), the calculations look up the relevant demand inputs from the DEM sheets. The model then calculates how much equipment is required to satisfy that demand based on the technical assumptions about the equipment as defined in the 'ND-Technical assumptions' sheet.

For each sheet, the main output is a summary table which lists the type of equipment that is required, such as ports, modules, chassis etc., and the amount of equipment that is required. The sheets also calculate ancillary requirements such as floor space and power.

In each sheet, there is also information on node mapping. This reports how nodes in the network are connected to nodes higher up the network, and lower down the network – using unique IDs. For example, each access node is connected to two aggregation nodes, and each aggregation node aggregates traffic from multiple access nodes. In turn, each aggregation node is connected to two IP Edge nodes, and so on. Therefore, once equipment is dimensioned at each of the individual access nodes, traffic is aggregated higher up the network and the dimensioning exercise is repeated.

6.2.1 ND – Node Mapping

This sheet gives information on node mappings. This sheet lists the exact location of buildings in the network, using site IDs, and lists how they are connected to other nodes in the hierarchy. In particular, the sheet reports the node mapping for:

- Aggregation nodes to remote access nodes to access nodes;
- Access nodes to aggregation nodes; and
- Aggregation nodes to IP Edge nodes.

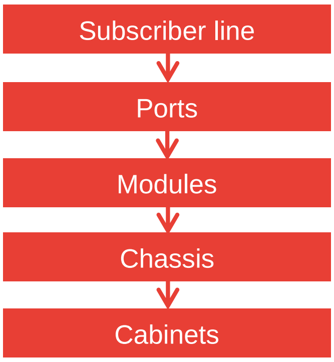
This is based on information from the 'POP inputs' section of the model.

6.2.2 ND – Remote equipment

The 'ND – Remote equipment' sheet determines the amount of equipment, and type of equipment required at remote nodes in order to satisfy demand for subscribers using FTTC technology. The main output of the sheet is a summary of the equipment requirements for each remote node stating the exact amount of, and type of equipment required. This information is then carried over to the costing section.

This sheet performs a number of calculations. The number of subscribers and their associated traffic at each node is summarised from the demand section. The model then dimensions the appropriate type and amount of equipment specific to FTTC/VDSL technology (see 'ND – Technical assumptions') for this demand. The dimensioning process is described in the figure below. A similar process is used throughout the network hierarchy.

Figure 4. Dimensioning process for remote MSAN equipment (using technical assumptions)



Each of the subscriber lines that terminate at the remote MSAN requires a port. Ports come in modules, and each module can hold multiple ports. Modules are placed in chassis.
And in turn, a chassis can hold up to several modules depending on the type of chassis – there are often several variants.
Finally, chassis come in cabinets which each have one fibre uplink.

Note: As traffic moves higher up the network, a similar dimensioning process is used. However instead of 'subscriber lines' being dimensioned, these become 'fibre uplinks'. And for all other nodes in the network, apart from the remote MSANs, 'chassis' are placed in 'racks' and not 'cabinets'

By using the number of subscribers and their associated traffic, the model calculates the required number of ports, modules, chassis, cabinets and uplinks as well as ancillary requirements such as floor space.

Finally, using the 'ND – Node mapping' sheet, each remote access node is connected to its closest access node. All uplinks from the remote nodes are 1GB fibre cables.

6.2.3 ND – GPON P2P remote node aggregation

This sheet calculates the amount of equipment required at the access nodes where fibre connections terminate. This covers:

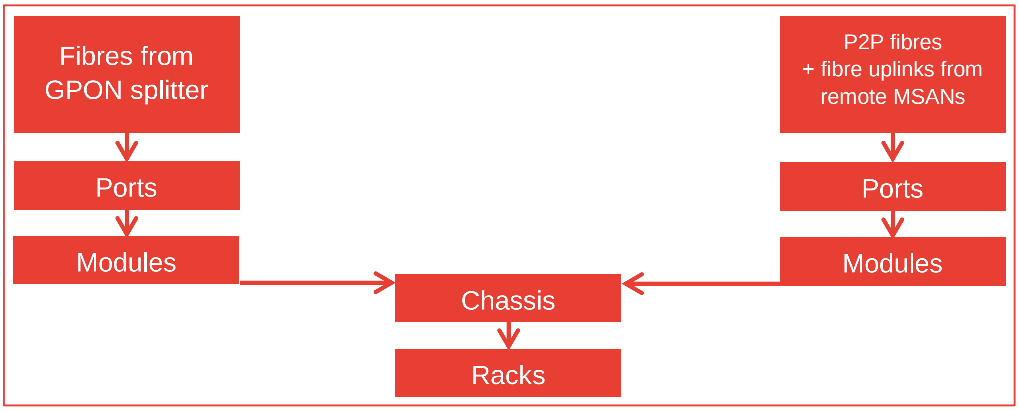
- P2P FTTH;
- GPON FTTH; and
- The fibre uplinks from FTTC nodes (see above).

For P2P and GPON subscribers, the calculations follow a very similar dimensioning process as described in the section and figure above. The calculations use the number of terminating fibres and the associated traffic based on the DEM section, (and the 'ND – GPON splitters' sheet in particular for GPON). The equipment from the 'ND – Technical Assumptions' worksheet is then used to dimension the equipment required to meet this demand.

The fibre uplinks from remote nodes are dimensioned in a similar way. For each access node, the model identifies all the remote nodes that are connected to it. This is based on the node mappings and node IDs. P2P fibres and the fibre uplinks from FTTC nodes can be accommodated in the same modules. However, GPON fibres cannot be accommodated in the same module and these must be dimensioned in separate modules. The different modules can be placed in the same chassis though.

The dimensioning process is illustrated in the figure below.

Figure 5. Dimensioning at the OLT/Ethernet access



The calculations are similar to those for the remote access nodes, aside from the need to distinguish between GPON fibres, and P2P fibres and remote MSAN fibre uplinks.

Each chassis requires its own fibre uplink. The model also calculates whether the fibre uplinks should be 1GB uplinks or 10GB uplinks depending on the amount of traffic being aggregated.

For added resilience, each access node is connected to two aggregation nodes., based on the node mapping sheet (see 'ND – Node mapping').

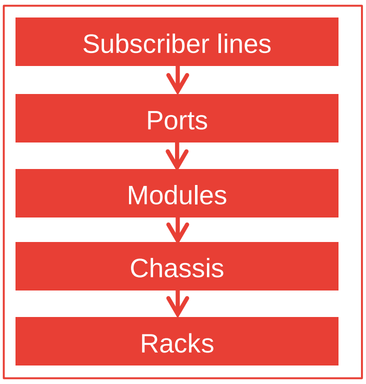
The output of the sheet is a table which lists the type and amount of equipment that is required, along with ancillary requirements.

6.2.4 ND – MSAN CU

This calculation is similar to the dimensioning of remote MSANs in the previous sheets. It dimensions the equipment required to accommodate subscribers using legacy copper access technology, along with ancillary requirements such as space and power.

The dimensioning process follows a similar logic (see figure below).

Figure 6. Dimensioning process for MSANs



The equipment used at the MSAN can be found in the worksheet 'ND – Technical Assumptions'. The output of the sheet is a table which summarises the required type and amount of equipment, along with ancillary requirements.

The node mappings are also listed to report to which two aggregation nodes each MSAN node is connected to. Uplinks can be either 1GB or 10GB depending on the volume of traffic.

6.2.5 ND – Aggregation Equipment

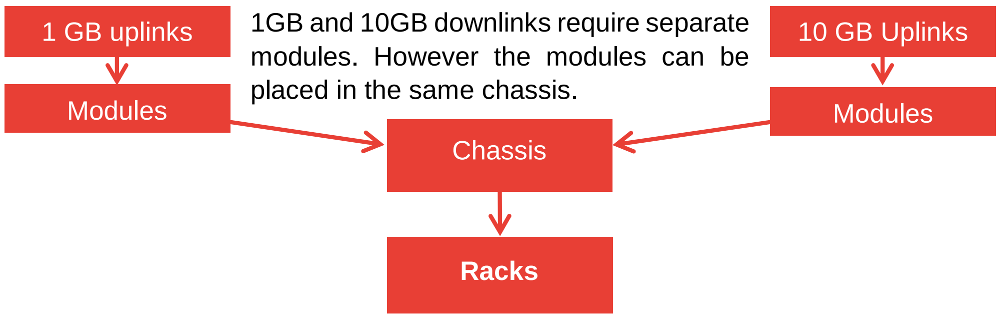
This sheet dimensions the type and amount of equipment that is requried at the first level of aggregation above the access nodes.

Access nodes are connected to two aggregation nodes for resilience. Therefore for each aggregation node the calculations look up the relevant access nodes – i.e. those access nodes which it is connected to. This is based on the node mappings and node IDs.

Equipment at the aggregation node is then dimensioned based on the sum of all the downlinks and the relevant traffic from the access nodes that are connected to it. Details on the equipment are taken from the worksheet 'ND – Technical Assumptions'.

The dimensioning process is similar to the process descibed in the previous sheets. The aggregation node handles both 1GB and 10GB downlinks which require different modules. The separate modules can be placed in the same chassis however. This is shown in Figure **7** below.

Figure 7. Dimensioning process at the aggregation node.



The model also dimensions ancillary requirements such as power and floor space. The sheet then summarises the total demand (in terms of uplinks and traffic) that then moves up to the next level of the network hierarchy. Each aggregation node is connected to two IP Edge nodes. This is based on the worksheet 'ND – Node mapping'.

6.2.6 ND – IP Edge equipment

The calculations in this sheet are similar to those in the 'ND – Aggregation Equipment' sheet.

For each IP Edge node, the model aggregates all fibre uplinks that originate from the aggregation level, along with the associated traffic. The calculations dimension the appropriate amount and type of equipment required to serve the relevant fibre downlinks and associated traffic from the aggregation level. This is based on the node mappings, and the relevant equipment described the 'ND – Technical Assumptions' sheet.

6.2.7 ND – IP Core equipment

The number of IP Core nodes is a user-defined input in the model. If the user selects *n* core nodes, then the calculations automatically designate the *n* largest IP Edge nodes to also be IP Core nodes. All IP Edge nodes are assumed to be connected to two IP Core nodes.

This sheet dimensions the equipment required at IP Core nodes. Again, similarly to the dimensioning algorithms outlined above, the equipment at each IP Core node is dimensioned to accommodate all the fibres and associated traffic that originates from the IP Edge nodes that it is connected to.

The IP Core level of the network is fully meshed. This means that every IP Core node is connected to every other IP Core node for resilience.

The IP Core nodes are also connected to BRAS nodes and softswitches. These are dimensioned based on the volume of broadband traffic and voice traffic respectively. The model therefore separates broadband and voice traffic from the total volume of traffic in order to dimension the uplinks to the BRAS and softswitches. The number of BRAS nodes is a user-defined input in the model. The BRAS are assumed to be co-located at the largest IP Core nodes.

The calculations also dimension interconnection links.

The output of the sheet is a summary the type and amount of equipment and ancillary requirements required at the IP Core given the level of traffic and the 'ND – Technical Assumptions'.

6.2.8 ND – BRAS equipment

This sheet dimensions the amount of equipment required at BRAS nodes based on the worksheet 'ND – Technical assumptions'. This volume of traffic and the fibre downlinks to dimension are drawn from the IP Core sheet.

6.2.9 ND – Other equipment

This sheet dimensions other core equipment including:

- Softswitches; and
- Media gateways.

6.3 ND – Output

6.3.1 ND – Equipment summary

This sheet summarises the results of the network dimensioning section. It lists all the equipment that is required in the modelled network and the number of units that are required for each piece of equipment.

This is the final sheet of the network dimensioning module.

7 Costing Module (CO)

The table below summarises the sheets in the costing module. The input data used in these sheets and the calculations are described in further detail in the rest of this section.

Table 7. Costing module calculations-sheets (CO)

Section	Sub-section	Description of input data/calculations
CO – Inputs and Settings		
	CO – Settings	Input assumptions and data used in the costing module
	CO – Classifications	Classification of services and network elements used to provide those services
	CO – Mappings	Usage of different network elements by different services
	CO – Volume inputs	Summary of network volumes estimated in the demand module
	CO –Equipment summary	Summary of network equipment required in each year modelled
	CO – Equipment cost inputs	Input data relating to unit prices, working lives and price trends for all equipment
CO – Network Costing		
	CO – Volume by Element	Total network usage for each network element
	CO – Capex	Calculcation of GRC for each equipment type
	CO – Capex annualisation	Calculation of annual capital charges (depreciation and return on capital employed)
	CO – Network element costing	Annualised cost for each network element
CO – Service Costing		
	CO – Network service costing	Allocation of costs to services
	CO – Product costing	Allcoation of network service costs to products
	Pure LRIC calculation	Estimation of pure LRIC of call termination and reallocation of costs to call origination

7.1 CO – Inputs and settings

The costing section estimates both the cost of the network infrastructure and also the costs of services that are provided over the network.

It uses information relating to:

- Demand (from the 'DEM' section);
- Equipment requirements (from the 'ND' section);
- Gross replacement cost (GRC) for pieces of equipment; and
- Other assumptions including opex, power and air conditioning costs, common costs, and wholesale specific costs.

7.1.1 CO – Settings

This sheet covers a range of assumptions for the costing module. These relate to:

- Operating costs;
- Power and air conditioning costs;
- Common costs; and
- Wholesale specific costs.

The inputs that are defined depend on the scenario manager in the 'Sensitivity inputs' sheet.

There are no calculations in this worksheet.

7.1.2 CO – Classifications

This sheet specifies the types of network, retail, and wholesale services for which the model estimates costs and the building blocks used to build up network costs. The classifications are:

- Service types and related units; and
- Network elements.

There are no calculations in this sheet.

7.1.3 CO - Mappings

This sheet sets out the routing and usage of different network services to network elements. It maps:

- The routing of each network service over the network (i.e. a list of all the elements in the network that each network service requires); and

- The usage factors of each network service over the network (i.e. a factor quantifying how much each network element is used by a given network service).

7.1.4 CO – Volume inputs

This sheet summarises network service volumes as calculated in the demand module of the model.

7.1.5 CO – Equipment summary

This sheet summarises the required network equipment for the whole network, for all years over the modelled period. These equipment requirements are defined in the network dimensioning module.

7.1.6 CO – Equipment cost inputs

The 'CO – Equipment cost inputs' sheet contains unit cost information for all pieces of equipment listed in the previous sheet and the inputs required to estimate depreciation charges for assets. This includes:

- Gross replacement costs for equipment;
- Asset working life; and
- Inflation (price trend over time).

This sheet also contains a categorisation of whether the network element is an NGA asset or a non-NGA asset.

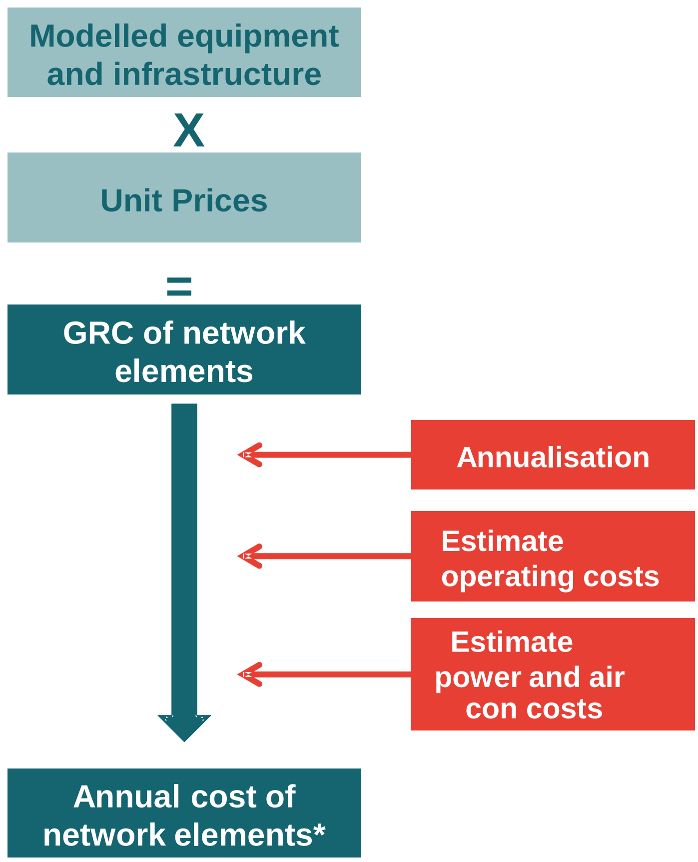
For key asset categories (such as duct and trenching), the inputs for working lives and price trends are drawn from the scenario manager. This enables the model user to easily change these input assumptions.

7.2 CO – Network costing

This section of the model estimates the total annualised cost for each network element. This takes the amount of equipment dimensioned in the modelled network and multiplies by the unit cost of the equipment to give the total GRC for each network element.

This GRC is then annualised based on financial assumptions (WACC, price trends and asset lifetimes). Operating costs are then added. Finally, air conditioning and power costs are added to give the total annualised cost for each network element. This figure does not include any wholesale specific costs or common costs, which are added later in the model. The figure below provides an overview of the calculations that are performed in the following network costing sheets of this model.

Figure 8. Overview of network costing calculations



*Excluding all wholesale specific costs and common costs

7.2.1 CO – Volume by element

This sheet combines the mapping and usage factors set out in the 'CO – Mappings' sheet with the network service volumes (from the sheet 'CO – Volume inputs'), to calculate the total usage for each network element. This is calculated for each year throughout the modelled period.

7.2.2 CO – Capex

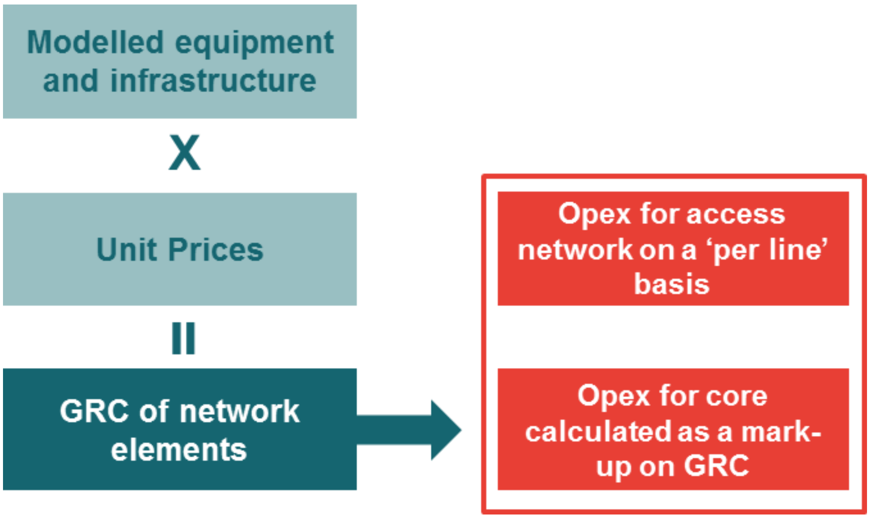
This sheet calculates two main outputs:

- Total GRC for each type of equipment in the modelled network. This is calculated by multiplying the unit GRC of each type of equipment by the number of pieces of equipment required as determined in the network dimensioning section.

- Operating costs which are based on:
  - A mark-up on GRC for the core network; and
  - A 'per line' basis for the access network

These costs are calculated for each of the modelled years. This is illustrated in the figure below.

Figure 9. CO - Capex calculations



7.2.3 CO – Capex annualisation

This sheet takes the total GRC figures for each equipment type, as calculated in the previous sheet, and derives annual capital costs for each type of equipment. This is based on an annuity formula which considers the following inputs:

- WACC as defined in the scenario manager and taking account of whether the asset is a NGA specific asset (as defined in 'CO - Equipment cost inputs')
- Price trends as input in 'CO – Equipment cost inputs'; and
- Working life of assets as input in 'CO – Equipment cost inputs'.

The price trends and working lives for key asset categories, (such as cables and duct), are defined in the scenario manager. This enables the model user to test how sensitive the overall results are to these assumptions.

The figure below shows the tilted annuity formula used.

Figure 10. Annual capital charge calculation formula

$$\text{Annual capital charge} = (CoC + Depr) = GRC \times \frac{WACC - trend}{1 - \left(\frac{1 + trend}{1 + WACC}\right)^{Asset\ life}}$$

The annualised GRC figure is calculated by using the formula above.

7.2.4 CO – Network element costing

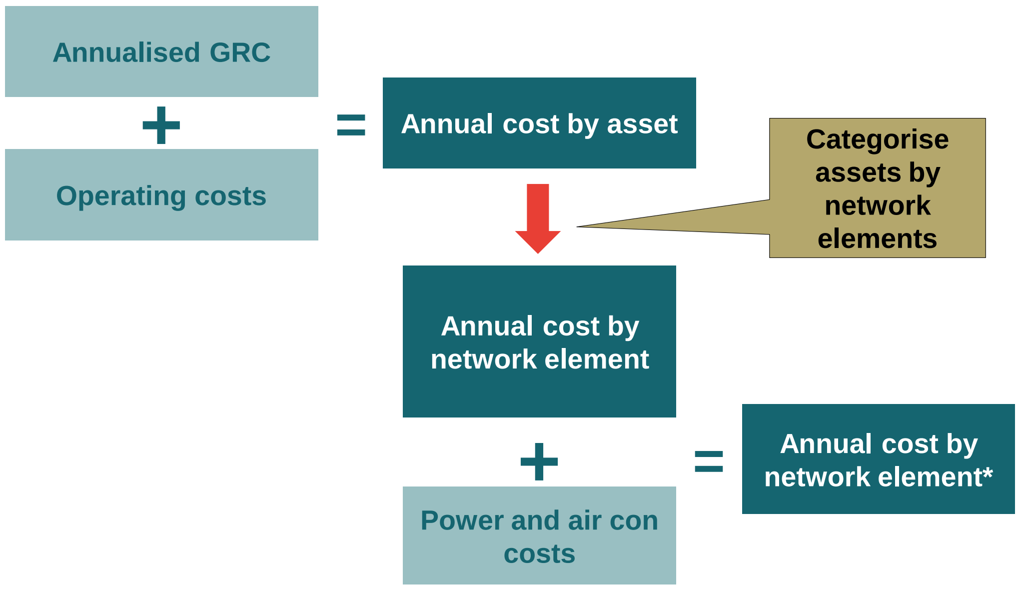
This sheet combines two of the outputs from the previous two sheets. In particular, the calculations take the following figures for each equipment type:

- Annualised GRC ('CO – Capex annualisation'); and
- Opex ('CO – Capex').

The sum of these two figures gives the total annual cost of equipment for each individual type of equipment – excluding power and air conditioning costs. These individual figures are then summed across wider network element categories. For example, the costs for all individual D-side fibre cables of different sizes are summed together under one heading.

Power and air conditioning costs are then added. This is calculated based on the power usage of equipment. This then gives the total annualised cost for each network element. (These figures do not include common costs and wholesale specific costs – which are added in the service costing section.) The calculations are illustrated in the figure below.

Figure 11. Calculations in 'CO - Network element costing'

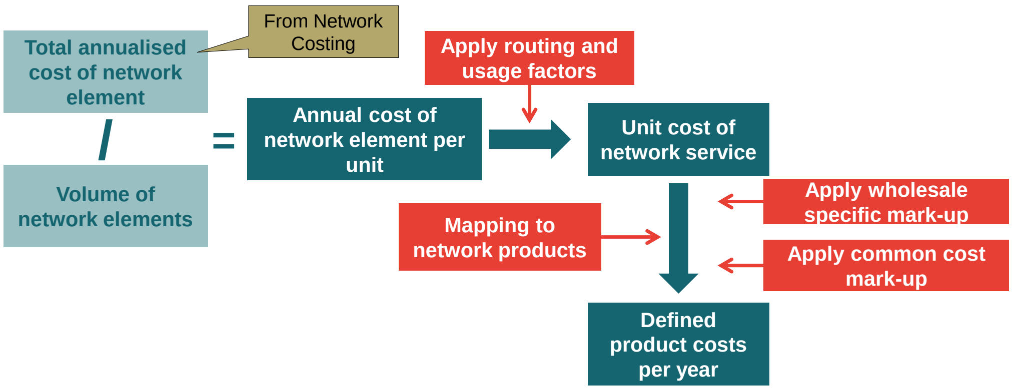


*Excluding all wholesale specific costs and common costs

7.3 CO – Service Costing

In the 'CO – Service Costing' section, the model calculates the total cost and the unit cost for each network service as an intermediate step. The model then calculates the unit costs of wholesale products based on the mapping from network services to wholesale products. This is illustrated in the figure below.

Figure 12. Illustration of service costing



The model also calculates the pure LRIC of call termination.

7.3.1 CO – Network service costing

The calculations in this sheet are as follows:

- For each network element, the annual cost (as shown in **Figure 11**) is divided by the number of each network element. This gives a cost per network element; and
- Unit cost for each network service (e.g. cost per minute or per subscriber) is then estimated by using routing factors, usage factors and service volumes.

7.3.2 CO – Product costing

This sheet maps network services to wholesale products based on the information in the 'CO – Mappings' sheet to derive a product cost. Two further mark-ups are applied to calculate the unit cost of defined wholesale products:

- Wholesale specific mark-up; and
- Common cost mark-up.

7.3.3 Pure LRIC calculation

The last sheet in this module estimates the cost of call termination under a pure LRIC approach. This is calculated by taking the difference between the total annualised network costs with total forecast demand including call termination included and the total network costs with total forecast demand excluding call termination. In other words, the model is run twice: once under each demand assumption. Dividing this difference in cost by the number of termination minutes gives the unit pure LRIC of termination.

The common costs and wholesale specific costs that were recovered by termination under the LRIC approach are re-allocated to on-net calls and call origination based on the volumes of those services.

This is the final sheet of the costing module.

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