



**Report for the Norwegian
Communication Authority**

Documentation of Nkom's vAcc2.3 model

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1 Introduction

The Norwegian Communication Authority ('Nkom') has commissioned Analysys Mason Limited ('Analysys Mason') to update the existing long-run incremental cost (LRIC) model in relation to wholesale services on fixed access networks.

The latest European Commission (EC) Recommendation on relevant markets (the New Market Recommendation, published in October 2014) updated the list of markets where regulation is still needed to safeguard competition.¹ These markets have also been defined by the European Free Trade Association Surveillance Authority (EFTA Surveillance Authority, or ESA).² There are three relevant markets in this context:

- Market 3a (wholesale local access provided at a fixed location)
- Market 3b (wholesale central access provided at a fixed location for mass-market products).
- Market 4 (wholesale high-quality access provided at a fixed location).

Between 2009 and 2011, Analysys Mason supported Nkom (NPT at the time) on the development of a LRIC model of fixed access networks. The final version (v1.7) of the model was published on Nkom's website in September 2012 and is used as a starting point for the model update.³ This model was published alongside the draft market analysis and decisions regarding Markets 4 and 5 (the relevant markets according to the EC's previous definition).⁴ This document refers to the relevant market terminology contained within the New Market Recommendation.

After this publication, in September 2013, the EC published a Recommendation on consistent non-discrimination obligations and costing methodologies (the '2013 Recommendation').⁵ The 2013 Recommendation covers a wide range of issues including the valuation of re-used assets and the technologies to cost in relation to services that are relevant to broadband access. Analysys Mason and Nkom have agreed an approach to update the existing cost model, in order to reflect the 2013 Recommendation. The model's draft specification was published on Nkom's website in April 2015,⁶ and the industry participants' contributions were received and taken into consideration while developing the final model specification. This model specification has been finalised and used to update the existing model. The updates reflect both the evolution of the Norwegian fixed access markets and the 2013 Recommendation, in order to inform Nkom's future regulation of Markets 3a, 3b and 4.

¹ For the EC definition, see COMMISSION RECOMMENDATION C(2014) 7174 of 09.10.2014 on relevant markets within the electronic communications sector susceptible to ex ante regulation in accordance with Directive 2002/21/EC. See http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?action=display&doc_id=7045

² See <http://www.eftasurv.int/media/decisions/College-decision---Revision-of-ESA-Recommendation-on-Relevant-Markets-susceptible-to-ex-a.pdf>

³ This model is available from <http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-aksess>

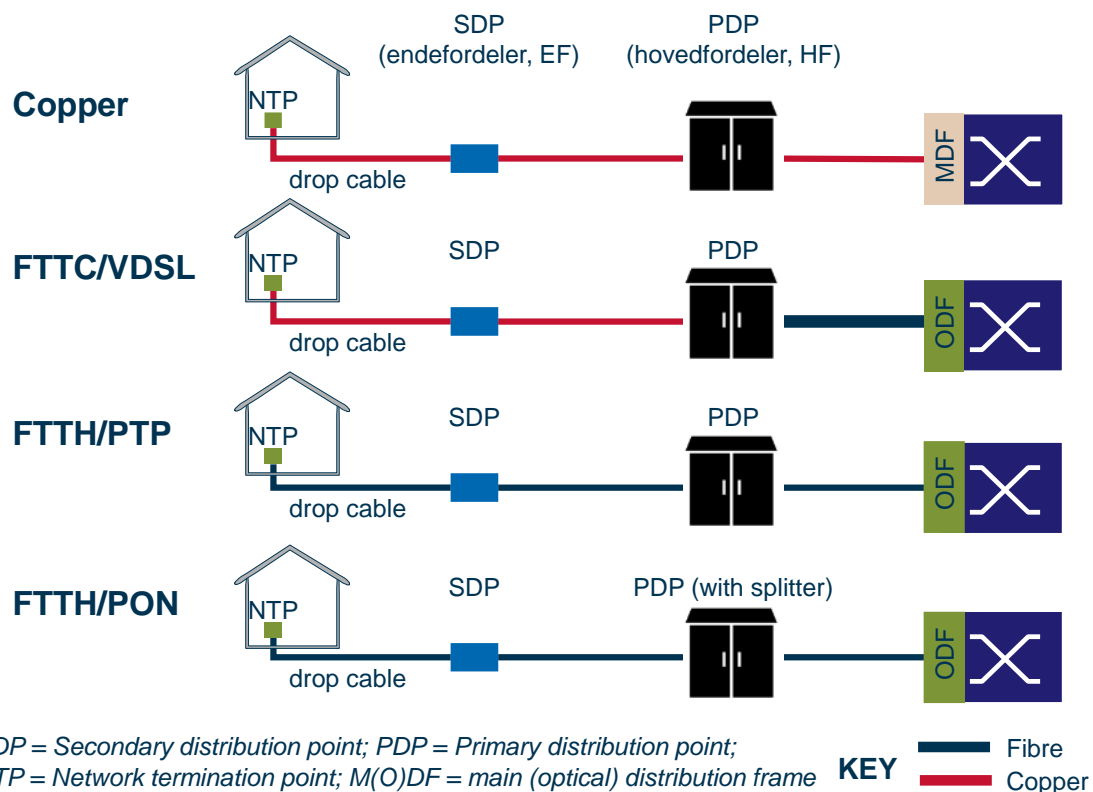
⁴ For the previous EC definition, see its Recommendation on relevant markets 2007/879/EC. For the corresponding ESA document of November 2008, see <http://www.eftasurv.int/media/esa-docs/physical/15344/data.pdf>

⁵ Recommendation C(2013) 5761 of 11 September 2013, see <http://ec.europa.eu/digital-agenda/en/news/commission-recommendation-consistent-non-discrimination-obligations-and-costing-methodologies>

⁶ See http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-aksess/_attachment/17907?_download=true&_ts=14d0a3ab706

The v1.7 model had the capability to consider multiple access network architectures, namely copper-to-the-home (CTTH), fibre-to-the-node (FTTN/VDSL), fibre-to-the-home passive optical network (FTTH/PON) and FTTH point-to-point (PTP). These architectures are all assumed to connect buildings in an area back to a single network node containing a distribution frame, via a hierarchy of intermediate distribution points, connected by copper and/or fibre cabling, as illustrated below in Figure 1.1.

Figure 1.1: Illustration of access architectures [Source: Analysys Mason, 2018]

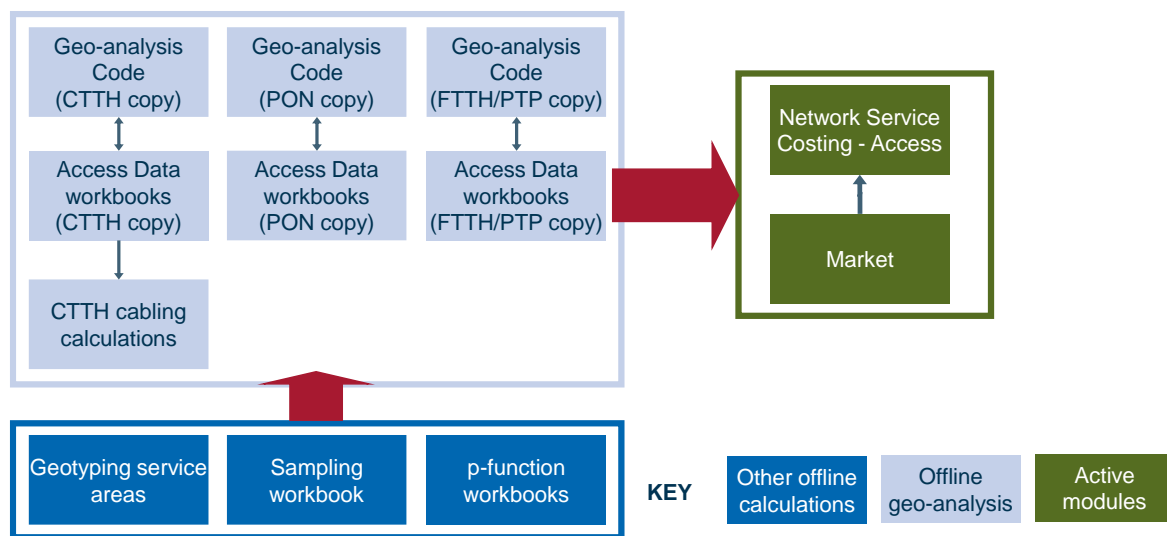


The v1.7 model, as published in 2012, consisted of three modules (Excel files): *Network Design – Access*; *Service Costing – Access*; and *Market* (the *Market* module is also used for Nkom's LRIC model of fixed core networks). The aim of this project has been to update and further develop this model in the context of the evolution of the Norwegian fixed access markets and the 2013 Recommendation. The updated version of the model that we refer to throughout this document is the vAcc2.3 model ('v' corresponding to version, 'Acc' corresponding to 'model of access networks').

A draft vAcc2.0D model was published in 2015. Following the release of our consultation response document in February 2016, which Telenor responded to with further comments, a small number of changes were made to derive a "vAcc2.1" model. These changes are described further in Section 5.4 and Annex D.8. A further set of updates to key inputs (demand, WACC, inflation) were made in 2017 to arrive at the vAcc2.2 model, which was released for consultation in January 2018. A final set of updates was made to determine the vAcc2.3 model.

The vAcc2.3 model now consists of only two **active** modules, each implemented as a single Excel workbook: the *Market* module and the *Network Service Costing – Access* module. The latter is a (largely) rebuilt, combined version of the *Network Design – Access* and *Service Costing – Access* modules from the v1.7 model. The *Network Service Costing – Access* module takes parameter values from detailed **offline** calculations. These offline calculations are confidential and cannot be shared with industry parties without redaction. They include a detailed (building-level) geographic analysis (geo-analysis) of the CTTH, FTTH/PTP and FTTH/PON architectures: inputs for FTTN/VDSL are derived from the geo-analysis for CTTH. The offline and active components of the model are shown schematically in Figure 1.2 below.

Figure 1.2: Schematic overview of the vAcc2.3 LRIC model of fixed access networks [Source: Analysys Mason, 2018]



This document sets out the revisions that have been undertaken as part of this update, and is structured as follows:

- Section 2 provides an overview of the vAcc2.3 model
- Section 3 gives an overview of the offline calculations and the geo-analysis
- Section 4 describes the changes made to the demand forecasting in the *Market* module
- Section 5 describes the changes made to the network design calculations in the *Network Service Costing – Access* module
- Section 6 describes the changes made to the service costing calculations in the *Network Service Costing – Access* module.

The report includes a number of annexes containing supplementary material:

- Annex A describes the structure of the Excel files within the offline geo-analysis
- Annex B summarises the assumptions made in the offline geo-analysis
- Annex C provides a description of the Visual Basic underpinning the offline geo-analysis
- Annex D details the changes made to the vAcc2.0D model to derive the vAcc2.2 model
- Annex E details the changes made to the vAcc2.2 model to derive the vAcc2.3 model
- Annex G outlines our approach to modelling a bitstream service using Nkom's existing models
- Annex H includes a list of the acronyms used in this document.

Note that throughout this report confidential information and comments are marked in such a way that Nkom can anonymise the document if required. We use the scissor symbol '✂' to denote confidential information.

2 Overview of our modelling approach

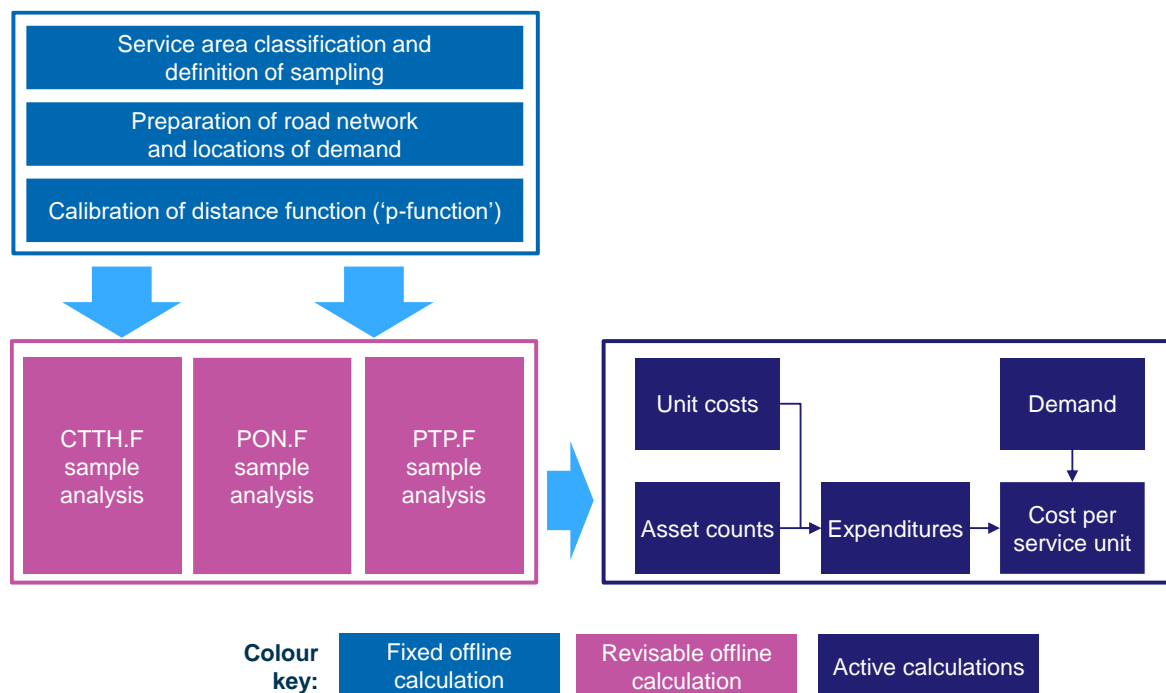
This section outlines the structure and use of the vAcc2.3 model of fixed access networks:

- Section 2.1 sets out the model structure
- Section 2.2 describes how the model can be run
- Section 2.3 outlines the network architectures that are modelled.

2.1 Model structure

The vAcc2.3 model is a set of interlinked Excel workbooks, whose structure is summarised in Figure 2.1 below.

Figure 2.1: Structure of the vAcc2.3 model [Source: Analysys Mason, 2018]



As shown in Figure 2.1 above, the model splits into a set of 'offline' calculations and an Excel-based cost model that forms the 'active' calculations: we will refer to this active part as 'the vAcc2.3 LRIC model'. The vAcc2.3 LRIC model comprises two modules: a *Market* module and a *Network Service Costing – Access* module.

The offline calculations determine asset-related inputs to be used by the vAcc2.3 LRIC model. The offline calculations subdivide further into 'fixed offline' calculations and 'revisable offline' calculations, which are enclosed by the lighter blue and pink borders respectively in Figure 2.1 above. There are separate revisable offline calculations for the fibre network modelling and the copper network modelling.

The remainder of this subsection explains how to calculate results, understand the formatting and structure of the entire model suite, and change inputs.

Fixed offline calculations

Once finalised, these calculations do not need to be revised. They:

- define a set of geotypes for the whole of Norway and a sample of areas within those geotypes for detailed analysis
- define the locations of all buildings in Norway and their associated demand requirements (in terms of number of lines required)
- determine a set of distance functions (or p-functions) that capture the road distance between points in the sampled service areas.

The outputs from these calculations are then used to structure the revisable offline calculations.

Revisable offline calculations

These calculations are a set of algorithms, rendered in Microsoft Excel Visual Basic (VB), which determine the access network assets required to connect all locations passed in a sampled area back to its parent node. These algorithms can be run on a set of sampled areas according to either a copper (CTTH), a fibre PON or a fibre PTP architecture.

We have prepared all the necessary geographic data so that a sample of 400 service areas (defined in the original modelling in 2009–2011) are analysed using our algorithms. These offline calculations are described in more detail in Section 3. The outputs of this analysis are then used to determine asset counts for use in the modelled access network.

Active calculations

The active calculations are described in detail in Sections 4–6. They consist of two modules: the *Market* module and the *Network Service Costing – Access* module:

- The *Market* module forecasts the relevant demand volumes for the modelling period.
- The *Network Service Costing – Access* module calculates the number of assets required for a hypothetical fixed access network of a chosen technology and calculates the capex/opex associated with that network. These costs are then allocated to the modelled subscriber volumes, derived from the outputs of the *Market* module.

Throughout all sheets of all modules the formatting of cells has been kept consistent. This is to increase the transparency of the model, as well as making it easier to understand and modify. A number of standardised cell formats are used to distinguish inputs, assumptions, calculations and links. These conventions are shown in the figure below.

Input Parameter	100	An input to the model that it is expected the user will change (change at will)
Input Data	100	A piece of real data (only change if you have better data)
Input Estimate	100	An estimate used in the absence of real data (only change if you have a better estimate, or real data)
Input Calculation	100	An input to the model that has been calculated from other inputs (e.g. interpolated input values)
Input Link	100	An input to this part of the model, which is linked to a source on this worksheet within this workbook
Input Link (different Worksheet)	100	An input to this part of the model, which is linked to a source on another worksheet within this workbook
Input Link (different Workbook)	100	An input to this part of the model, which is linked to a source on a worksheet in a different workbook
Input revision	100	An input to this part of the model, which has been updated compared to the model issued in 2012
Input redaction	100	An input to this part of the vAcc2.0D model, which has been redacted prior to publication
Calculation	100	A calculation of the model
Total	123	A total (use if not part of a "Sub-total row" or a "Total row" in a table - see below)
Checksum	0.00	A side calculation intended solely to cross check a result (and which therefore should not be referenced anywhere else in the model)
Checksum	0.10	Consider using Conditional Formatting (on Home tab) to highlight unacceptable results of cross-check calculations (e.g. non-zero)
Output	100	A key result from this part of the model (in particular one that will be used elsewhere in the model)
Name	Name	An Excel Name applying to one or more adjacent cells – use Create from Selection (on Formulas tab) to actually create the Excel Names
Note	Note	A note (NB smaller than standard font size)
Highlight	100	A cell that is special in some way

Figure 2.2: Formatting conventions used in the vAcc2.3 model [Source: Analysys Mason, 2018]

2.2 Running the model

There is no need to update the fixed offline calculations once they have been finalised. Significant geo-analysis would need to be undertaken in order to update the fixed offline calculations and the data that they underpin in the revisable offline calculations and subsequently the vAcc2.3 LRIC model.

However, the revisable offline calculations can be re-run under new network assumptions for the purposes of scenario-testing the network dimensioning in the vAcc2.3 LRIC model. These revisable offline calculations take several hours to run on a desktop PC.

Therefore, the starting point for a user will most likely be the two Excel workbooks comprising the active calculations. If both workbooks are open, then users can change inputs, re-calculate the workbooks and investigate the impact of the implemented change. The two workbooks should be opened together.

Specifically, in order to produce a result, the vAcc2.3 LRIC model can be run by pressing **F9** to perform the calculation (the two workbooks are provided with manual calculation enabled). When the vAcc2.3 LRIC model has completed a calculation, 'calculate' is no longer displayed in the Excel status bar. If 'calculate' does not disappear, then perform a full calculation by pressing **Ctrl+Alt+F9**.

The key results of the vAcc2.3 LRIC model, such as the unit costs of an unbundled line (nationally and by geotype), can be found on the *C3MainResults* worksheet in the *Network Service Costing – Access* module.

The costs of each modelled technology can be derived by changing the value in cell *A1Ctrl!D19* and re-calculating the model.

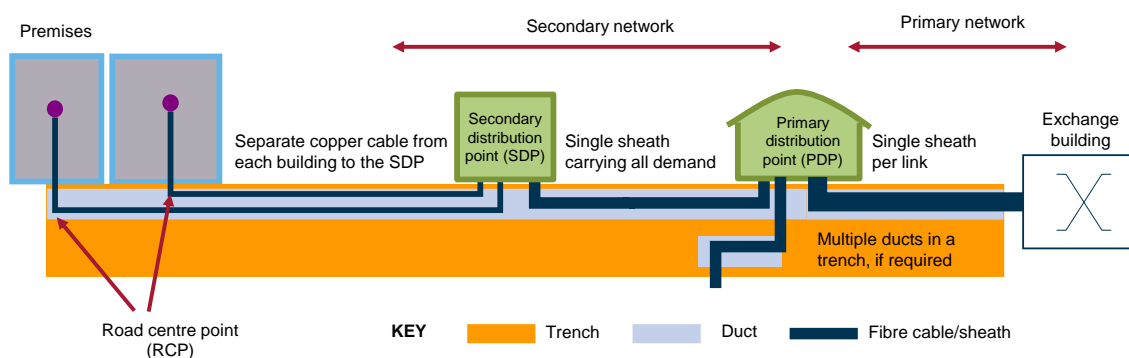
2.3 Modelled architectures

In order to determine the infrastructure required for an access network connecting a set of premises, our offline algorithms (rendered in VB in Microsoft Excel) take the locations of the premises to be connected and an exchange location as the raw geographic inputs. Premises are then clustered and linked together by cabling in an efficient way so that (for a copper technology):

- several premises are served by an SDP
- several SDPs are served by a PDP; pair gain systems (PGS) can be deployed where a PDP served by copper would have loops too long to provide sufficient quality-of-service (QoS)
- copper cabling is deployed
 - from the premise to a road centre point (RCP) lying on the road and then back to the SDP
 - from the SDP to the PDP
 - from the PDP to the exchange location
- PTP fibre cabling can also serve individual premises (e.g. business sites).

This network design is summarised below in Figure 2.3.

Figure 2.3: Overview of the copper network deployed by our algorithms [Source: Analysys Mason, 2018]



An analogous network hierarchy is modelled for PON and PTP fibre. In the case of the PON architecture, splitters are deployed at the PDP, meaning that multiple lines can be carried on a single fibre in the primary network. In the case of CTTH (respectively PTP fibre), a dedicated copper pair (respectively fibre strand) is dimensioned between the premises and the exchange building.

A change made in the vAcc2.3 model (compared to the v1.7 model) is that we now assume that the costs of the final drop trench and customer premise equipment for the FTTH technologies are excluded from the monthly costs derived. They are assumed to be recovered by other means (i.e. the assets are customer-funded/provided or are recovered by separate installation charges), consistent with how operators charge for these services in Norway.

3 Overview of the geo-analysis

This section provides an overview of the geo-analysis undertaken as part of the bottom-up modelling. In particular:

- Section 3.1 describes the street data we have used and how it has been processed
- Section 3.2 explains the distance function we have used to quantify road-based distances between locations
- Section 3.3 describes the classes of algorithms used within the revisable offline calculations
- Section 3.4 outlines the stages within the revisable offline calculations
- Section 3.5 describes how the revisable offline calculations can be re-run.

3.1 Geographic datasets

This section describes the datasets used in our offline calculations. This offline analysis was undertaken in 2009/2010, using the most up-to-date datasets available at the time.

3.1.1 Buildings

Bygningspunkter data was used as the basis for a location database. There were approximately four million entries in total in this database. We first removed all garages and the locations in Svalbard, as per Principle A2 of the model specification. Each entry was then classified using one of 170 building types, which we grouped into 18 categories. We also considered the data on building status (e.g. in use, to be approved, to be demolished) and the number of flats/floors in the building. Below in Figure 3.1 we illustrate the number of buildings by category.

Figure 3.1: Buildings by (selected) category [Source: Analysys Mason, 2018]

Analysys Mason category	Number of buildings
Housing	1 463 654
Agricultural	507 251
Holiday housing	450 908
Other unconnected buildings	180 149
Other business	65 476
Industrial	55 284
Education	16 071
Fibre-fed (assumed)	1163
Other categories	55 199
Total	2 795 155

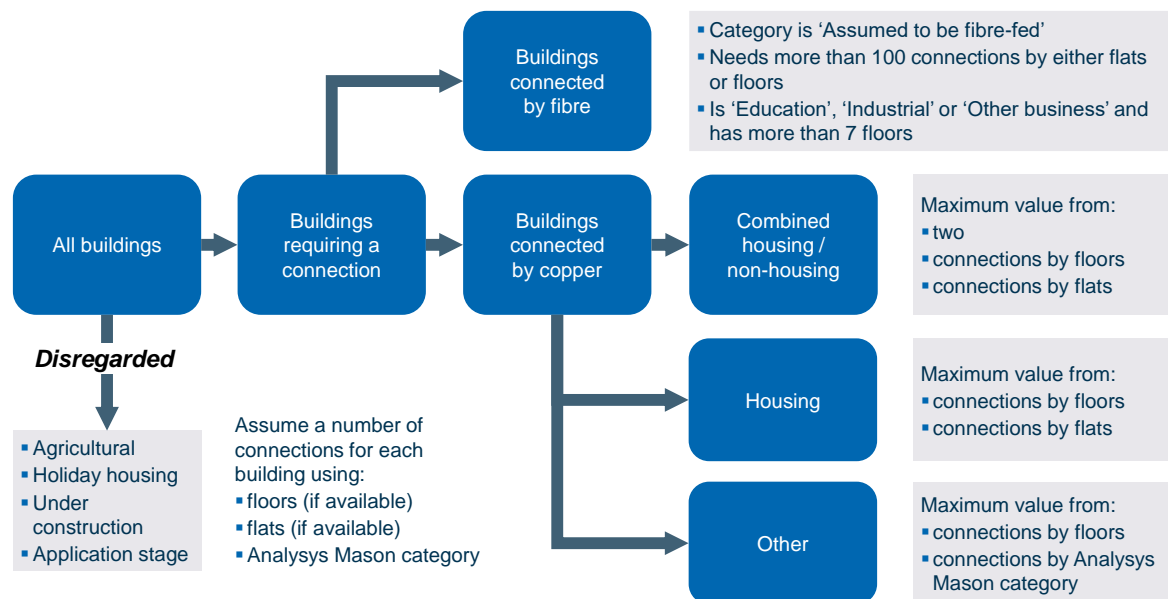
We assigned copper/fibre connections to buildings using a set of deterministic rules. Initially, we determined the number of connections needed by floors/flats and by Analysys Mason categories, as shown in Figure 3.2 below.

Figure 3.2: Assumed number of connections based on number of floors, flats and Analysys Mason categories [Source: Analysys Mason, 2018]

Floors	Connections
1–2	1
3–6	2
7–14	5
Over 15	10
Flats	Connections
Any size	1
Analysys Mason category	Connections
Agricultural	–
Holiday housing	–
Other unconnected buildings	–
Other business	2
Industrial	2
Remaining categories	1

We then used the set of rules illustrated in Figure 3.3 below to estimate the connections needed.

Figure 3.3: Deterministic rules to assign connections to buildings [Source: Analysys Mason, 2018]



Following the rules shown above, approximately 1.6 million buildings were assumed to need a connection. In the context of the CTTH (respectively PON fibre) architectures, 2817 buildings were assumed to be served by a PTP fibre overlay, with the remainder served by CTTH (respectively PON fibre). In the case of a PTP fibre deployment, all of the 1.6 million buildings were assumed to be served by PTP fibre.

The rest of the buildings in the dataset (approximately 1.2 million: mainly holiday homes, agricultural buildings and buildings under construction) were assumed not to be served by the network, although

some may be passed as the network passes the 1.6 million buildings served. 2.7 million lines were estimated as being required across the 1.6 million buildings served, which is the total number of active lines there would be if every connected building subscribed to the modelled network.

3.1.2 Street network

The actual Norwegian road network forms an integral part of our analysis. We used the StreetPro Norway dataset, which geocodes the road network in Norway. Figure 3.4 shows a roadmap plot of Norway; routes have been calculated using the route plotting software RouteFinder.



Figure 3.4: Illustration of StreetPro Norway
[Source: Analysys Mason, 2018]

The data supplied by MapInfo contained street and railways, classified under a number of different types, as shown in Figure 3.5.

Road type	Road description
S1	Motorways
S2	Major roads
S3	Other major roads and secondary roads
S4	Local/connecting road (high importance)
S5	Local road (minor importance)
S6	Back road, walkway, other road, etc.
R	Railways

Figure 3.5: MapInfo road classifications [Source: Analysys Mason, 2018]

This dataset has been used for multiple purposes in the access modelling, including defining the geotypes and calibrating the p-function.

A five-step process has been performed on the StreetPro Norway database to make it usable by RouteFinder. This process is shown in Figure 3.6.

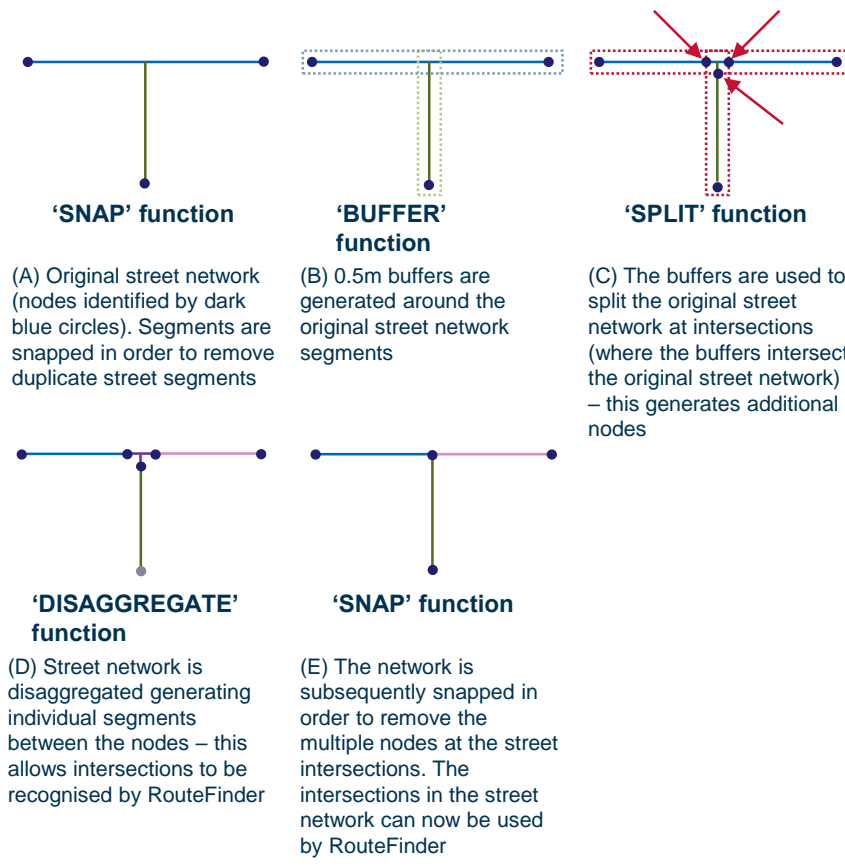


Figure 3.6: Illustration of the process used to make StreetPro usable by RouteFinder [Source: Analysys Mason, 2018]

RouteFinder can only distinguish a junction in a road network if all road segments crossing that junction terminate at it, rather than pass through it. A series of processing steps (each using particular MapInfo functions) are needed to break up the road segments into shorter pieces, so that no segment passes through a junction. These processing steps (or ‘functions’) are described in Figure 3.7 below.

Function	Purpose
SNAP	Removes duplicate records
BUFFER	Buffers the road network to use as a cutting tool
SPLIT	Splits the original road network using the buffered road network
DISAGGREGATE	Divides up roads into the split-up segments
SNAP	Joins the roads together where they have been split apart

Figure 3.7: MapInfo functions [Source: Analysys Mason, 2018]

3.1.3 Telenor data

Telenor provided remote switching stage/unit (RSX) locations data and service area boundaries for its copper network. Based on our own investigation of the Telenor data, we derived a set of locations housing all RSX equipment and a set of boundaries, with each boundary containing exactly one RSX location. Some service areas have been merged or split up in order to derive these final boundaries.

The number of individual locations derived is lower than the total number provided by Telenor because Svalbard locations are excluded and some locations within close proximity of each other

(less than 250 metres) have been rationalised. For the avoidance of doubt, location/boundary data is not present in the active modules as it is only used to derive parameter values in the offline calculations.

3.2 Fixed offline calculations

This section describes the key aspects of the fixed offline calculations, undertaken in 2009/2010.

3.2.1 Definition of geotypes and sample

Service areas were classified according to their ratio of road per location and the distribution of the buildings in the service area, based on their ‘crow-flies’ distance to the RSX.

Using Telenor data, a set of 3948 RSX locations and corresponding service area boundaries was derived. For each service area, the following parameters were derived:

- road kilometres within the area (using StreetPro)
- buildings assumed to be connected
- ‘as-the-crow-flies’ distance from each of these buildings to its parent RSX location
- distribution of these distances (in 1km groupings).

A service area was defined as ‘clustered’ if 98% of locations were within four kilometres of the RSX (as-the-crow-flies); all other service areas are defined as ‘spread’. Geotypes were then defined using the ratio of road per connected building and whether service areas were clustered or spread. The definitions for this classification are shown in Figure 3.8.

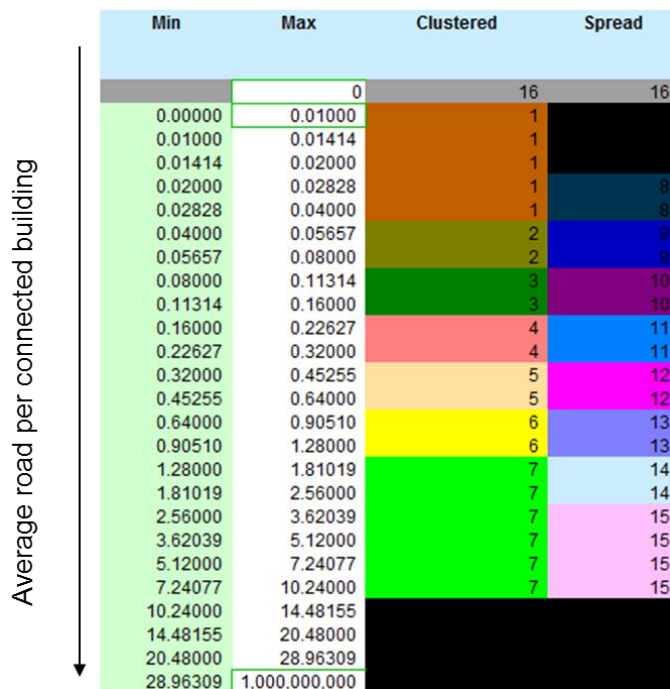


Figure 3.8:
Classification of service areas [Source: Analysys Mason, 2018]

A sample within each geotype was selected at random from a total sample size of 400 service areas. This was designed as a stratified sample, based on both the total connected lines within the geotype and the standard deviation of the average road per connected building for each geotype. The sample contained 10% of all service areas and more than 10% of connected buildings. Figure 3.9 lists all the geotypes and their respective sample sizes.

Figure 3.9: Illustration of sample size calculation [Source: Analysys Mason, 2018]

Geotype	Areas	Roads	Locations	Stratum size (demand)	Proxy for s.d. of cost	Sample size
1	470	14 536	485 664	1 065 517	0.0067	46
2	403	14 922	270 994	469 230	0.0118	35
3	388	13 646	123 414	175 448	0.0230	26
4	348	11 961	54 245	70 291	0.0450	20
5	207	7359	17 178	21 513	0.0911	12
6	56	2167	2620	3178	0.1734	4
7	30	1686	897	1114	1.0999	8
8	10	952	29 454	58 580	0.0042	2
9	95	8261	135 567	210 112	0.0108	14
10	313	22 421	187 317	252 254	0.0225	36
11	625	41 911	185 022	237 107	0.0436	66
12	554	38 214	88 512	109 673	0.0895	63
13	293	24 394	28 352	33 952	0.1805	39
14	108	11 388	6919	8330	0.3366	18
15	33	4125	1160	1507	1.1540	11
16	15	–	328	328	–	–
TOTAL	3948	217 943	1 617 6433	2 718 134		400

3.2.2 Distance function

A p–function is used to quantify the road distance between two points (x_1, x_2) and (y_1, y_2) , using the following formula – this is calibrated in a separate offline workbook:

$$j \times k \times \{(x_1 - x_2)^p + (y_1 - y_2)^p\}^{1/p}$$

For example, Euclidean ‘crow-flies’ distance uses $j=k=1, p=2$; while rectilinear ‘Manhattan’ distance uses $j=k=p=1$. However, over larger distances, it is better to use a different pair of values to account for the fact that, in reality, trench and cable will follow roads and this will not be captured by either crow-flies or Manhattan distance alone. The simpler problem of identifying suitable values for k and p has been the subject of several academic studies.⁷ In their paper, Love and Wesolovsky concluded that “*it is inappropriate to simply assume a convenient value for p in a location study*”. This is because experimental data finds that there are several values of p that can lead to good

⁷ For example, the paper by Love, M. and Wesolovsky, G. (1988), *Facilities location models and Methods*. Ed Saul J Goss, North Holland.

approximations. Also, different values of k can be used to scale distances to be a better approximation.

Furthermore, we believe that the treatment of the lengths of cable and trench needs to be slightly different within the offline calculations, as a single trench can actually hold multiple cables. An illustration of this effect is shown in Figure 3.10 below.

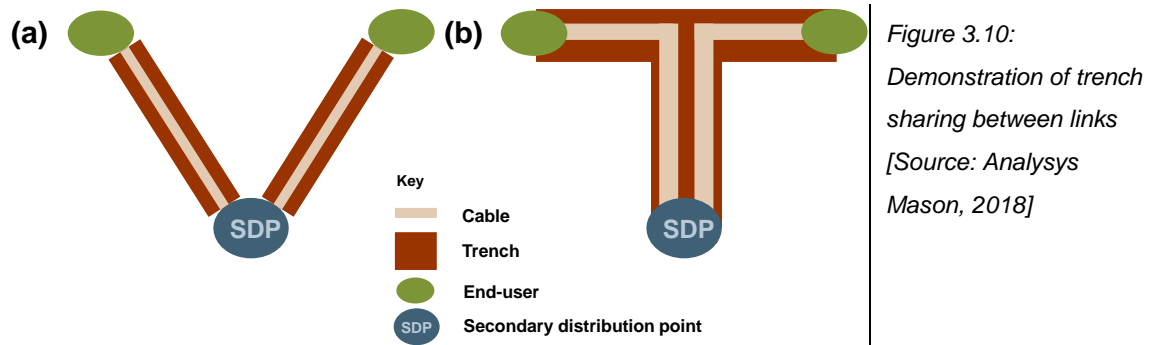


Figure 3.10 above shows two links joining end users to their parent SDP. Diagram (a) indicates how these links would be viewed if trench and cable used the same distance measure. Diagram (b) shows what is happening between these links for our example in reality: they are sharing part of the total trench as the locations lie across a junction. Although a calibrated p -function would get correct *cable* lengths, it would over-estimate the trench/route lengths. Therefore, Analysys Mason has calculated a separate trench-sharing coefficient, j , in addition to determining the values of k and p . Cable length is calculated using the p -function, while the total trench lengths are calculated using the p -function *and then* further scaling by j .

The p -function is not used for all length calculations within VB. In particular, it is not used when:

- distances between points are only being compared (e.g. in the clustering algorithms): crow-flies distance is used since it has a faster calculation time
- the length of a link that lies along a straight road is being calculated.

The offline calculations are able to test whether a link lies along a straight road, due to the location data available. Both the building location and its equivalent point on the road network (road centre point, or RCP) are stored. The data available for each location is shown in Figure 3.11 below. If the link lies along a straight road, as illustrated in the left diagram, then the angle α is approximately 90° and the angle β is approximately 180° . In such cases, crow-flies distance is used; otherwise the p -function is used.

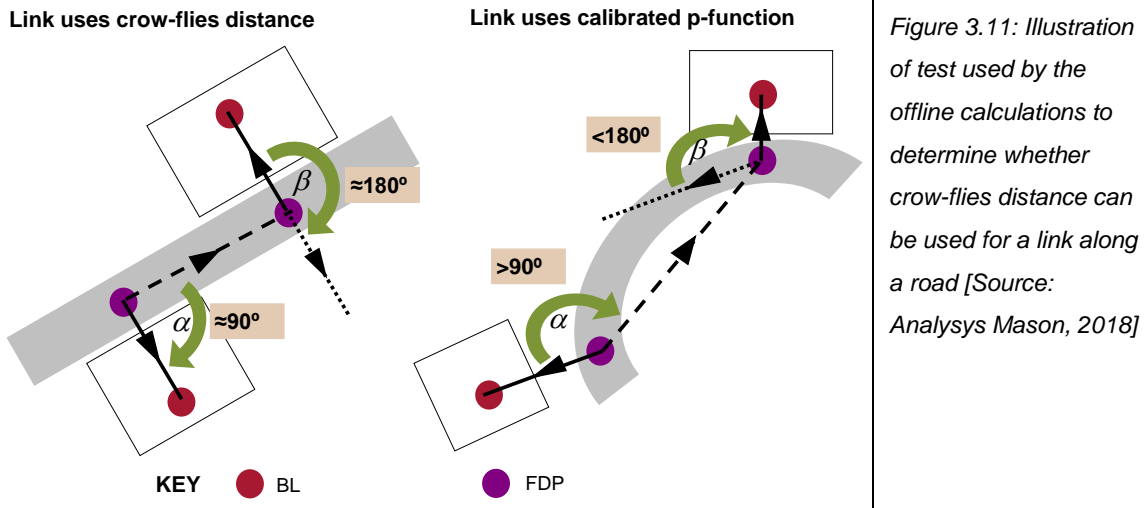


Figure 3.11: Illustration of test used by the offline calculations to determine whether crow-flies distance can be used for a link along a road [Source: Analysys Mason, 2018]

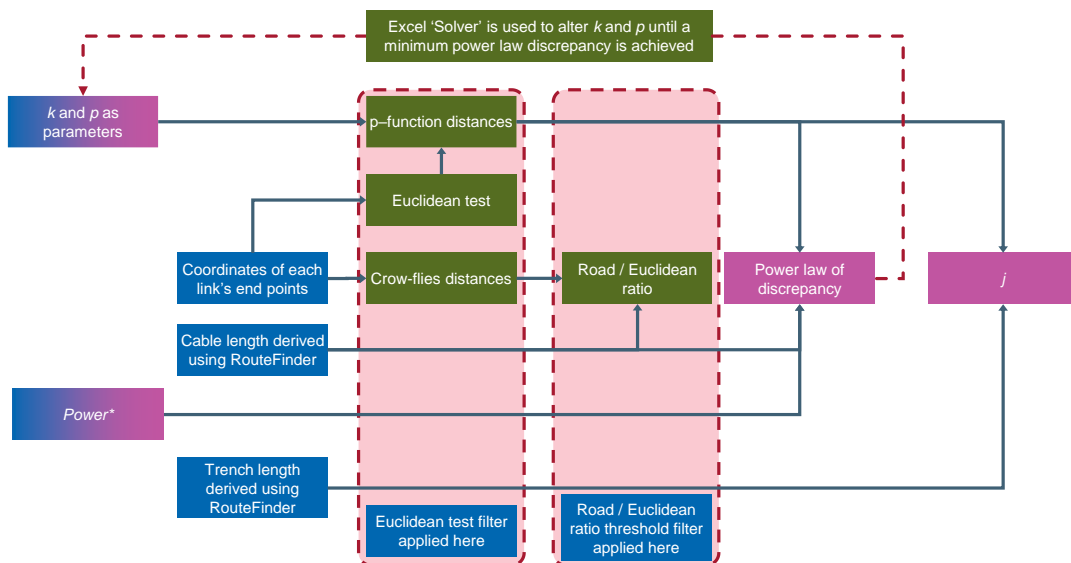
We have calibrated values of j , k and p separately for each of the geotypes, using:

- a processed StreetPro dataset
- PTP links from the 400 sampled service areas
- the actual road lengths of these links plotted with RouteFinder.

The data for these analysed PTP links are stored in a separate set of workbooks.

We have calibrated values for j , k and p by comparing the discrepancy between the distances calculated with the p -function and the actual road distances. In order to find optimal values of j , k and p , this calibration is iterated over many combinations of j , k and p , and repeated using different power laws to measure the discrepancy between calculated and actual distance. The process for determining j , k and p values is shown schematically in Figure 3.12.

Figure 3.12: Determination of j , k and p for the p -function [Source: Analysys Mason, 2018]



(*) We separately tested several values of this power (1, 1.25, 1.5, 1.75, 2, 2.25 and 2.5).

Figure 3.13 provides an illustration of the p–function inputs.

Geotype	k	p	j
1	1.55	2.12	66%
2	1.52	2.14	75%
3	1.45	1.87	78%
4	1.50	1.95	80%
5	1.66	2.47	79%
6	1.32	1.40	79%
7	1.68	14.09	89%
8	1.62	2.76	70%
9	1.62	2.48	73%
10	1.41	2.36	86%
11	1.42	1.91	83%
12	1.41	1.73	84%
13	1.37	1.91	88%
14	1.31	1.44	89%
15	1.20	1.18	91%
16	1.00	2.00	100%

Figure 3.13:
Illustration of p–
function inputs
[Source: Analysys
Mason, 2018]

3.3 Classes of algorithms used within the revisable offline calculations

The subroutines used in the revisable offline calculations are written in VB and are described in Annex C. They are encoded in the Excel workbook called ‘Geo-analysis Code’. The building data and outputs of the revisable offline calculations are stored separately for each service area in a set of workbooks called the ‘Access Data’ workbooks. Although there are three distinct deployment methodologies (one for each architecture), the same fundamental algorithms in the ‘Geo-analysis Code’ workbook are used in both: these are clustering algorithms and spanning tree algorithms, as described below.

3.3.1 Clustering algorithms

We have used clustering algorithms to group locations into groups to be served by a network node. Our clustering algorithm requires three inputs:

- *Capacity criterion* – if each point has an associated demand, then do all of the points taken in the cluster together exceed that capacity?
- *Distance criterion* – if we calculate the centre of the points in a cluster, or determine a central point in the cluster, then do all points in the cluster lie within a certain distance of that centre?
- *Control cluster criterion* – if two points are flagged as being in different ‘control clusters’ and those control clusters form a forbidden pair, then the two points are forbidden from ever being in the same cluster.

To illustrate the last criterion, if all locations in an area have the same control cluster index, then there are no restrictions on two points being in the same cluster. However, if the first point in the list

is in control cluster 1, all other points are in control cluster 2 and the control clusters 1 and 2 are a forbidden pair, then the first point must be in its own singleton cluster, since it is forbidden from sharing a cluster with any of the other points.

Given a set of locations and these three sets of basic inputs, the algorithm determines the number of clusters in two stages: a creation phase and a refinement phase. The creation phase determines the number of clusters using a top-down methodology, starting with the initial set of locations. The refinement phase uses a sequence of individual algorithms to improve these initial clusters according to various criteria. These are summarised in Figure 3.14 below.

Figure 3.14: Refinement algorithms used within the clustering algorithm [Source: Analysys Mason, 2018]

Algorithm	Description
Simple reassignment	Moves a point from one cluster to another subject to the constraints, so that the distance from the point to the cluster centre is minimised
Full optimisation	Moves a point from one cluster to another subject to the constraints, so that the total distance within a cluster between its points and the cluster centre is minimised
Swap	Swaps two points sitting in different clusters, subject to the constraints, to minimise the distance between these points and their cluster centres
High-demand simple re-assignment	Moves a point with at least two units of demand from one cluster to another subject to the constraints, so that the distance from the point to the cluster centre is minimised
High-demand swap	Swaps points which have at least two units of demand from one cluster to another subject to the constraints, to minimise the distance between these points and their cluster centres
Single demand swap	Swaps two points with unitary demand sitting in different clusters, subject to the constraints, to minimise the distance between these points and their cluster centres

All of these clustering algorithms make distance-based decisions using only crow-flies distance.

It is important to note that the distance criterion is *not* intended as a technical limit. For example, a distance criterion of 600m for a PDP cluster is not intended to mean that such PDPs cannot serve locations further than 600m away. Rather, it should be seen as a *control* for the algorithm, which allows the refinements to produce more sensible, tightly knit clusters by reducing the number of points for consideration. In urban areas, most PDP clusters can reach capacity within such a distance anyway, due to the density of locations: the capacity constraint dominates in this case.

We have used the control cluster criterion to account for the fact that some exchange areas cover multiple islands. Each island is given a separate control cluster identifier, with all these identifiers forming forbidden pairs. Therefore, a distribution point can never serve buildings on different islands.

3.3.2 Spanning tree algorithms

There are a variety of algorithms available in order to determine how trench and cabling are set out in an access network for a set of locations. These algorithms determine a set of edges linking the

locations forming a tree, allowing any point to reach any other point by following the edges of the tree. The model employs two minimum spanning tree algorithms.

Such algorithms calculate the shortest/cheapest amount of duct/cable to link a set of locations (with varying demand) together into a tree. The simplest algorithms of this type effectively derive the shortest duct network to link all premises. However, such an output may not be ideal, since focusing on minimising the duct network may lead to inefficient cable deployments. A simple, albeit extreme, example of this is shown in Figure 3.15 below.

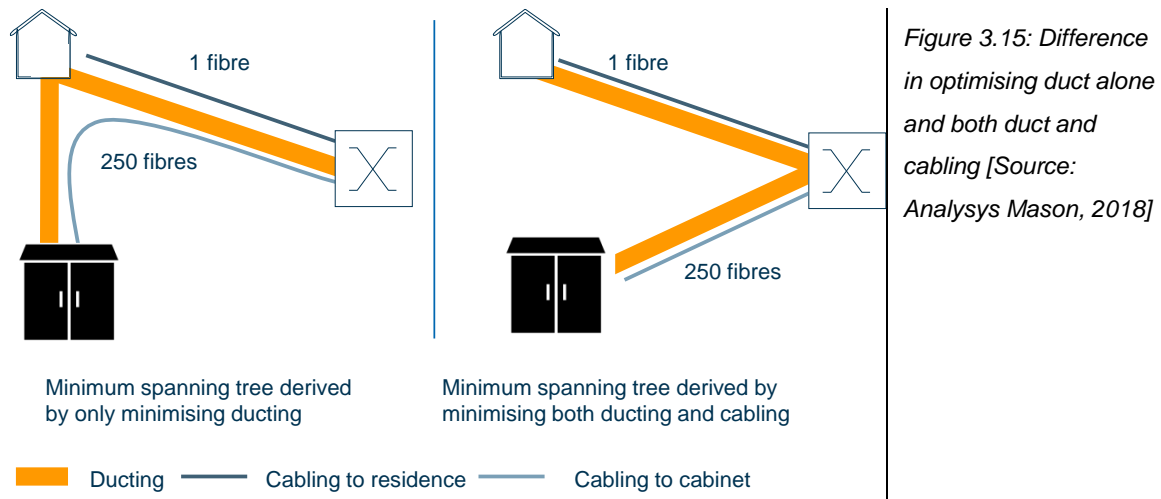


Figure 3.15 above shows a very simple case of a household, a street cabinet and a switch. The left diagram shows the deployment when only ducting is optimised. The shortest route of duct is to connect the cabinet via the house. However, since the street cabinet needs 250 pairs, significantly more cable is required in this scenario than in that on the right, which has a marginally longer distance of duct. Although this is only an illustration, it does demonstrate that, for more complex clusters, the cost of cabling should also be considered.

We have used two minimum spanning tree algorithms in the network design. Both minimise a cost function which includes the costs of both cabling and trenching when determining the shape of our spanning trees. Although the output may not be a minimum spanning tree, it will be a configuration of lowest cost. Each of these cost functions have been calibrated for our model using the sampled areas. Cost functions for fibre and cable have been separately derived. These two algorithms are:

- a modified version of *Prim's* algorithm, similar to that in the Federal Communications Commission's (FCC) Hybrid Proxy Cost Model (HCPM),⁸ is used to derive the minimum spanning trees within clusters served by an SDP
- a version of *Dijkstra's* algorithm⁹ is used to derive a minimum spanning tree to
 - connect SDPs to PDPs and then PDPs to the main node location in the fibre deployment

⁸ Bush, C. A., Kennet, D. M., Prsbrey, J. and Sharkey, W. W (October 1999), *Computer Modelling of the Local Telephone Network*, Federal Communications Commission.

⁹ Dijkstra, E. W. (1959), *A note on two problems in connexion with graphs*. In *Numerische Mathematik*, 1 (1959), S. 269–71.

- identify links if deploying a fibre ring (in central business areas).

The proxy cost functions used in our minimum spanning tree algorithms are of the form:

$$k_1*d + k_2*c + k_3*d*c + k_4*d$$

where d is the distance between two points and c is a measure of the size of the cable between the two points (number of fibres for the fibre network and copper pairs in the copper network). k_4 has the specific purposes of only being used when a trench link would be deployed between two locations on the opposite side of a road. k_4 is deactivated in the model since we deploy trench links through the centre of the roads.

The values of k_1 , k_2 , and k_3 are inputs in the 'Geo-analysis Code' workbook (k_4 is set to 0, i.e. it is inactive) and can be changed in this workbook. This cost function is employed slightly differently in the two algorithms, but:

- allows the maximum cable distance between the access node and the end user to be controlled, by considering both the costs of trench and cable
- allows the ability to track the cabling requirements within any link, by dimensioning the cable according to the demand that the link needs to be able to serve.

This proxy cost function makes incremental cost decisions when developing the tree, which differs from the global decision that would create the lowest-cost spanning tree. Therefore, the cost function has to be calibrated to result in the lowest-cost spanning tree. This is why the cost function is considered to be a *proxy* cost function rather than an *actual* cost function.

3.4 Stages in the revisable offline calculations

The algorithms described above are used by the revisable offline calculations to determine the access network asset requirements to connect a set of locations passed back to an exchange location. The process is shown in Figure 3.16 below and is broadly split into two phases: node determination and trench/cable network determination.

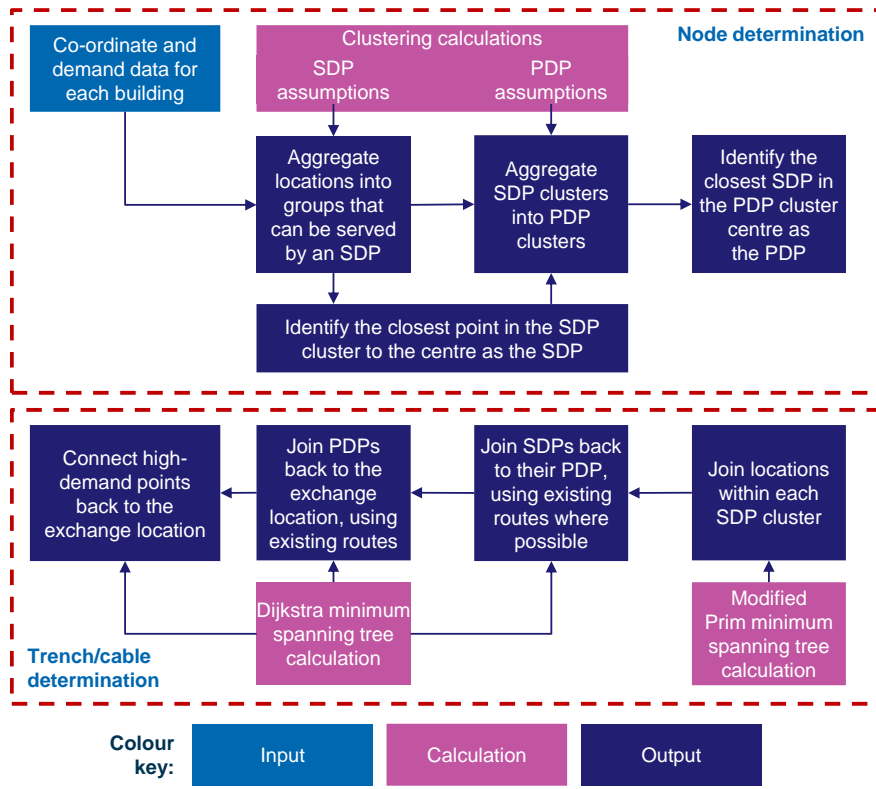


Figure 3.16: Process for determining deployment
[Source: Analysys Mason, 2018]

The following subsections explain these two phases in more detail.

3.4.1 Node determination

The determination of the nodes in the network uses the clustering algorithms. The deployment first clusters locations into SDP clusters and then groups these clusters further into PDP clusters. More precisely:

- Points are grouped into SDP clusters and the point closest to the demand-weighted centre is deemed the SDP. The SDP cluster containing the exchange location uses it as its SDP.
- SDP clusters are grouped into PDP clusters using the SDP locations. The SDP closest to the demand-weighted centre of the cluster is deemed to be the PDP. The PDP cluster containing the exchange location uses it as its PDP.

Our clustering methodologies consider two types of cluster capacity: absolute capacity and practical capacity (i.e. absolute capacity subject to an assumption of normal utilisation). For example, we assume that copper PDPs have a maximum capacity of 100 lines: this constraint is never relaxed. However, we also assume that a PDP cluster is designed to be 90% utilised (i.e. 10% spare), meaning that a PDP cluster should usually not exceed 90 lines.

In SDP clustering, the maximum absolute capacity is used to limit the total number of lines from a collection of locations. Where a single location has a demand higher than that of the maximum absolute capacity, but less than the limit for it to be served by fibre, it becomes an SDP of its own with no other demand locations included in that cluster.

3.4.2 Trench and cable determination

Having clustered the locations into clusters served by SDPs and then PDPs, the trench and cable networks are built up incrementally, by using the minimum spanning tree algorithms described in Section 3.3.2, joining up the following elements:

- points of demand within SDP clusters (PBP–SDP links)
- SDPs to their parent PDP (SDP–SDP links)
- PDPs to their parent access node (PDP–PDP links).

PBP–SDP

PBP-SDP links use the modified Prim algorithm to form the trench network within an SDP cluster and calculate the number of fibres required to reach the end-customer location. Being a dozen or so points at maximum, these are calculated very quickly. The (non-repeated) trench required to connect all the points to the SDP is calculated. With regard to cable sheath, for both copper and fibre networks, it is assumed that individual cables go from the SDP to the PBP. Joints are calculated at the PBP depending on the number of active pairs deployed to the PBP. Only particular cable sizes are used, with 2 pairs being the smallest copper size. Each level of demand at a point is served by combinations of cable. For example, three units of demand are currently assumed to be fed by one 4-pair copper cable, or by one 12-fibre cable.

Where it is determined that a cable link in the PBP–SDP tree lies along a straight road, the length is calculated using Euclidean distance. Otherwise, the p–function is used.

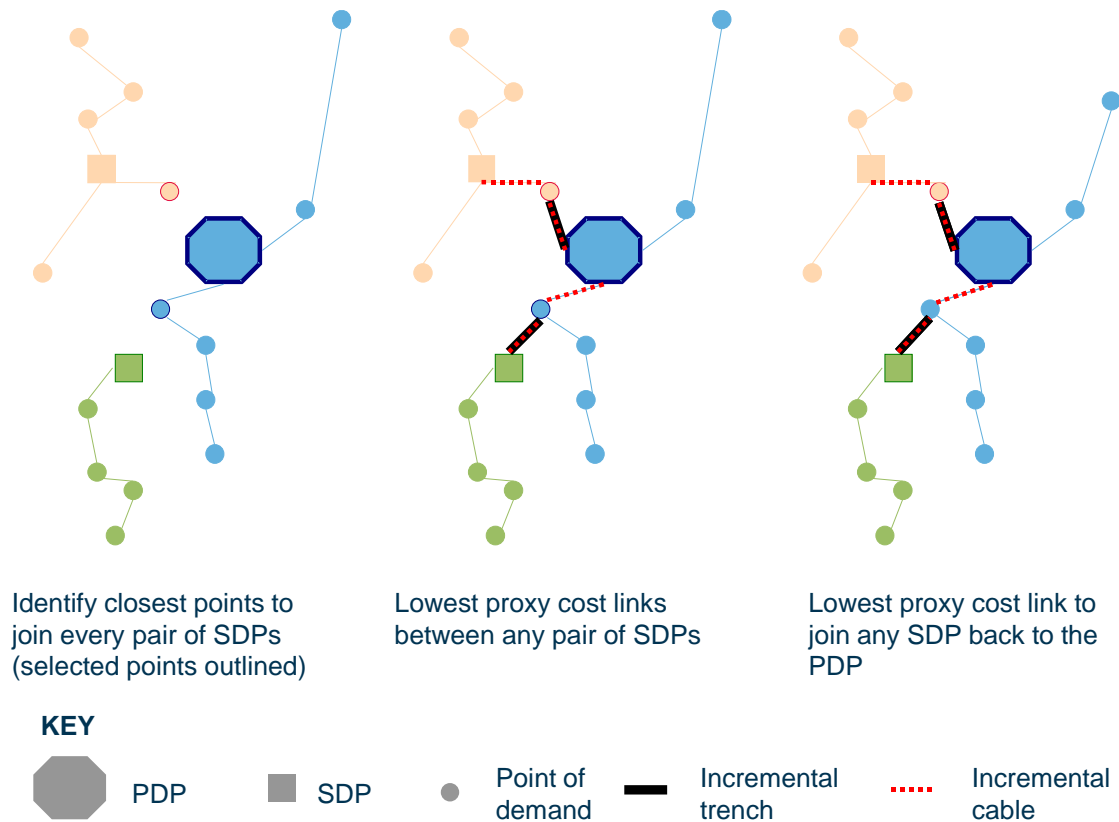
SDP–PDP

The modified Dijkstra algorithm uses a pre-calculated full mesh of trench links to join SDPs to their parent PDP. The pre-calculation and subsequent algorithm proceeds by:

- for each pair of SDP clusters, identifying a point within each cluster that produces the shortest link between the two SDPs
- creating a fully meshed set of lowest proxy cost links between SDPs using these points; these links can form a ‘daisy-chain’ via other SDPs and assume that the trench within the SDP clusters has already been laid
- using the Dijkstra algorithm to select the least proxy cost subset of links that allow each SDP to be joined back to the PDP.

This process is illustrated for a simple example of three SDP clusters, one of which contains the parent PDP, in Figure 3.17 below:

Figure 3.17: Use of the Dijkstra algorithm [Source: Analysys Mason, 2018]



In the context of the fibre network, these links can be assumed to have two designs: either ‘tapered’ or ‘non-tapered’. Our tapered and non-tapered methodologies are explained below.

Tapered

For a given SDP-PDP link, a single cable sheath is used, whose size is dimensioned by the demand downstream of the SDP furthest along the trench network away from the PDP. For example:

- to link an unconnected SDP to the network, the cable used is the smallest that can accommodate the capacity of this SDP
- to link an SDP to the PDP, the cable used is the smallest that can accommodate the capacity of all the SDPs linked to the PDP along this network path.

Joining occurs at each SDP. We also assume a certain utilisation of the secondary network cabling. For example, a utilisation of 100% means that a 50-pair copper cable can be used for up to 50 units of downstream demand, whereas with a utilisation of 80%, it can only be used for up to 40 lines.

Non-tapered

In the non-tapered case, only two cable sizes are used. The main cable size is a certain number of pairs, with a minor cable size to use at the most extreme points in the network. We also assume a certain level of cable

utilisation in this case. Setting the minor cable size to zero means that the secondary network can be fully non-tapered.

The cable size is dimensioned using the downstream demand at the SDP as in the non-tapered case. If the downstream demand exceeds the minor cable size (multiplied by the utilisation), then the required number of sheaths of the major cable are used. As an example, if we assume a major tapered cable size of 96 fibres and a utilisation of 80%, then 90 units of demand are served by 2×96 -fibre cables.

In the context of the copper network, the secondary network is assumed to be fully tapered.

The modified Dijkstra algorithm leads to daisy-chaining of SDPs, since an SDP may go back to the PDP via several SDP clusters and will go through each SDP.

Since the cable must pass through the SDP location of every SDP cluster that it passes through back to the PDP, this can lead to a small amount of 'back-tracking' in the route, as demonstrated below in Figure 3.18. This will lead to a small over-estimation of the cable requirements. However, since this is restricted to the scale within an SDP cluster, we do not believe this to be a significant source of inefficiency in the route.

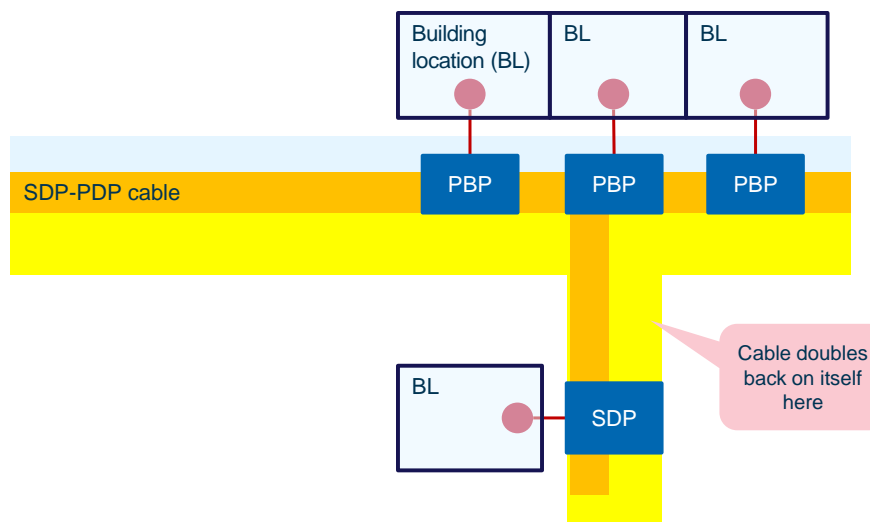


Figure 3.18:
Demonstration of
doubling back by the
SDP-PDP cable
[Source: Analysys
Mason, 2018]

PDP-MDF

► *Cable routing*

A similar algorithm is used as in the SDP-PDP case, but with some differences:

- The proxy cost function used has different cost coefficients, which is necessary as the main cable may be specified with more fibres than the SDP-PDP cable, which allows a different bias between cable and trench in the PDP-PDP links.

- The link between a PDP and the access node is assumed to be a discrete cable: if two PDPs use the same trench to get back to the access node, then it contains separate sheaths.
- A separate tube is used along the PDP–PDP link routes and is assumed to have a fixed capacity of cables per tube.

Due to the complexity of calculations at this level, there are several simplifying assumptions that have been made compared with the SDP-PDP level. These are:

- PDP links are calculated by finding the two closest *SDPs* in the PDP clusters, not the two closest *points* (and the link is assumed to be a single trench linking the two SDPs, rather than passing through any points in their clusters). This may over-estimate the trench required. However, a point in the SDP cluster is still in close proximity to the cluster centre, so the net difference per PDP link will be small.
- If a PDP needs to pass through several other PDP areas to get to the access node, then it is assumed to pass through each PDP location. This may over-estimate the cabling required, since a shorter route is likely to be possible without going through each PDP location.

These assumptions simplify the algorithm significantly at this stage. The algorithms also remove any occurrences where the cable doubles back on itself on its way to the access node, which can be a more significant effect at the scale of the PDP cluster. We re-calculate the required ducting, sheath lengths and jointing respectively.

3.5 Re-running the revisable offline calculations

If a user wishes to re-run the revisable offline calculations for a particular architecture, then they should firstly confirm that all the inputs for that architecture, both in the ‘Geo-analysis Code’ workbook and the ‘Access Data’ workbooks, are as they require. The offline calculations will run fastest if the files are on a desktop PC hard drive, rather than run over a network. The ‘Geo-analysis Code’ workbook and the ‘Access Data’ workbooks should all be in the same directory in order for the VB to work.

The user should set the relevant inputs in the ‘control panel’ section at the top of the *INselected* worksheet of the ‘Geo-analysis Code’ workbook. The user should verify that the ‘Access deployment option’, the ‘first service area’ and ‘last service area’ have respectively been set to the desired values.

It is recommended that the version of Excel being used is specified (2000/2003/2007/2010), otherwise the VB may stall.

To run the VB for the selected range of sampled areas with the chosen architecture, the user should then press the ‘Derive access network volumes’ button.

When the calculations are complete, external workbook links in the ‘Geo-analysis Code’ workbook should be updated using the ‘Edit Links’ window, which can be opened by the key combination

'Alt+E+K'. Links can be updated by selecting all of the listed workbooks and pressing the button labelled 'Update Values'. The workbook should then be re-calculated. This will ensure that the most recent calculated results are summarised in the 'Geo-analysis Code workbook'.

Finally, the user should ensure that the output ratios derived on the *SummAssets* worksheet for the selected VB scenario are pasted into the corresponding part of the active calculations on the *A2NwDsScen* worksheet of the *Network Service Costing – Access* module.

4 *Market* module

The *Market* module is common to Nkom's LRIC models of fixed core networks and fixed access networks. It calculates the volume of subscribers by service (e.g. retail telephony with and without broadband, wholesale telephony with and without broadband, broadband-only, leased lines etc.) for the purposes of both access and core models, while also calculating voice and data traffic volumes for use by the LRIC model of core networks. The previous version was the v2.0F model (updated from the v1.7 model), which was published with the v2.0F LRIC model of fixed core networks in April 2014.¹⁰

The *Market* module calculates subscriber and traffic volumes over the period 1991–2050 for the entire Norwegian market and then an assumed operator within that market. Since the development of the Nkom (NPT at the time) v2.0F model, actual data for recent years (2013–2017) has become available and certain new trends have emerged in the fixed market. We have updated the volumes for these years as a starting point and revised our forecasts. Data received from Nkom, operators and from publicly available data sets have been used to update demand parameters in the vAcc2.3 model:

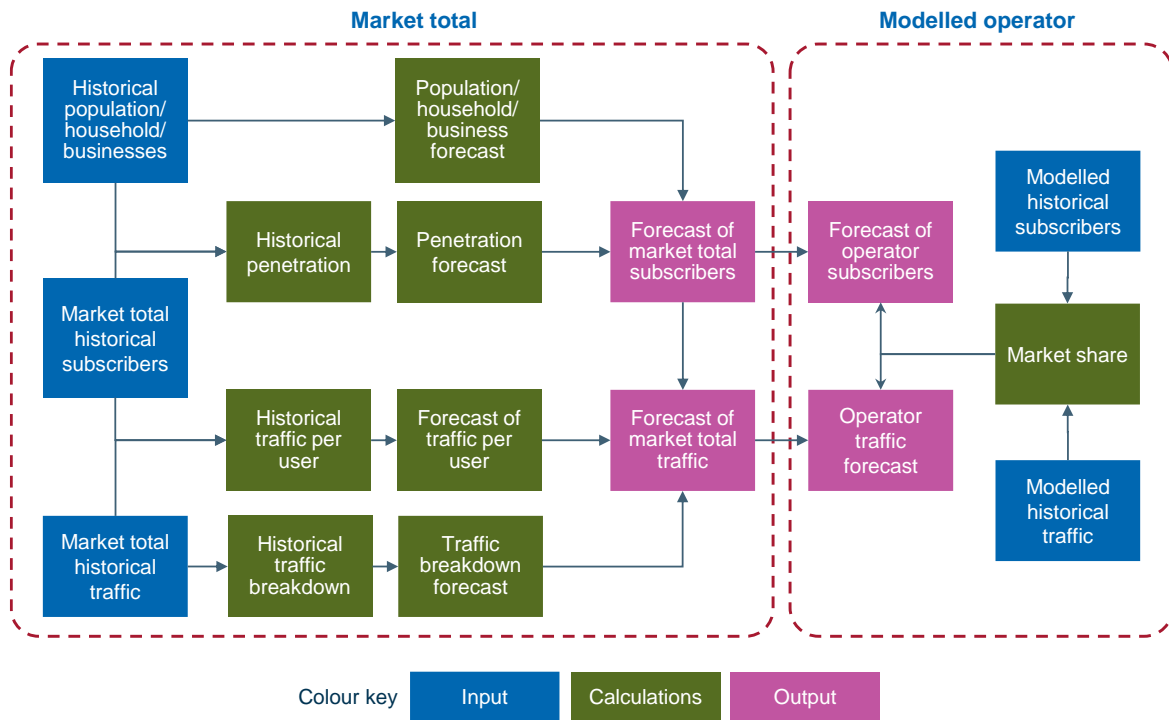
- Section 4.1 illustrates the high-level flows of the *Market* module
- Section 4.2 details the updates made to historical demand parameters
- Section 4.3 discusses the changes made to forecast demand parameters
- Section 4.4 indicates the assumed demand for the modelled access network.

4.1 High-level flows of the *Market* module

The *Market* module outputs a series of forecasts both at the market level and at the operator level. Mainly the subscriber and traffic forecasts are calculated in this module. A high-level illustration of the flow of calculations in the *Market* module is shown in Figure 4.1 below.

¹⁰ See http://eng.nkom.no/market/market-regulation-smp/cost-model/lric-for-fixed-core-networks/_attachment/13853?_download=true&_ts=146ec4269c7

Figure 4.1: High-level flow of calculations in the Market module [Source: Analysys Mason, 2018]



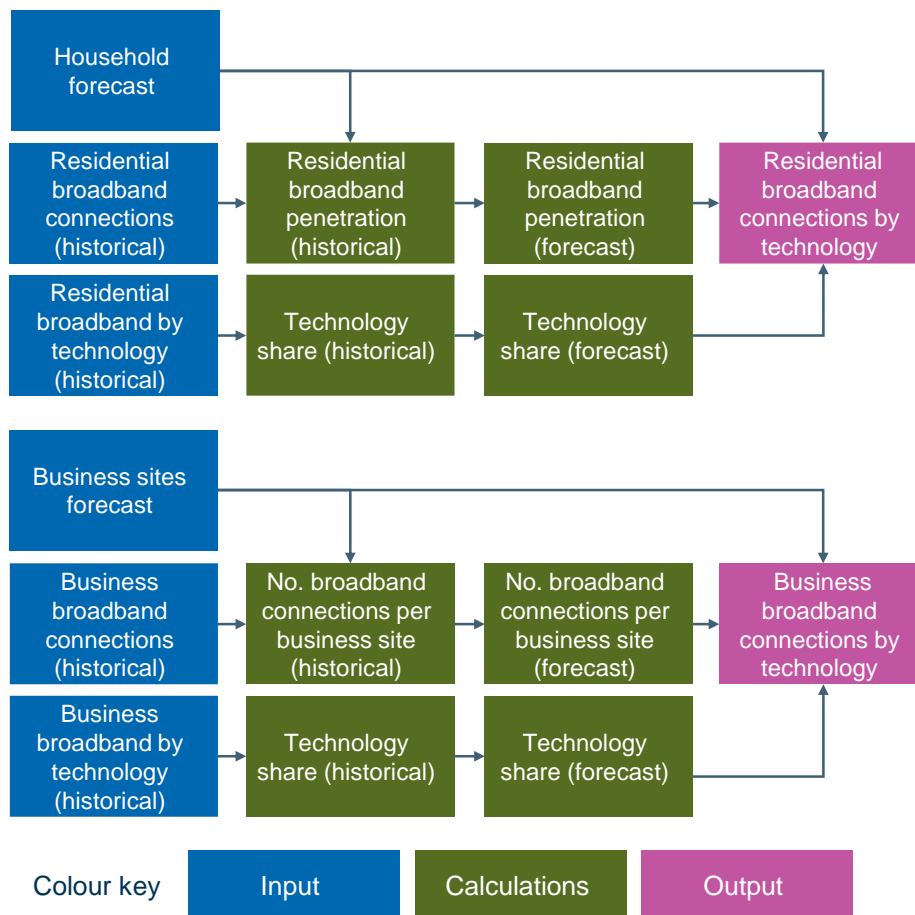
The *Market* module groups the subscriber forecasts under four main categories, and the traffic forecasts under two main categories. These categories and the level of detail at which the forecasts are conducted are shown in Figure 4.2 below.

Figure 4.2: Series of forecasts at the market level [Source: Analysys Mason, 2018]

Forecast series	Level of detail
Voice connections	<ul style="list-style-type: none"> By residential and business By technology (PSTN, ISDN, cable, VoIP)
Broadband connections	<ul style="list-style-type: none"> By residential and business By technology (xDSL, cable, fibre, fixed access, radio and satellite)
Business connectivity services	<ul style="list-style-type: none"> Leased lines – analogue, digital (by speed), fibre Data transmission services – legacy, IP-VPN, Ethernet VPN
IPTV connections	<ul style="list-style-type: none"> By type (linear broadcast, video-on-demand)
Business data connectivity throughput	<ul style="list-style-type: none"> Data transmission services – legacy, IP-VPN, Ethernet VPN

Both the number of fixed voice and broadband connections are forecast in a similar way in the *Market* module. As an example, Figure 4.3 below illustrates how the number of broadband connections is forecast in the *Market* module.

Figure 4.3: Calculation flow of fixed broadband connection forecasts [Source: Analysys Mason, 2018]



The number of residential fixed broadband connections is driven by the number of households in Norway (similar to residential fixed voice connections). Hence, we have extrapolated the growth in the number of households and the growth in fixed broadband household penetration to forecast the number of residential fixed broadband connections. This market is further split into five different fixed broadband technologies: xDSL, cable, radio and satellite, fibre, and fixed access. The technology shares are obtained by extrapolating them from historical data.

The number of business fixed broadband connections is directly related to the number of business sites (similar to business fixed voice connections) in Norway. The number of business fixed broadband connections is forecast by extrapolating the business site count and the fixed broadband business penetration. This market is also split into the five fixed broadband technologies listed above.

After calculating the market-level demand volumes, operator-specific volumes are forecast based on the market total demand and its market shares. These are output on the *A4_Output* worksheet and linked into the *Network Service Costing – Access* module.

The output of the *Market* module is a time series for the period 1991–2050 of active access lines by type. The main types modelled are shown in Figure 4.4 below.

Figure 4.4: Access-related services modelled [Source: Analysys Mason, 2018]

Service description	
PSTN/ISDN end-user access	xDSL access
Wholesale line rental (WLR)	Bitstream
Full local loop unbundling (LLU)	Leased lines
Shared LLU	Access lines
Full sub-loop unbundling (SLU)	Fibre access lines
Shared SLU	Cable access lines

4.2 Updates of historical demand parameters

Historical demand updates for the years 2013–2017 were provided in the Nkom market data (now available from the Ekomstatistikken website) and for 2013–2017 by Telenor in response to a data request. These have been used in the update of historical demand parameters finalised for the v2.0F model, and retained in the vAcc2.3 model.

As in the v2.0F model, the demand volumes for the incumbent scale operator in the vAcc2.3 model are assumed to be based on either Telenor's own data (stored on the *CONF_TN* worksheet, which is internal to Nkom) or using data available from public sources (stored on the *PUBLIC_TN* worksheet). The default selection for consultation is to use the data on the *PUBLIC_TN* worksheet.

The model worksheets that contain all the relevant market data (*A2_Market demand*, *CONF_TN* and *PUBLIC_TN*) have been updated for the vAcc2.3 model in order to align demand inputs with the Nkom market data. All forecast parameters on the *CONF_TN* worksheet have been directly linked to their corresponding parameter on the *PUBLIC_TN* worksheet to ensure consistency between the two sets of forecasts. The sources used to update the v2.0F model are shown below.

Figure 4.5: Overview of sources used to update the Market module [Source: Analysys Mason, 2018]

Source	Input updated
Confidential Telenor data	Telenor traffic and subscribers for 2013–2017 on the <i>CONF_TN</i> worksheet (these values are not included in the public release of the vAcc2.3 model)
Statistisk sentralbyrå (http://www.ssb.no)	Population in 2013–2017 (Tabell: 01222), population forecast 2018–2050 (Tabell: 11167), households 2013–2016 (Tabell 10986) and establishments 2013–2017 (Tabell 09029)
Nkom Ekomstatistikken database	Fixed telephony subscriptions, fixed broadband subscriptions, Telenor broadband subscribers, connections for non-Telenor NGA providers (http://www.nkom.no/files/ekomportal/alle.csv)
Telenor's analytical tool	Telenor voice subscribers and Telenor wholesale subscribers (https://www.telenor.com/preliminary-telenor-group-analytical-tool-q416-reflecting-india-and-financial-services-4/)
Market data provided by Nkom ¹¹	Leased lines, data transmission services for 2014–2016

¹¹ This is the data that Nkom collates from operators and aggregates to write its regular reports on the Norwegian market for electronic communications services.

4.3 Updates of forecast demand parameters

The changes made to the 2013–2017 parameters in the vAcc2.3 model discussed in Section 4.2 have resulted in revisions being made to some of the long-term demand forecasts. The most significant revisions are described in more detail below (using the *PUBLIC_TN* worksheet):

- macro-economic indicators (Section 4.3.1)
- fixed voice connections (Section 4.3.2)
- fixed broadband connections (Section 4.3.3)
- business connectivity services (Section 4.3.4).

4.3.1 Macro-economic indicators

The year-end population data for 2013–2017 has been updated, as well as the population forecasts with low-, medium- and high-growth levels for 2018–2050 using data from Statistisk Sentralbyrå (SSB).¹² However, we have also kept the population forecast used in the vAcc2.2 model for reference. The medium-growth forecast is used in the vAcc2.3 model. A comparison of this forecast with that used in the v2.0F model is shown in Figure 4.6.

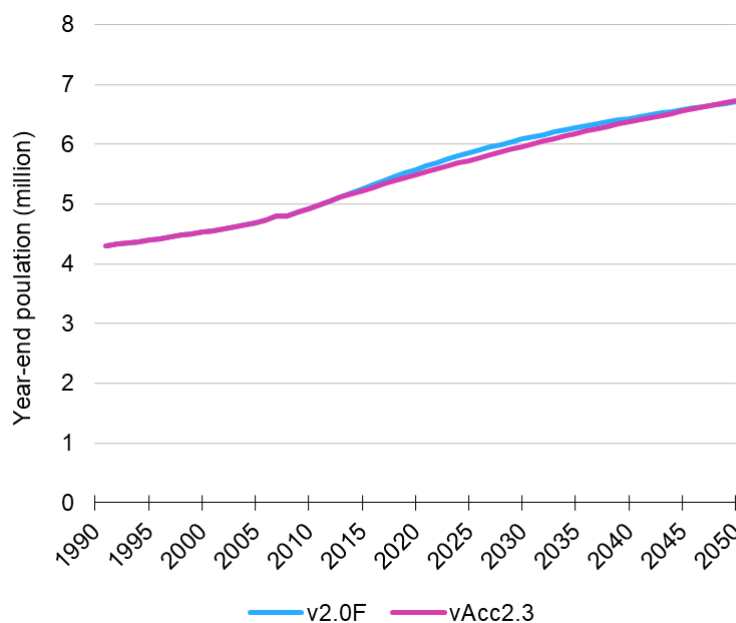


Figure 4.6: Population, historical and forecast, in the v2.0F and vAcc2.3 models
[Source: Analysys Mason, 2018]

The historical value for households has been updated for 2013–2016 and the forecast has been revised based on the new starting point. The time series assumed in the v.2.0F and vAcc2.3 models are illustrated in Figure 4.7 below.

¹² See <http://www.ssb.no/befolkning/>

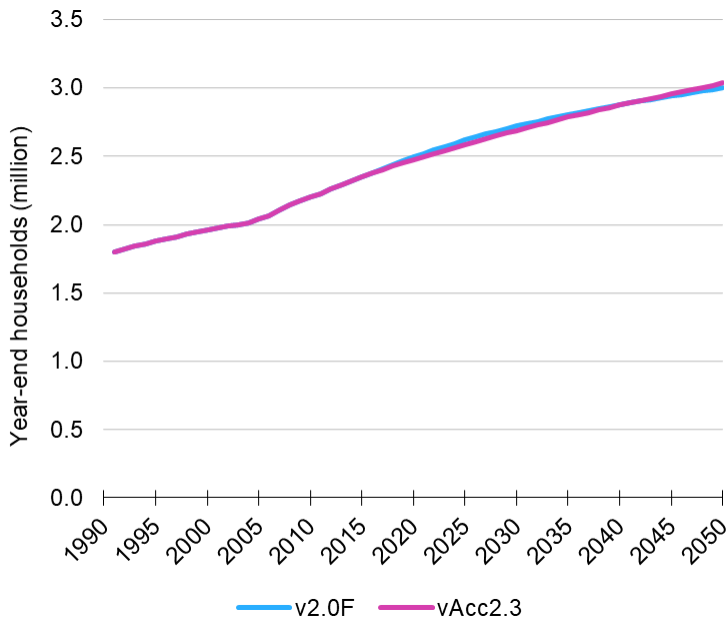


Figure 4.7: Households, historical and forecast, in the v2.0F and vAcc2.3 models [Source: Analysys Mason, 2018]

Figure 4.8 below shows the forecasts used in the v.2.0F and vAcc2.3 models.

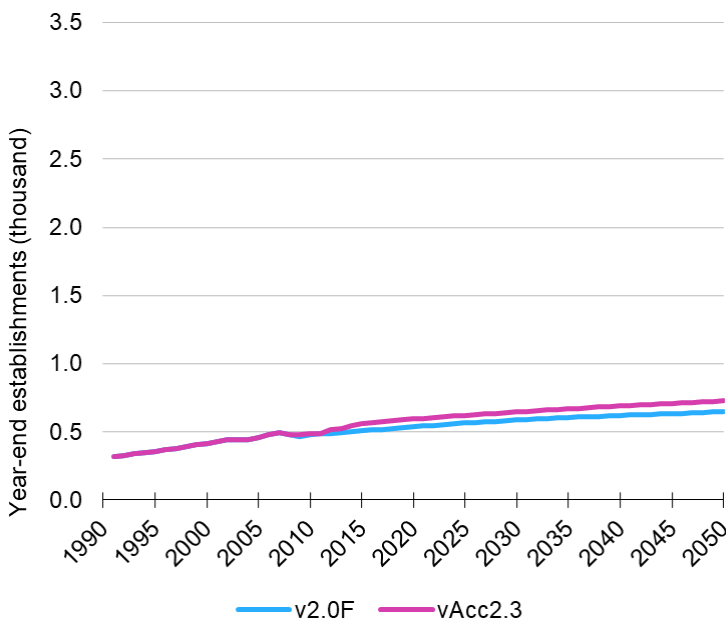


Figure 4.8: Establishments, historical and forecast, in the v2.0F and vAcc2.3 models [Source: Analysys Mason, 2018]

4.3.2 Fixed voice connections

The number of business and residential voice connections over the period 2014–2017 has declined more than was forecast in the v2.0F model (see Figure 4.9 below). Therefore, in the vAcc2.3 model we have reduced the number of fixed voice connections accordingly, but still assume a stable level of connections in the long term, as was the case in the v2.0F model. On the basis of operator forecasts of fixed voice subscribers sent to Nkom, we have now modified the v2.0F model so that voice connections continue to decline in the future, as shown in Figure 4.10 below. To do this, we have reduced the average number of fixed voice connections per household and per business site that are forecast in the long term.

Figure 4.9: Market-level fixed voice connections
[Source: v2.0F model, Analysys Mason, 2014]

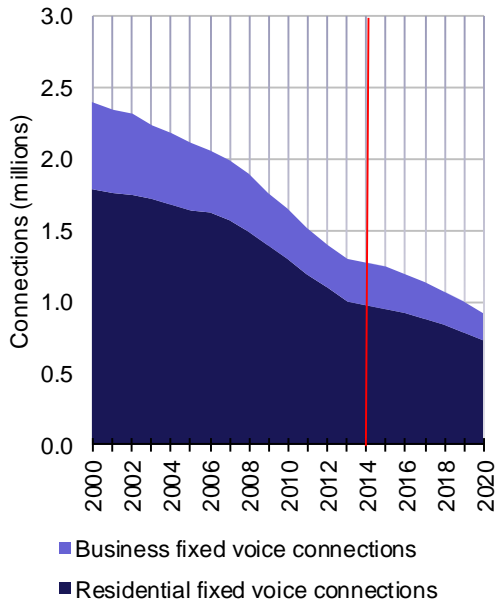
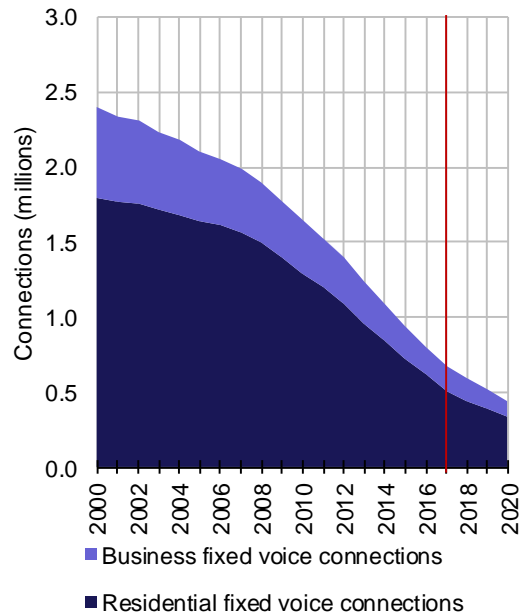


Figure 4.10: Market-level fixed voice connections
[Source: vAcc2.3 model, Analysys Mason, 2018]



Analysys Mason Research’s own forecasts of fixed voice connections also assume a continued year-on-year decline after 2014.

4.3.3 Fixed broadband connections

We have slightly modified the forecast for fixed broadband connections by adjusting the saturation of fibre and wireless connections. This is shown in Figure 4.11 and Figure 4.12 for the v2.0F and vAcc2.3 model, respectively.

Figure 4.11: Fixed broadband connections [Source: v2.0F model, Analysys Mason, 2014]

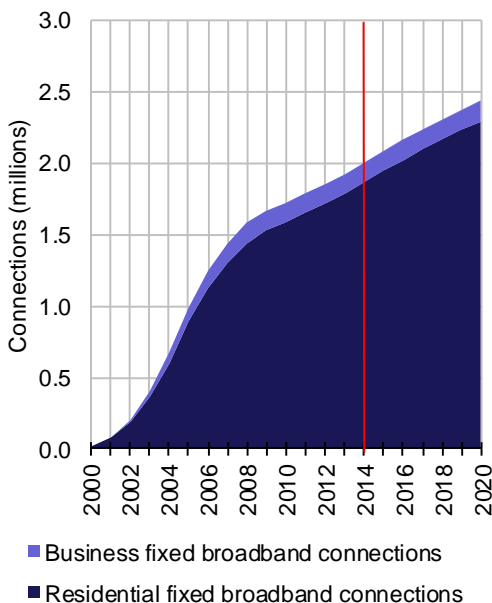
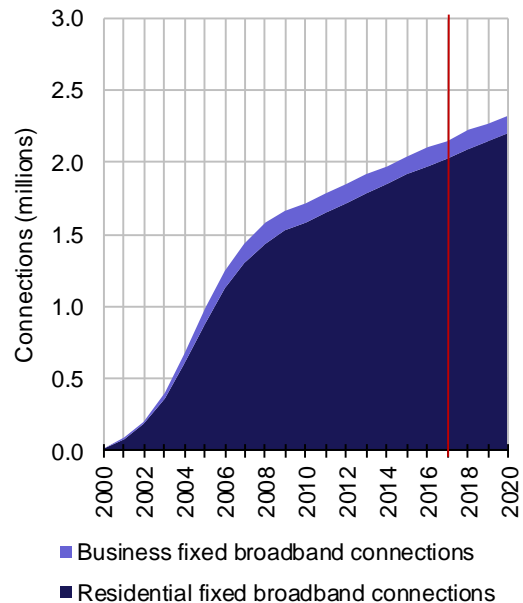


Figure 4.12: Fixed broadband connections [Source: vAcc2.3 model, Analysys Mason, 2018]



Following the recent trends in the fixed broadband market, we have increased the saturation of fibre, radio and satellite connections while reducing the saturation of xDSL connections. The following two figures show the forecast number of fixed broadband connections by technology.

Figure 4.13: Fixed broadband connections by technology [Source: v2.0F model, Analysys Mason, 2014]

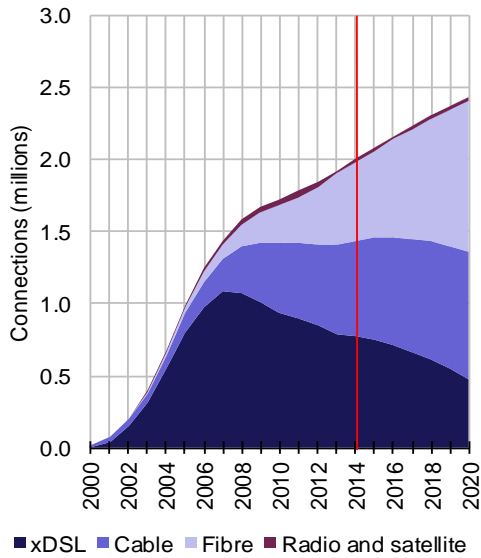
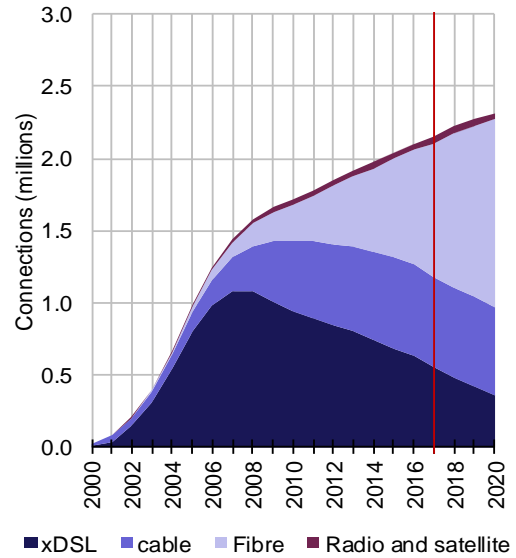


Figure 4.14: Fixed broadband connections by technology [Source: vAcc2.3 model, Analysys Mason, 2018]



4.3.4 Business connectivity services

We have not revised the forecast parameters of business connectivity services. The difference between the forecast volumes in the v2.0F and vAcc2.3 models is a result of updating the historical data points for 2013–2017 and using the same forecast parameters. The number of business broadband connections is assumed to rise in the long-term due to the increase in business sites.

Figure 4.15: Business connectivity [Source: v2.0F model, Analysys Mason, 2014]

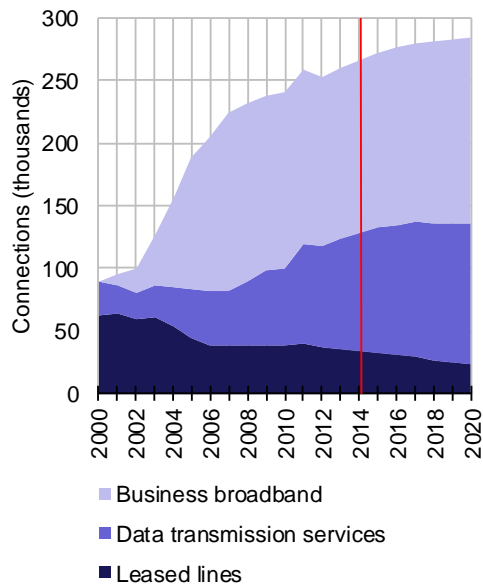
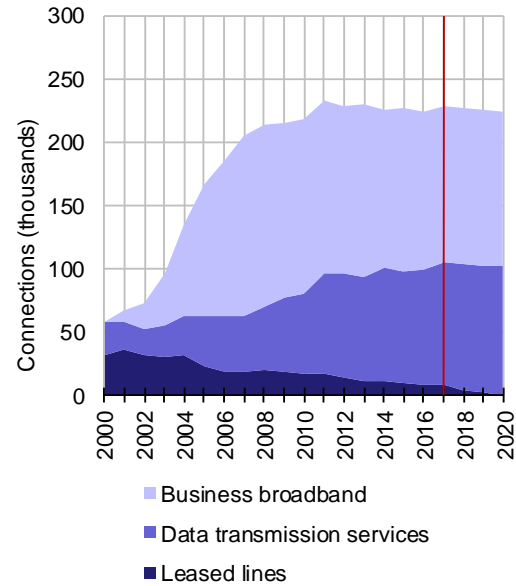


Figure 4.16: Business connectivity [Source: vAcc2.3 model, Analysys Mason, 2018]



4.4 Assumed demand for the modelled access network

After updating the 2013–2017 market-level demand volumes, we have slightly adjusted the market share of the modelled operator in order to reflect the recent trends. We have increased the market share of retail fibre connections in the short term.

The operator modelled in the vAcc2.3 model must also now carry the demand of both Telenor's cable broadband connections and those fibre connections served by fibre providers where Telenor will not build a competing NGA infrastructure. This is as described under Principle A18 of the model specification.

According to Nkom statistics, 70.2% of all fibre connections in Norway in 2017 (down from 77.6% in 2013) arise on NGA networks that are owned by Altibox partners or other companies (excluding Telenor; we also exclude the HFC-based Get TDC customers) and therefore should be included in the modelled demand.¹³ We include these lines using a market share forecast of "other relevant NGA connections".

The assumed demand for the modelled access networks in the v.2.0F and vAcc2.3 models is shown in Figure 4.17 and Figure 4.18, respectively.

¹³ See http://www.nkom.no/marked/ekomtjenester/statistikk/det-norske-ekomarkedet-rapporter/_attachment/18156?_ts=14d705b522d, page 30 and page 27 of https://www.nkom.no/forside/_attachment/28845?_download=true&_ts=15c9c1ab4f0

Figure 4.17: Access lines by technology for the modelled operator [Source: v2.0F model, 2014]

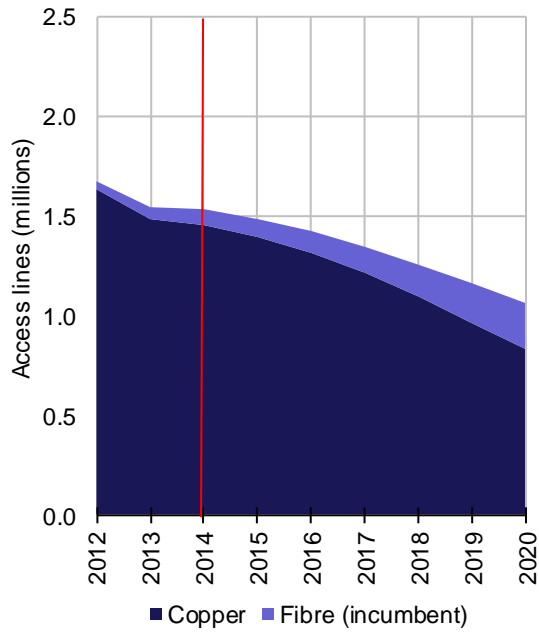
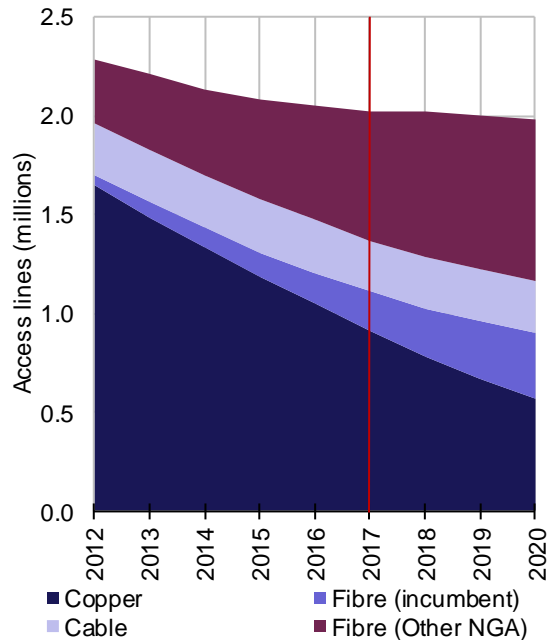


Figure 4.18: Access lines by technology for the modelled operator [Source: vAcc2.3 model, 2018]

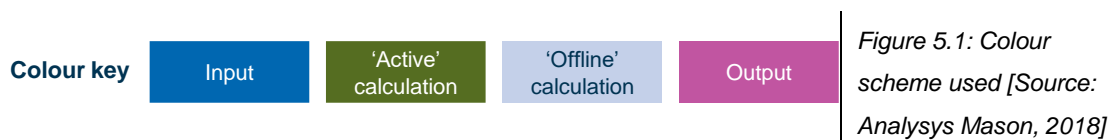


5 Network design calculations

This section is intended to provide more detail about the network design calculations used in the *Network Service Costing – Access* module, and is set out as follows:

- Section 5.1 provides an overview of the relevant worksheets in the model
- Section 5.2 provides an overview of the high-level flow of the network design calculations
- Section 5.3 describes the CTTH network design in more detail
- Section 5.4 sets out our definition and implementation of reusable assets
- Section 5.5 provides a summary of key network design adjustments.

The colour scheme shown in Figure 5.1 below is used throughout this section.



5.1 Overview of model worksheets

A summary of the worksheets in the *Network Service Costing – Access* module that are relevant to the network design is provided below in Figure 5.2.

Figure 5.2: Description of worksheets related to network design in the *Network Service Costing – Access* module [Source: Analysys Mason, 2018]

Name	Description
A0Lists	Defines the names of commonly used lists in the model
A1Ctrl	Lists the main controls/switches for the module
A2NwDsScen	Scenario sheet for network design inputs
A3NwDsFrcst	Scenario sheet for forecasts related to the network design
A4AssetIn	Defines asset inputs
A5NwDs	Calculates network assets required by geotype
A6ReUse	Calculates asset counts and costs for reusable assets in the modelled NGA networks
A7ResidualValueCopper	Calculates the residual capital value and economic lifetimes for the assets in the modelled copper network
B1FullNw	Collates the number of network elements required in each year according to demand drivers and network design rules

5.2 High-level flow of network design calculations

Schematics of the high-level flow of the network design calculations are shown in this section. Figure 5.3 shows the high-level flow of calculations for the CTTH network, and Figure 5.4 and Figure 5.5 show analogous schematics for the FTTH/PON and FTTH/PTP networks, respectively.

Section 5.3 then describes the CTTH network design in more detail: the other two network designs are analogous (except that the FTTH/PTP architecture does not have a fibre network overlay for high-demand locations and FTTH/PON dimensions separate splitter assets).

Figure 5.3: High-level flow of the CTHH network design calculations [Source: Analysys Mason, 2018]

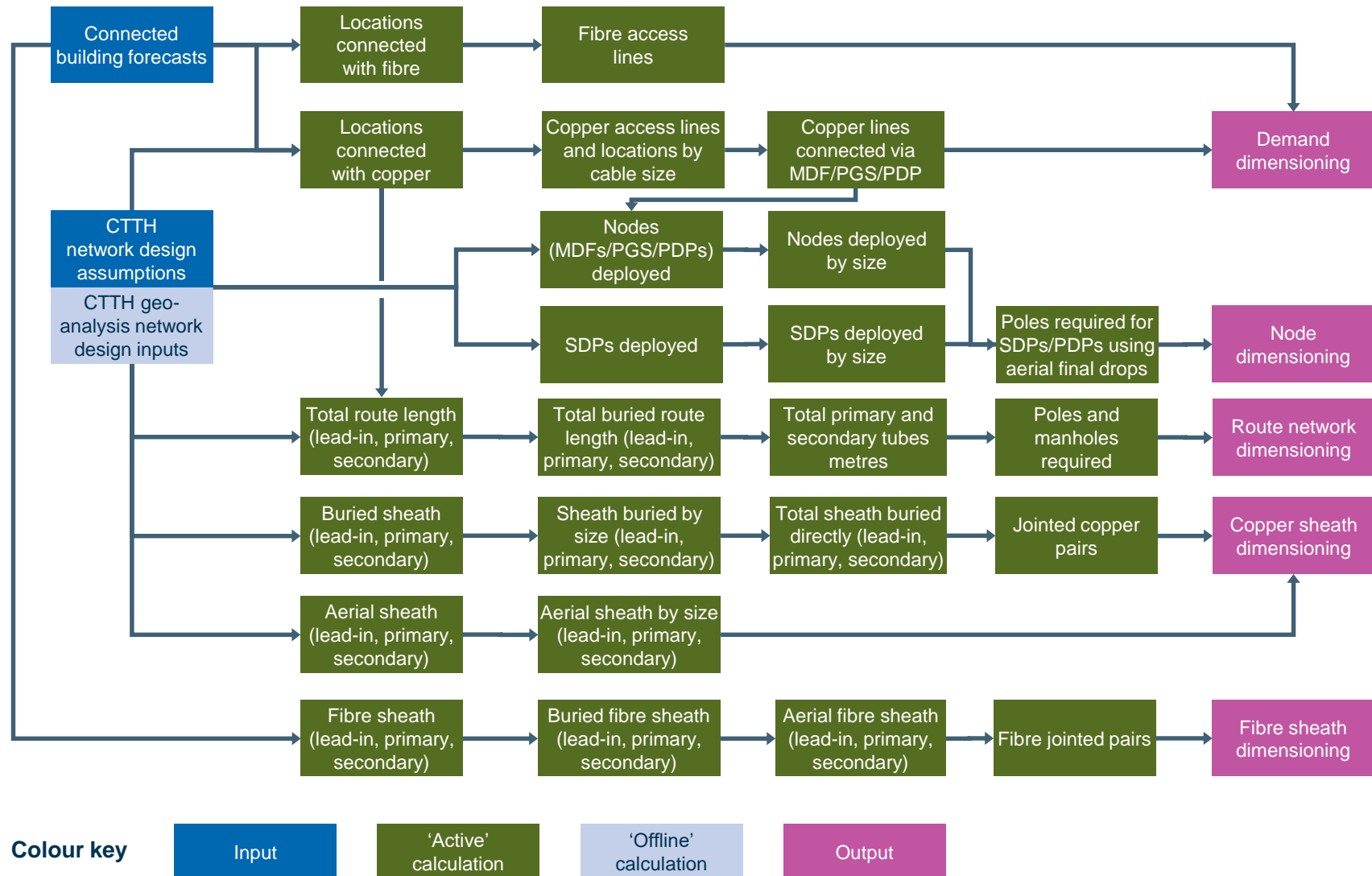


Figure 5.4: High-level flow of the PON FTTH network design calculations [Source: Analysys Mason, 2018]

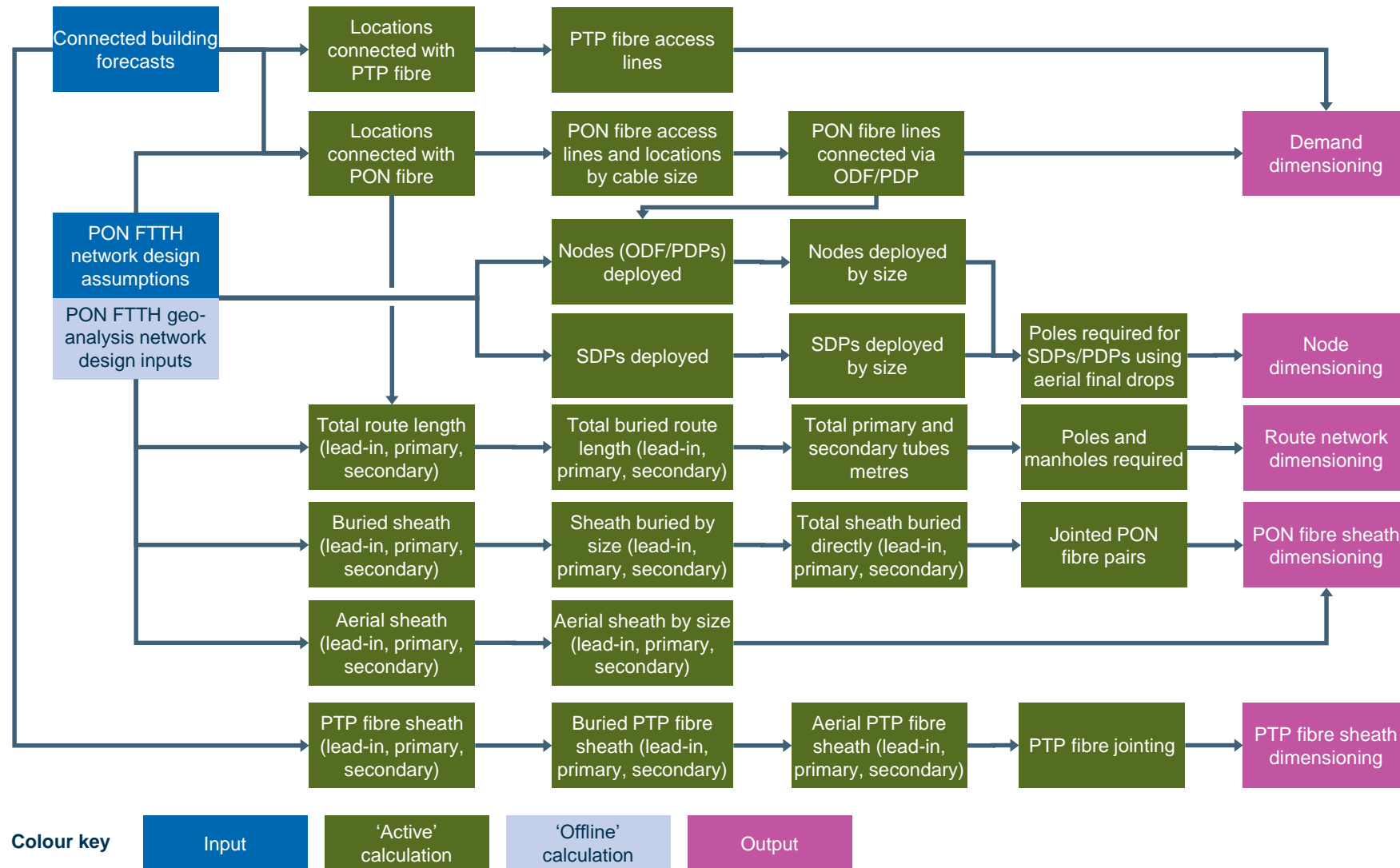
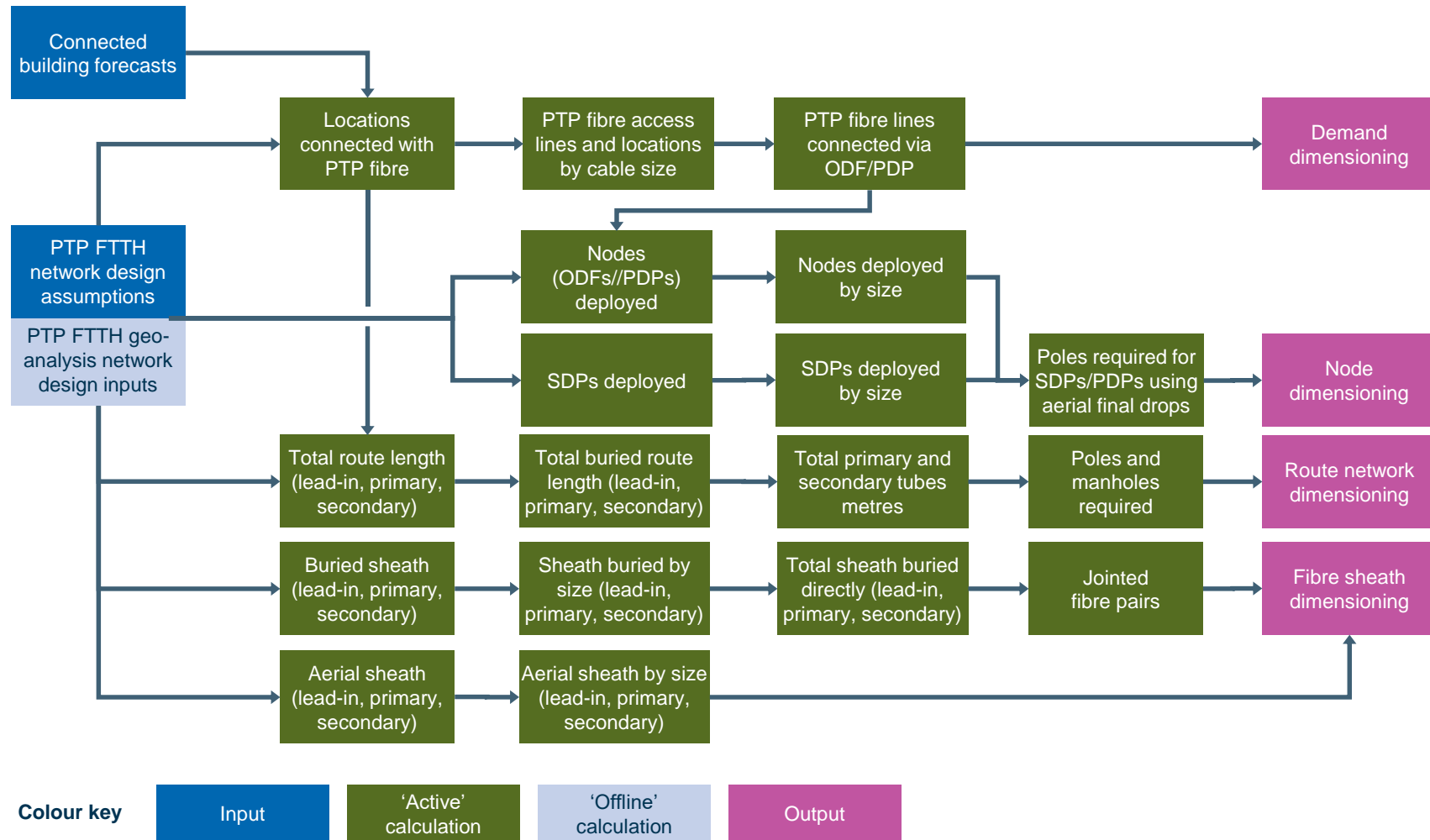


Figure 5.5: High-level flow of the PTP FTTH network design calculations [Source: Analysys Mason, 2018]



5.3 Description of the CTTH network design calculations

The following aspects of the CTTH network design calculations are explained in more detail in this section:

- demand and node calculations
- route network
- copper cabling
- jointing
- fibre network for high demand.

5.3.1 Demand and node calculations

The number of copper-connected and fibre-connected buildings is derived from the proportions connected in the sampled areas of the geo-analysis. Connected access lines are then derived from the average number of connected lines per connected building, as shown in Figure 5.6 below.

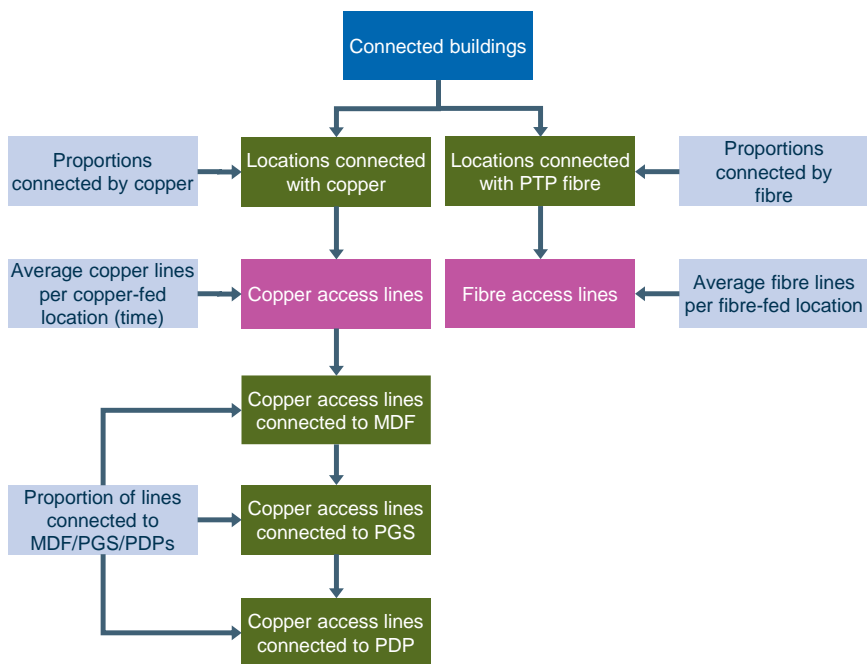
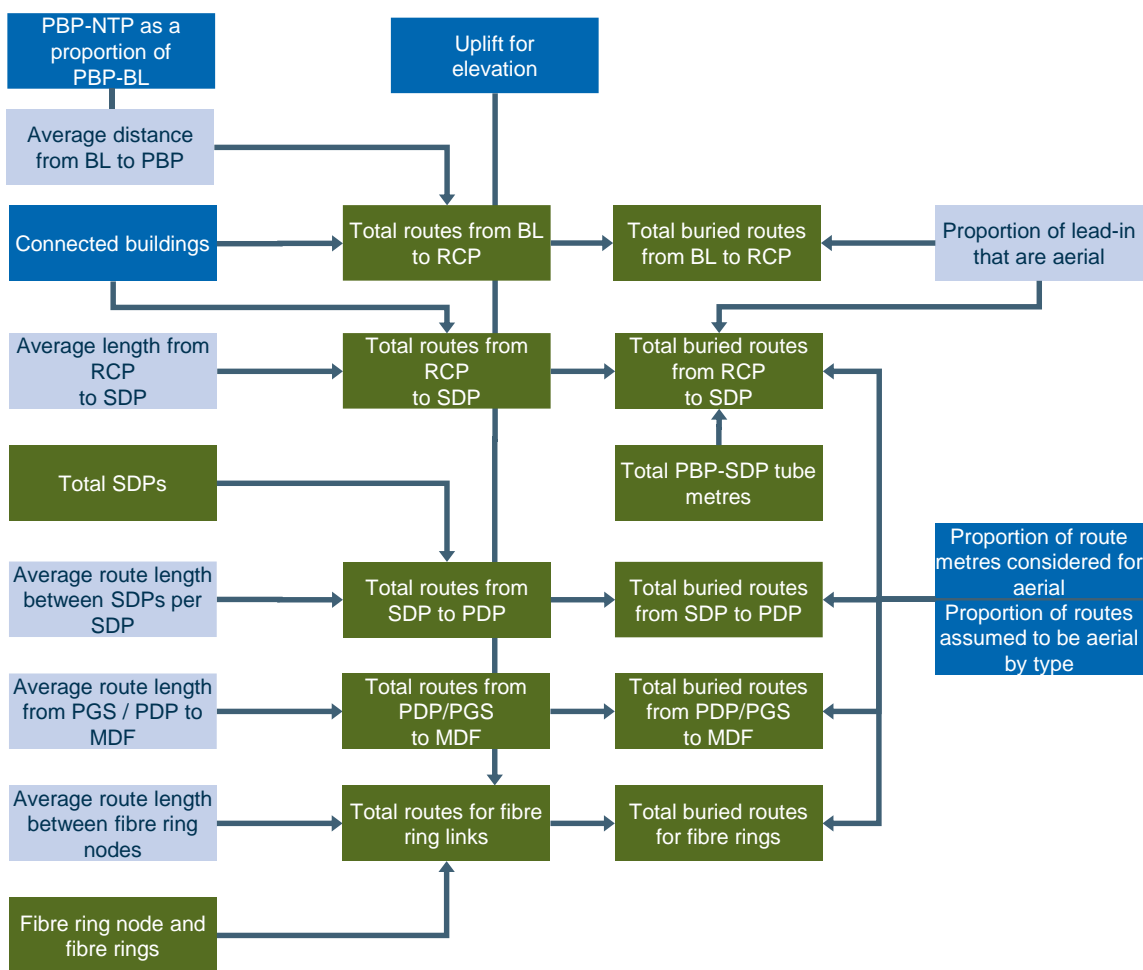


Figure 5.6: Calculation of access lines [Source: Analysys Mason, 2018]

Volumes of the various access node types are derived separately to the access lines. Each node is derived separately (SDP, PDP, PGS) with a proportion of each assumed to be deployed on poles. SDPs and PDPs are distributed by size based on distributions derived from the geo-analysis, as shown in Figure 5.7 below.

Figure 5.8: Calculation of the buried route network [Source: Analysys Mason, 2018]



After the buried routes have been calculated, they are then analysed in terms of tubes (with a proportion of tubes removed where direct burial has been assumed). The flow of the calculation of tubes in buried routes is shown in Figure 5.9.

The final part of the route network calculation consists of determining the additional pole and manhole requirements. The tube metres in buried routes that have been revised to be aerial routes are calculated for both the primary and secondary networks. These are then used to derive the additional pole requirements, as shown in Figure 5.10.

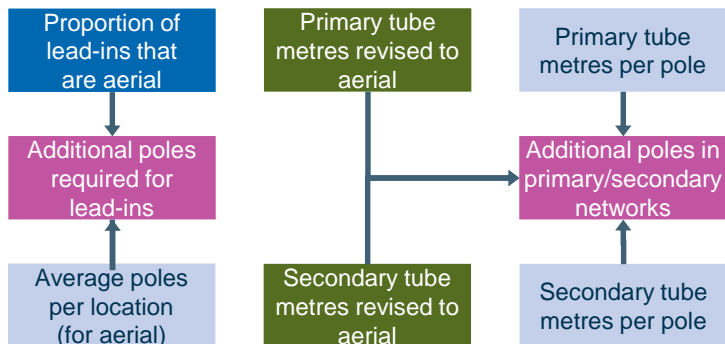


Figure 5.10: Additional calculations for poles [Source: Analysys Mason, 2018]

A proportion of the tube metres in the remaining buried routes are then removed, with the cabling determined to be in these removed tube metres assumed to be directly buried.

Figure 5.11 shows a schematic of additional calculations for manholes. Manholes can be deployed only at the following network locations:

- at each SDP or PDP location (though these manhole assets can be turned off using a switch on the A2NwDesScen worksheet)
- in the secondary network
- in the primary network.

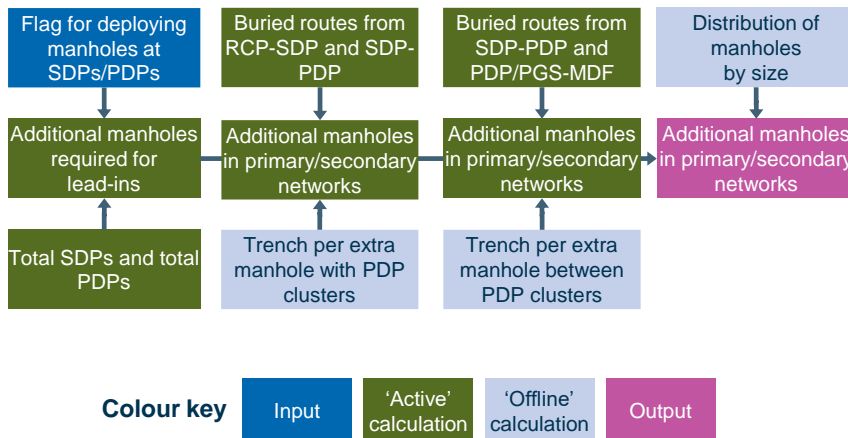


Figure 5.11: Additional calculations for manholes [Source: Analysys Mason, 2018]

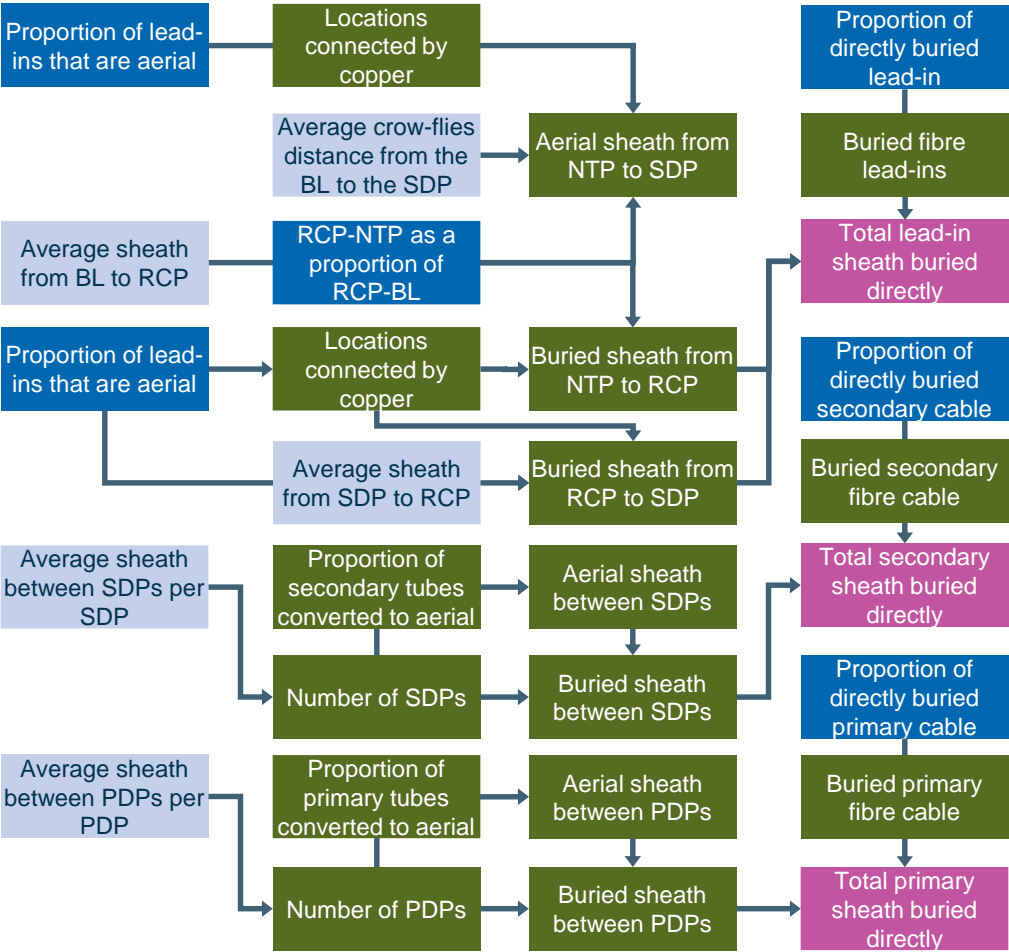
5.3.3 Copper cabling

The total buried copper sheath and total aerial copper sheath are first calculated for three levels:

- within SDPs (lead-in network)
- between SDPs (secondary network)
- between PDPs (primary network).

The assumed proportions of buried cabling in each of these levels of the network are assumed to be buried directly. The total cabling buried directly includes sheath from the fibre overlay network. After these cabling lengths have been determined, they are used to calculate mark-ups on the cable costs for direct burial. Aerial lead-in calculations use the average distance from the building location (BL) to the SDP, assuming a star topology for the final drop from an aerial SDP. Figure 5.12 shows the steps involved in calculating the total buried copper sheath.

Figure 5.12: Calculation of the total copper sheath network [Source: Analysys Mason, 2018]



Cabling lengths by cable size (in pair terms) are calculated using distributions. For each of the total copper cabling volumes, a distribution of sheath metres is calculated using the geo-analysis. Copper cabling metres by number of pairs are then derived. These calculations include uplifts capturing the effect of elevation for both buried cabling and aerial cabling. Figure 5.13 and Figure 5.14 show the aerial sheath in the lead-in and primary/secondary networks, respectively.

Figure 5.13: Aerial sheath in the lead-in network
 [Source: Analysys Mason, 2018]

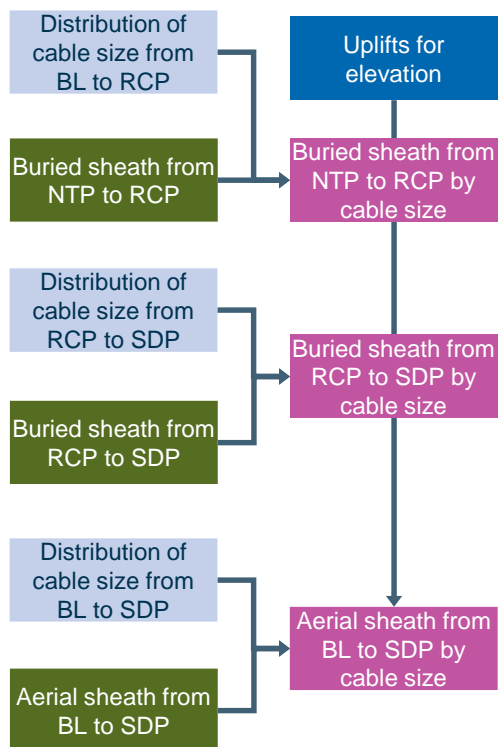
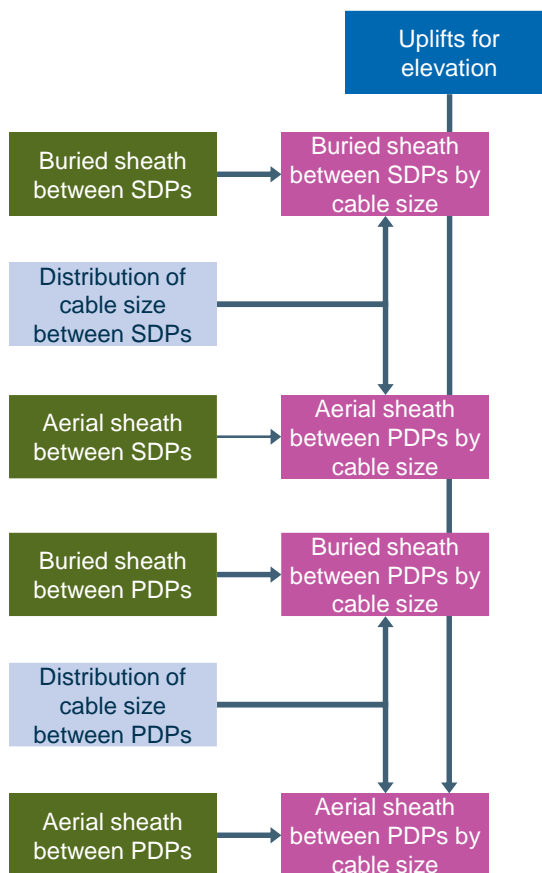


Figure 5.14: Aerial sheath in the primary and secondary networks
 [Source: Analysys Mason, 2018]



5.3.4 Jointing calculations

The jointing in the CTTN network can be calculated assuming either tapered cabling or non-tapered cabling. Figure 5.15 shows the various parameters associated with the tapered cabling architecture.

Figure 5.15: Jointing parameters associated with tapered cabling [Source: Analysys Mason, 2018]

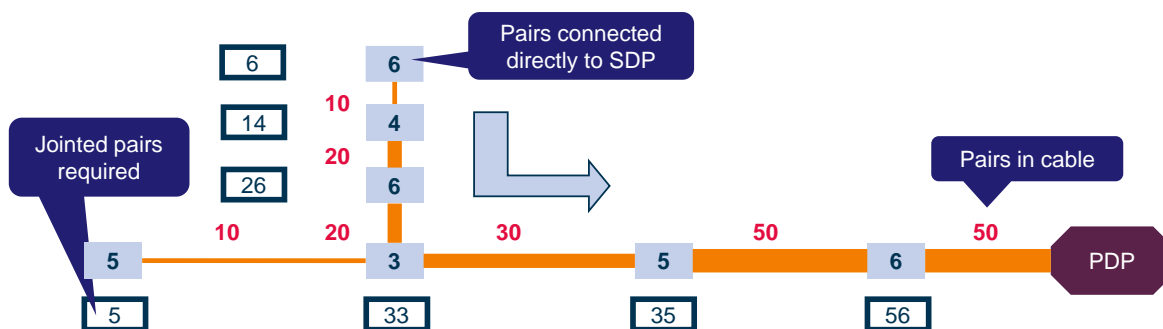
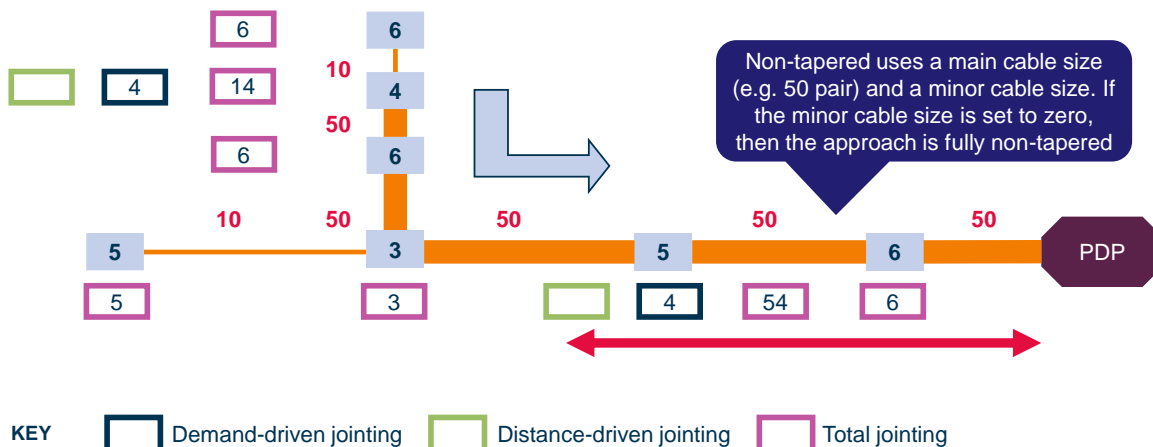


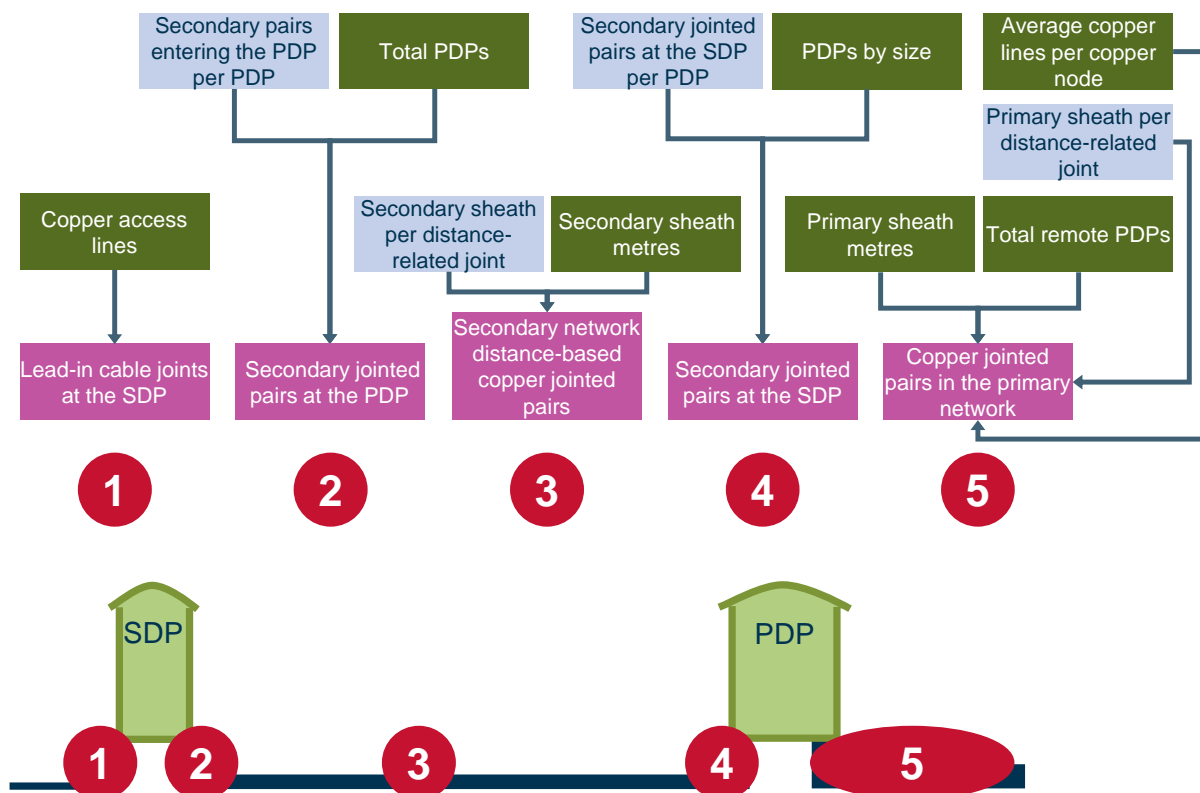
Figure 5.16 shows the various parameters associated with the non-tapered cabling architecture.

Figure 5.16: Jointing parameters associated with non-tapered cabling [Source: Analysys Mason, 2018]



Copper jointed pairs are calculated at each of the various levels in the network, from the lead-in side of the SDP to the primary network. As well as copper jointed pairs at different distribution points, distance-based jointed pairs are also calculated (where the hauling limits of cabling requires an intermediate joint). Figure 5.17 illustrates the joints in the network hierarchy and the calculations of copper jointed pairs.

Figure 5.17: Calculations of copper jointed pairs and illustration of joints in network hierarchy [Source: Analysys Mason, 2018]



5.3.5 Fibre network for high demand

The asset requirements for a fibre network to locations with high demand are dimensioned as a fibre cabling overlay. The fibre network deployed alongside the copper network is made up of several components:

- to locations with high demand (lead-in, secondary and primary)
- from PGS to the MDF location
- between PDPs as a ring structure for locations with high demand.¹⁴

We describe the calculation of the fibre cabling and fibre jointing separately below.

Fibre cabling

The fibre overlay calculations for the different parts of the network are shown in the following figures.

Figure 5.18 below shows the calculation of the lead-in fibre cable network.

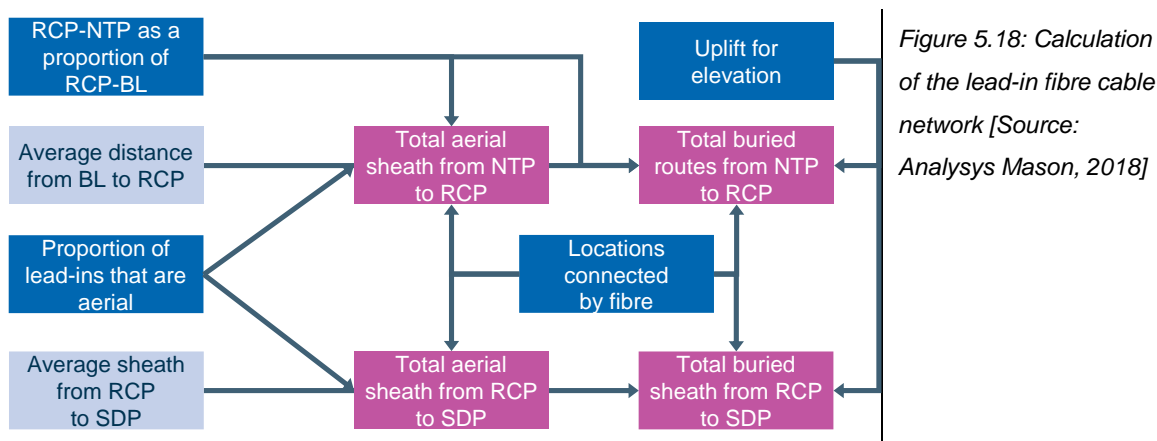


Figure 5.18: Calculation of the lead-in fibre cable network [Source: Analysys Mason, 2018]

Figure 5.19 below shows the calculation schematic of the secondary fibre cable network.

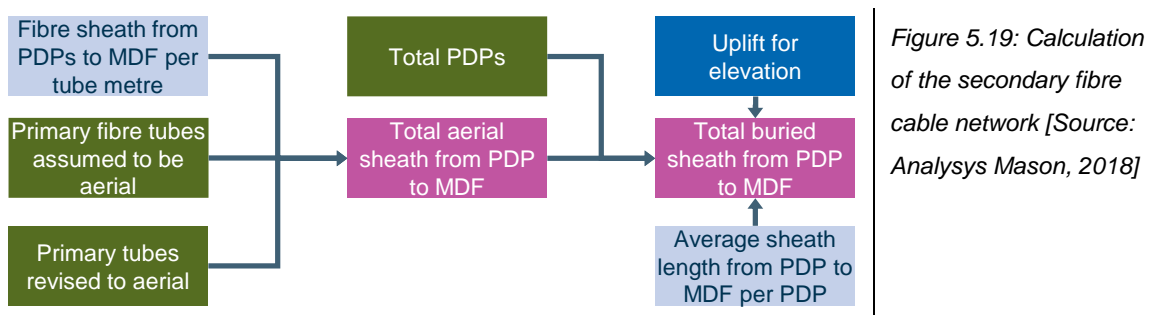


Figure 5.19: Calculation of the secondary fibre cable network [Source: Analysys Mason, 2018]

¹⁴ In the modelling of both the copper network and the PON fibre network, there are two choices for the point-to-point fibre overlay architecture for locations with high demand. The first is for each location to be connected to its distribution frame location using a dedicated point-to-point fibre cable. The second is to deploy a dedicated fibre cable to the PDP and then join all these PDPs together in a ring system. The model currently uses the first option in all cases.

Figure 5.20 below shows the calculation schematic of fibre cable in the primary network.

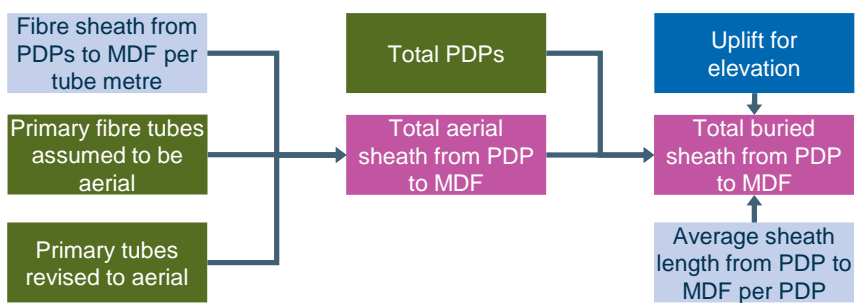


Figure 5.20: Calculation of fibre cable in the primary network
[Source: Analysys Mason, 2018]

Figure 5.21 below shows the calculation schematic of fibre from PGS.

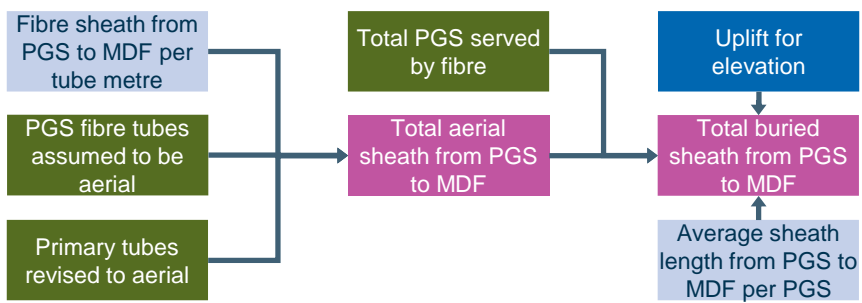


Figure 5.21: Calculation of fibre from PGS
[Source: Analysys Mason, 2018]

Figure 5.22 below shows the calculation schematic of fibre ring links.

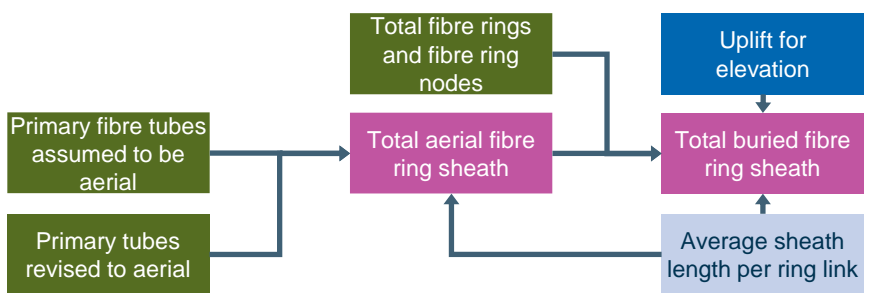


Figure 5.22: Calculation of fibre ring links
[Source: Analysys Mason, 2018]

Fibre jointing

Fibre jointed pairs are calculated as a number of separate assets. These are calculated in both the primary and secondary networks, along both fibre rings (currently inactive) and PGS links, and at PDP locations. This can be seen in Figure 5.23.

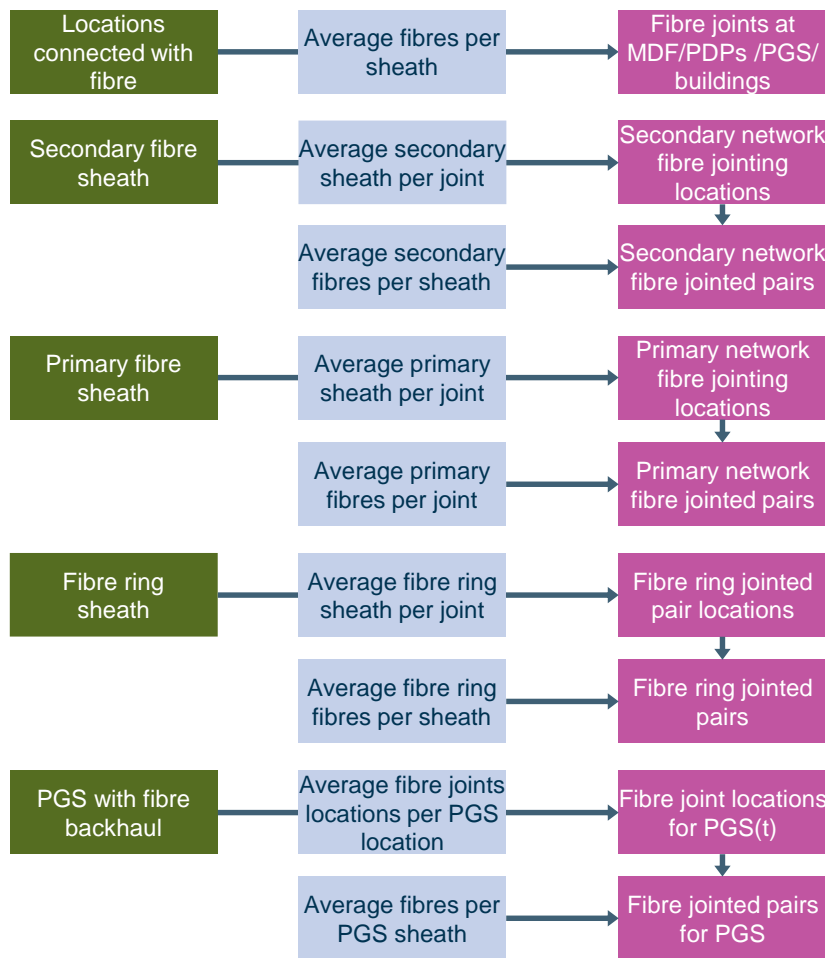


Figure 5.23:
Calculations of fibre
jointing [Source:
Analysys Mason, 2018]

5.3.6 Analysis of Geotype 16

In the v1.7 model, assets relevant to Geotype16 were excluded since there was no road data available for the premises in Geotype16. We analysed Geotype16 for the purposes of the vAcc2.3 model even though these data gaps remain. In order to estimate asset counts for Geotype16 service areas, we created a new data workbook ('Access – DATA – G16.xls'), including all the locations for the 15 exchange areas in the geotype. In the absence of road data, we:

- took building locations as is when calculating the shortest route to the distribution point
- used crow-flies distance to model the route from the exchange or cabinets to these premises (i.e. we used the p-function of $j=k=1, p=2$).

When the premises in the same service area were located on different islands, we clustered them separately, with each cluster being served by a different distribution point. We also updated the 'Geo-analysis Code' workbook to include these new service areas.

The estimated assets and demand for this geotype can be included in the model by setting cell *A1Ctrl!D88* in the *Network Service Costing – Access* module to 1 (and excluded by setting this value to zero). Our analysis indicates that this has no material impact on the final cost results, since it is a negligible fraction of the total network footprint.

5.4 Definition of re-useable assets

The 2013 EC Recommendation gives emphasis to differentiate between depreciation methods used specifically for what it refers to as legacy *reusable civil engineering assets* (RCEA) compared with the methods of cost recovery used for other assets.

RCEA are assets that would be unlikely to be replicated for an NGA deployment because they already exist and can be re-used for the NGA deployment, albeit possibly with some refurbishment. We assume that, for FTTH networks, RCEA include:

- poles
- trenches with spare duct space
- manholes (implicitly along the re-used trenches)
- lead-in cables (restricted to more modern lead-ins deployed using hybrid copper/fibre cabling).

In our final model specification, we also considered the possibility of re-using existing cabinet and distribution point locations. However, we now understand from operator submissions that no aspects of existing distribution point locations are re-used for FTTH deployments in Norway and therefore we do not consider these as RCEA in the vAcc2.3 model.

As indicated in the final model specification, we have included two versions of this calculation:

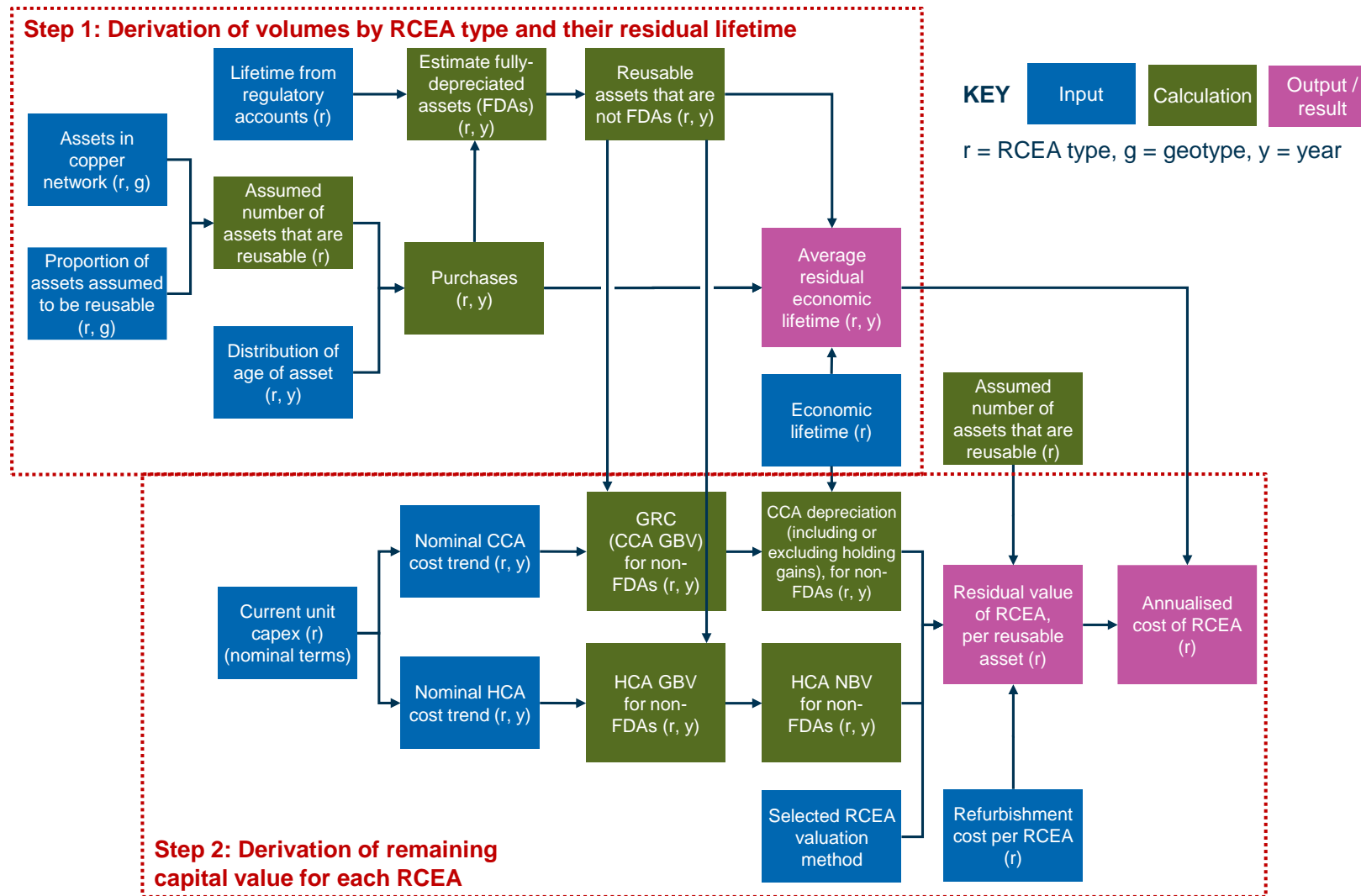
- The first, on the *A6ReUse* worksheet, is used to derive the remaining capital value and economic lifetime for each RCEA type for the FTTH network cases
- The second, on the *A7ResidualValueCopper* worksheet, can be used to derive the remaining capital value and economic lifetime for all assets in the copper network. These can be used for two different purposes, namely:
 - for all secondary network assets reused in a FTTN network
 - an estimation of the remaining value/life in the copper network; this approach will produce outputs that can be compared (in principle) to Nkom's previous historic cost accounting approach that made use of Telenor's regulatory accounts.

In order to align our modelling approach with the 2013 EC Recommendation, the model now includes the functionality to consider up to 40 different 'RCEA types' for the FTTH modelling. The RCEA types defined in the vAcc2.3 model are all based on assets defined in the existing copper model, but with the copper model asset name prefixed by '[RCEA]'.¹⁵ This allows values for the RCEA type to be compared to its corresponding asset in the modelled copper network.

For the FTTN/copper modelling, the calculation accommodates the full asset list. An overview of our asset re-use calculations (effectively the same for both cases) is presented below.

¹⁵ For example, the RCEA equivalent of the owned pole asset ('Pole: owned') is listed as '[RCEA] Pole: owned'.

Figure 5.24: Overview of asset re-use calculations [Source: Analysys Mason, 2018]



There are two key steps:

- Step 1: Derivation of volumes by RCEA type and their residual lifetime
- Step 2: Derivation of the remaining capital value for each RCEA type.

We describe these in turn below.

5.4.1 Step 1: Derivation of volumes by RCEA type and their residual lifetime

The key inputs are summarised in the table below. The cell reference is for the *A6ReUse* worksheet of the *Network Service Costing – Access* module, unless stated otherwise. The calculation on the *A7ResidualValueCopper* worksheet has a similar form.

Figure 5.25: Overview of the main inputs to the RCEA volume calculation [Source: Analysys Mason, 2018]

Description	Cells	Purpose	Source
Copper network assets	E49:T88	Starting point for reusable asset base	Run the model in CTTH.F mode, copy cells A6ReUse!E5:T44 and paste values into A6ReUse!E49:T88
Proportion of assets assumed to be reusable	E136:T175	Specified by RCEA type and geotype	Derived based on Telenor data. A level of pole re-use has been assumed based on similar or higher levels of aerial assumed for the FTTH networks compared to the copper network
Regulatory accounting lifetimes	A4AssetIn, column AB	States regulatory accounting lifetime to determine fully depreciated assets (FDAs)	Derived from Telenor's regulatory accounts
Asset age distribution	Row 363	Spreads the totality of copper assets across the period 1951–2020	Informed by Telenor data; alternative assumptions have also been included (e.g. uniform distribution)
Economic lifetime	A4AssetIn, column AA	Used to estimate average residual lifetime by RCEA type	Primarily the v1.7 model

For each RCEA type, the reusable assets in the national copper network are derived on a per-geotype basis and then aggregated to a national total.

On the *A7ResidualValueCopper* worksheet, all copper assets are assumed to be fully reused for the purposes of the copper network calculations. A proportion of primary network assets and all secondary network assets are assumed to be reused for the FTTN network calculation.

These total counts by RCEA type are then spread over the period 1951–2020 based on the asset age distribution. For each RCEA type, its regulatory accounting lifetime is used to define how many of each RCEA type are not fully depreciated assets (FDAs) for the selected costing year (i.e. the year for which cost results are derived in the model: 2015 for the vAcc2.3 model). For example, if the regulatory lifetime for an RCEA type is 20 years, then all of the units estimated as purchased before 1997 are assumed to be FDAs.

For each RCEA type, for those units that are not FDAs, the average age is calculated. New purchases within the costing year are assumed to be one year old at year-end. The residual lifetime of the RCEA type is then assumed to be the assumed economic lifetime of the RCEA type less the average age derived.

5.4.2 Step 2: Derivation of the remaining capital value for each RCEA type

The key inputs are summarised in the table below. The cell reference is for the *A6ReUse* worksheet of the *Network Service Costing – Access* module, unless stated otherwise. The calculation on the *A7ResidualValueCopper* worksheet has the same form.

Figure 5.26: Overview of the main inputs to the RCEA remaining capital value calculation [Source: Analysys Mason, 2018]

Description	Cells	Purpose	Source
Current unit capex	A4AssetIn, column T	Starting point for capex calculation	Primarily the v1.7 model
Nominal historical cost accounting (HCA) trend	P222:P261	Specified by RCEA type, used to calculate investment according to HCA	Taken to be modern equivalent asset (MEA) trends from the v1.7 model (as an alternative, CPI can also be assumed)
Nominal current cost accounting (CCA) trend	Q222:Q261	Specified by RCEA type, used to calculate investment according to CCA	Taken to be modern equivalent asset (MEA) trends from the v1.7 model (as an alternative CPI can also be assumed)
Selected RCEA valuation method	A1Ctrl, cell D13	Selects either the HCA or CCA methodology	Principled decision by Nkom
Refurbishment cost	K222:K261	Stated by asset, covers the cost of making an existing asset compatible with NGA deployments	Informed by operator data and benchmarks to the extent that they are available
Proportion of RCEA defined as replaced each year	L222:L261	Stated by asset, covers the cost associated with replacing a fraction of RCEA each year (as they become unusable)	Set to 0.5% for owned poles, based on asset churn inputs from the draft version of the original model

For each RCEA type, the residual value of the non-FDAs is calculated in parallel over time using both (i) HCA principles, (ii) CCA financial capital maintenance (FCM) principles or (iii) CCA operating capital maintenance (OCM) principles. The choice of whether (i)/(ii)/(iii) is used is a global input to the model.

Some of the RCEA may be replaced in the future. We have allowed for a proportion of RCEA defined as replaced each year (which might be zero) to be carried through into the costing calculations as an operating cost (in other words, such expenditures would be considered as ‘expensed’).

The unit residual value per RCEA (not per *non-FDA* RCEA) is then derived as follows:

$$\text{Unit residual value per RCEA} = \text{Residual value of non-FDA RCEA} / \text{Total RCEA}$$

The assumed refurbishment cost per RCEA is added onto this unit residual value. For a selected year, a RAB is then defined with this residual value as the starting point. As described in Section 6, for each year thereafter before its remaining lifetime has expired, the capital charge is calculated for the residual value using either CCA FCM depreciation or tilted annuity depreciation.

The calculation on the *A7ResidualValueCopper* worksheet allows the residual value of the copper network assets to be estimated. This is required for the FTTN calculation, where the entire secondary copper network is effectively reused, whilst some of the primary network can also be reused (to accommodate the fibre cable to the cabinet). This calculation is consistent with what is described in the 2013 EC Recommendation.

We have further adapted this aspect of the calculation to calculate the residual value of the entire copper network for the purposes of running the copper-based calculation. When calculated using HCA depreciation, our copper calculation gives outputs that can then be compared to those derived from Telenor's regulatory accounts (i.e. for an established copper network deployed over many decades, net of historic depreciation). This will give significantly different cost levels than a model that, for example, considers a copper network deployed as new (at full replacement cost).

5.5 Summary of important network design adjustments

Figure 5.27 provides a summary of the most important adjustments within the vAcc2.3 model network design. Many of these relate to infrastructure sharing, or adjusting the mix of aerial, direct burial and ducted cabling in the modelled networks.

Figure 5.27: Summary of key network design inputs [Source: Analysys Mason, 2018]

Description	Reference	Value	Source
Proportion of copper final drops deployed	A1Ctrl!D26:D41	100%	v1.7 model
Proportion of FTTH final drops deployed	A1Ctrl!E26:F41	80%	v1.7 model
Real-terms cost of capital	A1Ctrl!D6	5.3%	Professor Thore Johnsen
Proportion of secondary copper cable that is aerial	A2NwDsScen!E65:F65	20% in urban 50% in rural	v1.7 model
Proportion of primary copper cable that is aerial	A2NwDsScen!E66:F66	10% in urban 35% in rural	v1.7 model
Urban aerial inputs for FTTH	A2NwDsScen!E73:E74	As for copper	v1.7 model
Non-aerial in rural as a proportion of non-aerial in urban for FTTH	A2NwDsScen!F72	50%	Estimated from operator data
Proportion of buried copper cable metres buried directly	A2NwDsScen!E85:F87	60% in urban 90% in rural	v1.7 model (all lead-ins are assumed to be direct buried)

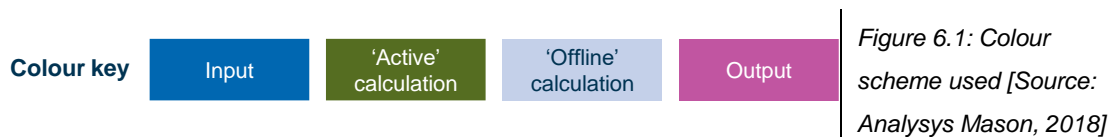
Description	Reference	Value	Source
Proportion of buried fibre cable metres buried directly	A2NwDsScen!E90:F97	0%	Assumption based on operator information and standard practices
Proportion of routes shared with utilities or other municipal ducts	A2NwDsScen!E110:F121	0–10%	Either retained from v1.7 model, or increased slightly to reflect greater opportunities in co-operative trench sharing
Final drop sharing or road crossing sharing	A2NwDsScen!E142:F154,E175:F187	None assumed	v1.7 model
Proportion of shared route costs attributed to access network	Various	50%	Assumption (some existing municipal ducts are assumed to be made available at zero cost)

6 Service costing calculations and results

This section provides more detail about the service costing calculations used in the *Network Service Costing – Access* module, and is set out as follows:

- Section 6.1 provides an overview of the relevant worksheets in the model
- Section 6.2 provides an overview of the high-level flows of service costing calculations
- Section 6.3 describes updates made to unit cost and lifetime inputs
- Section 6.4 introduces the depreciation method used in the model
- Section 6.5 describes the allocation of costs to services
- Section 6.6 explains the refinements made to the model to consider adjustments for State aid.

The colour scheme shown in Figure 6.1 is used throughout this section.



6.1 Overview of model worksheets

A summary of the worksheets in the *Network Service Costing – Access* module that are relevant to the network design is provided below in Figure 5.2.

Figure 6.2: Description of worksheets related to service costing in the *Network Service Costing – Access* module [Source: Analysys Mason, 2018]

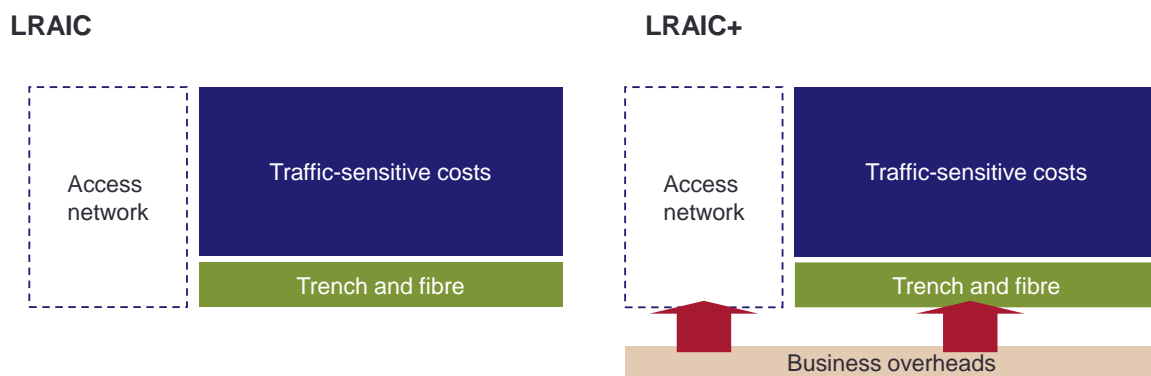
Name	Description
A0Lists	Defines the names of commonly used lists in the model
A1Ctrl	Lists the main controls/switches for the module
B1FullNw	Collates the number of network elements required in each year according to demand drivers and network design rules
B2StateAid	Calculates the State-aid contribution relevant to the model
B3ServiceDemand	Summarises network demand volumes for cost recovery
B4RF	Collates values and calculations specifying routing factor load of each service on each network element
B5NwEleOut	Calculates the recovery profile and demand loading on each type of network element
B6CostTrends	Determines the capex and opex cost trends for each network element
B7Capex	Calculates capex per network element according to base price and capex trend
B8Opex	Calculates opex per network element according to base price and opex trend
C1Annualisation	Annualises capex according to a variety of methods
C2CostByService	Allocates costs of assets to services based on routing factors
C3MainResults	Displays key results from model

6.2 High-level flows of service costing calculations

This *Network Service Costing – Access* module calculates the unit costs of access services using the assumed expenditures calculated in the network design calculations. In particular, the module uses a long-run average incremental cost approach including common costs (LRAIC+). This approach is consistent with the historical approach used in Europe for the costing of access services. Average incremental costs of access services are defined using a large increment (for example, all subscriber lines), and then allocated to the various access services using routing factors.

A large access increment implies that costs common to multiple access services are included in the average incremental cost of access, while common costs are included using equi-proportional cost-based mark-ups (EPMU). Without these common costs, only a LRAIC is calculated. We illustrate the difference between LRAIC and LRAIC+ approaches below in Figure 6.3.

Figure 6.3: Comparison of the LRAIC (left) and LRAIC+ (right) approaches [Source: Analysys Mason, 2018]

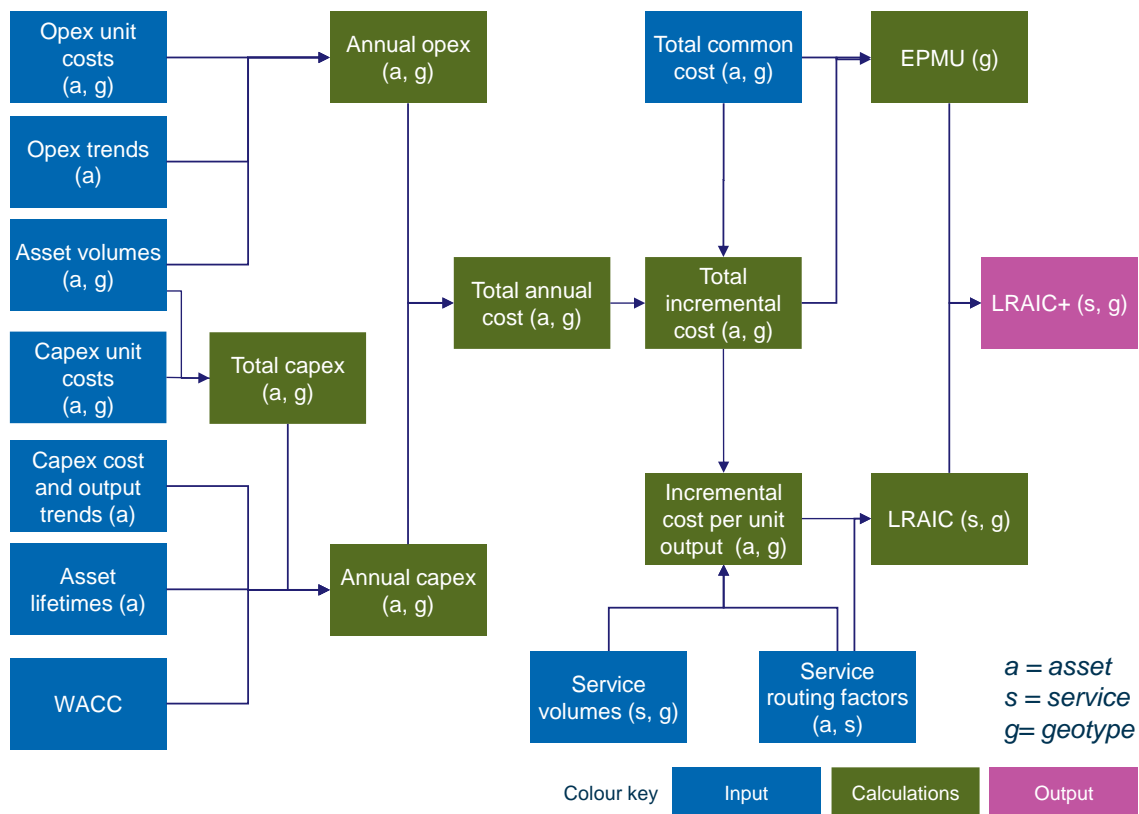


A high-level illustration of the calculation flow in the *Network Service Costing – Access* module is shown below in Figure 6.4. Capex is annualised and opex is recovered within the year it is incurred. As can be seen below, the output is LRAIC+ for each separately modelled service and geotype.

The model derives results for a single year (determined by the value in the cell called *selected.year* on the *AICtrl* worksheet). By setting this cell to a particular year, the model then calculates the:

- assets required for the chosen network architecture for the selected geotypes
- replacement capex of the non-RCEA in nominal currency
- residual capital value in nominal currency and remaining lifetime of the RCEA
- operating costs for the modelled network in nominal currency
- annualised capex according to the chosen depreciation methods
- costs allocated to the modelled demand volumes to derive final results.

Figure 6.4: High-level flow of calculations in the service costing calculations [Source: Analysys Mason, 2018]



6.3 Unit cost inputs and lifetimes

The v1.7 model included a full set of unit cost inputs and lifetimes, which have been the starting point for our update. We have updated particular inputs where either (i) sufficient up-to-date information has been available or (ii) the modelling approach has been modified.

The most important updates that we have undertaken relate to:

- inflation
- regulatory lifetimes
- trench unit costs for NGA networks
- network maintenance costs
- index-based cost trends
- other inputs.

These are described in turn below.

6.3.1 Inflation

Whereas the v1.7 model worked in real 2009 NOK, the vAcc2.3 model works in nominal NOK. The inflation index has been updated from that used in the v2.1 model (updated in 2014) using the latest

version of the Pengepolitisk report currently available.¹⁶ Therefore, all of the 2009 unit costs presented in real 2009 NOK from the v1.7 model have been converted into 2015 unit costs presented in real 2015 NOK, using the up-to-date inflation index and the cost trends within the model.

6.3.2 Regulatory lifetimes

For the purposes of the vAcc2.3 model, regulatory asset lifetimes are for the asset reuse calculations. We have included these in the model: a comparison of these regulatory lifetimes with the economic lifetimes is shown below in Figure 6.5.

Asset	Economic	Regulatory
Trench, ducts and manholes	50	30
Poles	20	12
Buried copper cable	50	12
Aerial copper cable	25	12
Copper jointing	20	12
Fibre cable	20	15
Fibre jointing	20	15
Distribution points/frames	20	30
NTP/CPE	10	3
Wireless assets	20	7

Figure 6.5: Comparison of lifetimes [Source: Analysys Mason, Telenor, 2018]

As can be seen above, we have increased the 40-year economic lifetimes to be 50 years in the vAcc2.3 model. We believe that this is a reasonable assumption based on the data received from Telenor regarding the average age of their existing assets, which is also used in the re-use calculation described in Section 5.4.

We have also compared the other economic lifetimes assumed with other more recent public access models and identified that assuming the jointing economic lifetimes to be 15 years appears low. We have therefore increased this lifetime to be 20 years, which is also more consistent with the cabling lifetimes (lifetimes for buried copper cables and fibre cables are both multiples of 20 years).

6.3.3 Costs of trenching

The costs of trenching are a significant component of the costs of an access network. In the original model, the unit costs of trench were defined for five terrain types. An estimate of the mix of route metres by terrain type for each geotype was also included in the model, allowing the total costs of trenches for a whole geotype to be calculated. These terrain types, and the accompanying unit costs, are shown below in Figure 6.6.

¹⁶ See http://static.norges-bank.no/pages/103842/PPR_3_15.pdf?v=24092015122239&ft=.pdf

Terrain type	Cost of trench (2009 NOK)
Urban Oslo	1125
Other urban	705
Other densely populated areas	340
Other housing/business areas	320
Rural areas	220

Figure 6.6: Terrain types and trench cost assumptions for 2009 from the original model [Source: Analysys Mason, 2018]

These inputs have been retained for the purposes of the copper network calculations.

For the purposes of the trench calculations for the modelled fibre networks, a new approach has been undertaken to estimate unit costs for each geotype. To accomplish this, data was requested from Norwegian stakeholders to provide data regarding the digging costs, metres of trench dug and location of actual NGA deployments undertaken since the start of 2014. Several stakeholders have provided this data (several hundred projects in total) in time for use in the vAcc2.3 model.

Using the location data for each project, the data has been assigned to the geotype for that location. Using the data gathered so far, all except the most rural geotypes have at least two projects in the dataset. Rural geotypes are those with large values of road per location as illustrated in Figure 3.8 i.e. geotypes 6–8 and 13–16.

Having calculated the average trench cost per metre in each geotype, we have observed that geotypes with a similar ratio of road per location have a similar average trench cost per metre. For example, the average costs for geotypes 3 and 10 are within 5% of each other. The same is also true for geotypes 2 and 9. Therefore, we believe that the trench cost per metre is not strongly related to whether ESAs are clustered or spread.

Therefore, we have aggregated the projects into five groups of geotypes (groups A–E) in order to increase the number of projects within each group. This allows us to allocate all geotypes to groups except geotypes 7 and geotypes 14–16, which have no representatives in the current dataset. This grouping is summarised below in Figure 6.7.

Min	Max	Clustered	Spread
	0	16	16
0.00000	0.01000	A	
0.01000	0.01414	A	
0.01414	0.02000	A	
0.02000	0.02828	A	A
0.02828	0.04000	A	A
0.04000	0.05657	B	B
0.05657	0.08000	B	B
0.08000	0.11314	C	C
0.11314	0.16000	C	C
0.16000	0.22627	D	E
0.22627	0.32000	D	E
0.32000	0.45255	D	E
0.45255	0.64000	D	E
0.64000	0.90510	D	E
0.90510	1.28000	D	E
1.28000	1.81019	7	14
1.81019	2.56000	7	14
2.56000	3.62039	7	15
3.62039	5.12000	7	15
5.12000	7.24077	7	15
7.24077	10.24000	7	15
10.24000	14.48155		
14.48155	20.48000		
20.48000	28.96309		
28.96309	1,000,000,000		

Figure 6.7: Grouping of geotypes for the purposes of deriving trench costs [Source: Analysys Mason, 2018]

For the remaining geotypes, we observe that these geotypes are almost entirely terrain type 5 and therefore we propose to reuse the trench cost for terrain type 5 from the original model, converted into 2015 NOK.

This analysis can be refined if stakeholders can provide the relevant information for additional projects undertaken elsewhere in Norway.

The current dataset of project costs indicates that the cost by geotype derived on this basis are similar to the costs in Figure 6.6 (after adjusting for cost trends and inflation, and transforming into costs by geotype using the distribution of terrain type by geotype from the existing model).

Since our new calculations seems to cross-validate the values established in the v1.7 model, we have transformed these existing values into 2015 values (adjusting for cost trends and inflation) and mapped them to costs by geotype using the existing distribution of terrain type by geotype. These values, which since they are based on public information can be included in the vAcc2.3 model, are shown in Figure 6.8 below.

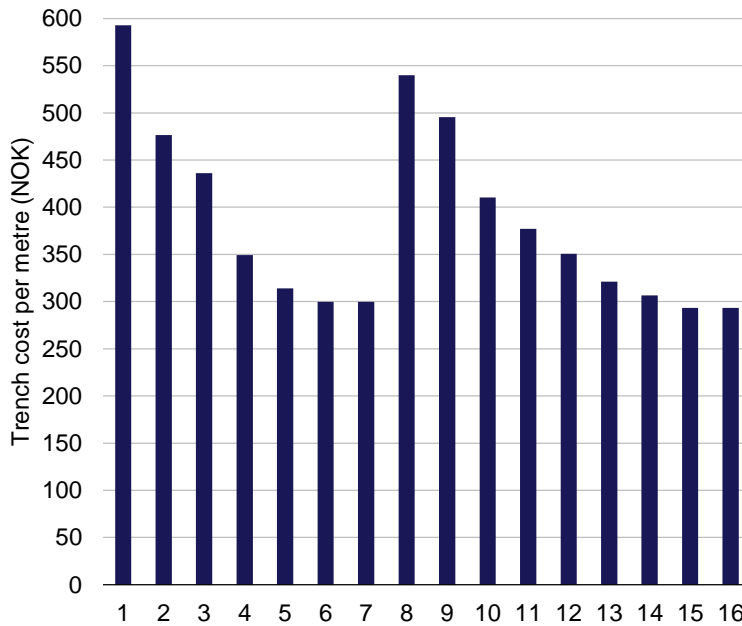


Figure 6.8: Trench costs by geotype used in the vAcc2.3 model (for 2015), derived using the trench costs from the v1.7 model [Source: Analysys Mason, 2018]

6.3.4 Network maintenance costs

Based on data submitted by Telenor, we have derived the number of fault events that occur in the copper network per 1000 buildings passed per year. According to our calculations, the equivalent ratio for the fibre network has been decreasing over time as the technology matures. Currently, we calculate that the fibre network experiences approximately the same fault event rate as the copper network, but we expect this ratio to continue to fall in the future. We have assumed that the fault rate in the fibre network is 25% less than that of the copper network, based on the fault rate reduction assumed in the model developed in Denmark. Data from Telenor has also informed the average number of man-hours to correct a fault event in the network.

We have used these statistics to determine the number of fault events and number of man-hours in the selected network. In order to derive the associated labour costs of these faults, we have used the inputs from Nkom's co-location model, updated using labour indices from SSB.¹⁷ This calculation is undertaken by geotype, as shown below in Figure 6.9.

¹⁷ See <http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/samlokaliseringsmodell>

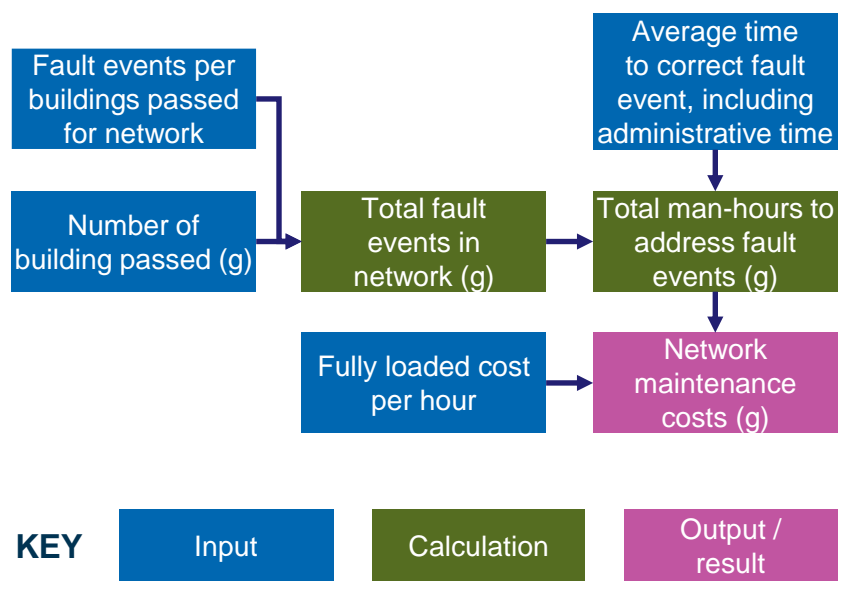


Figure 6.9: Calculation of network maintenance costs [Source: Analysys Mason, 2018]

This opex has been assumed to replace the opex calculated for the infrastructure that is not node-based i.e. trenches, ducts, cables, joints and manholes.

6.3.5 Index-based cost trends

We have revisited those cost trends that can be informed by suitable long-run indices. Our proposed updates are summarised below (previous values were informed by a combination of top-down calibration, benchmarks and index-based calculations).

Figure 6.10: Updates of cost trends in the model (shown in real-terms) [Source: Analysys Mason, 2018]

Cost trend	Previous value	Source	Updated value
Digging costs from 2010 onwards	+1.5%	SSB table 08662. Data for Q2 2010 to Q2 2017	+0.1%
Copper cabling from 2010 onwards	+1.0%	Indexmundi website ¹⁸ , 2010–2017	+0.0%
Distribution points from 2010 onwards	+2.0%	Average of values assumed in the models published by the regulators in Belgium, Sweden and Denmark	+0%
Fibre cabling from 2010 onwards	–9.0%	Average of values assumed in the models published by the regulators in Belgium, Sweden, Denmark, Luxembourg and Romania	–2%

6.3.6 Other inputs

The v1.7 model assumed one size of duct (100mm) across all modelled access networks. The model can now assume different duct sizes for each technology, as well as differentiating between lead-in

¹⁸ See <http://www.indexmundi.com/commodities/?commodity=copper&months=240¤cy=nok>

ducts and the ducts in the remainder of the access network. Whilst copper is still assumed to use 100mm ducts, PTP fibre uses 50mm ducts and PON fibre uses 14mm ducts, as described in Annex B. Separate unit costs have been derived for each duct size.

We have also revisited the unit cost inputs for the specialised assets in the PON fibre network (e.g. the splitter).

We have aligned the capex and opex for rented poles to the levels indicated by the pole access prices published by the electrical utility EnergiNorge.¹⁹

6.4 Depreciation/annualisation

The model allows for each asset to have its own depreciation methodology, from the choice of:

- standard annuity
- tilted annuity
- modified tilted annuity.

Each is calculated in parallel by asset and by geotype for the selected costing year. These methodologies are described in more detail in Annex B of the final model specification.

The formula for the modified tilted annuity is provided below. This method derives the annual cost to allow for full recovery of both the investment and the capital employed. The recovery of investment and capital employed is tilted with the forecast price trend of the asset and can also allow for small changes in demand (i.e. economic output):

$$AnnuityCharge = GRC \times \frac{WACC - Tilt}{1 - \left(\frac{1 + Tilt}{1 + WACC}\right)^{Lifetime}}$$

where *Tilt* is defined as $Tilt = MEAPriceChange + AdditionalTilt$.

The additional tilt is a user input, which is estimated by the rate of change of demand over time. For a tilted annuity, *AdditionalTilt* is assumed to be zero. For a standard annuity, *Tilt* is assumed to be zero. For the vAcc2.3 model, we have used the tilted annuity approach.

For the RCEA, we use a similar formula but with slightly different terms, namely:

$$AnnuityCharge = Remaining\ Value \times \frac{WACC - Tilt}{1 - \left(\frac{1 + Tilt}{1 + WACC}\right)^{Remaining\ economic\ lifetime}}$$

As described in Section 5.4 of the model, the model can use HCA/CCA OCM/CCA FCM to determine the value net of accumulated depreciation for the RCEA in the chosen costing year. The model then calculates the annual total capital charge (return of capital and return on capital) for this

¹⁹ See <https://www.energinorge.no/fagomrader/stromnett/infrastruktur/fellesforing/>

value in a future year using either CCA FCM or a tilted annuity depreciation method, with the total charge assumed to be recovered in year.

When calculating the annuities for the copper assets for the copper network case (and the FTTN case), the calculation on the *A7ResidualValueCopper* worksheet is used to derive the remaining lifetime and capital values for the calculation.

Opex does not use any depreciation method since it is recovered within the year it is incurred. This includes an allowance for a (small) proportion (which can be zero if this replacement is not occurring) of FDA RCEA that are assumed to be replaced each year as a part of network renewal. The replacement cost of these assets is modelled as an in-year opex.

6.5 Allocation of costs to services

The model calculates the incremental costs per unit output for each asset class. Routing factors determine the amount of each element's output required to provide each service and are defined on the *B4RF* worksheet. In order to calculate incremental service costs, incremental unit output costs are multiplied by the routing factors according to the following equation:

$$Cost(Service_k) = \sum_{assets} cost_per_unit_output(asset_i) \times RoutingFactor(asset_i, service_k)$$

6.6 Adjustments for State aid

Public subsidy schemes for the provision of broadband services have been in place for many years in Norway. We identified a number of sources that list some of the subsidies awarded, which we summarise below in Figure 6.11.

Figure 6.11: Summary of sources regarding the public subsidies awarded for broadband deployment [Source: Analysys Mason, 2018]

Year	Description	URL
2006	Provides a list of 30 projects	https://www.regjeringen.no/globalassets/upload/kilde/fad/prm/2006/0036/ddd/exel/289471-bredband_soknader_hoykom.xls
2006	Provides a list of 17 projects	https://www.regjeringen.no/globalassets/upload/kilde/fad/prm/2006/0041/ddd/pdfv/290557-bredbandsstotte.pdf
2007	Provides a list of 11 projects	https://www.regjeringen.no/globalassets/upload/kilde/fad/prm/2007/0005/ddd/pdfv/305263-bredband_infrastruktur.pdf
2006–2007	Provides a list of 44 projects	https://www.regjeringen.no/globalassets/upload/fad/vedlegg/ikt-politikk/bredbandsdekning08_teleplan.pdf (page 33)

The list of historical subsidies that can be derived from these sources is incomplete. Therefore, we consider the subsidies prior to 2014 and from 2014 onwards separately, as described below.

Subsidies prior to 2014

We observe that there were public subsidy schemes in place prior to 2007 (e.g. the 'Høykom-ordningen'). However, we believe that only a small proportion of this funding would have been used for wireline NGA technologies and therefore the relevant contributions would be negligible. We have not considered schemes prior to 2007 any further.

A report published in 2013 summarises the funding in the period 2007–2012.²⁰ This indicates that:

- NOK756.55 million of funding was invested in providing new broadband connections or upgrading existing basic connections in the period 2007–2012
- These investments led to 76 000 subscriber connections, of which 21 000 were upgraded broadband connections and 55 000 were entirely new broadband connections
- 29% of the 76 000 connections used wireless technologies and therefore are not relevant to our modelling.

We have assumed that 100% of the upgraded connections in the period 2007–2012 are relevant to NGA deployments, as well as two-third of the remaining new connections (the rest being assumed to be only basic broadband services). On this basis, and after further scaling to remove wireless technologies, we calculate that 54% of these connections are relevant to the model. We have therefore assumed that 54% of the 2007–2012 funding is therefore relevant to the model, or NOK408.5 million in total. We assume there is no significant funding in 2013.

Subsidies from 2014 onwards

In June 2014, the EFTA Surveillance Authority (ESA) approved a broadband State-aid scheme that Nkom will oversee for the period 2014–2017.²¹ In 2014, Nkom was allocated NOK160 million for the scheme and awarded NOK159.4 million to 35 projects (from 171 applicants).²² In 2015, Nkom awarded NOK109.6 million to projects.²³ In 2016, the budgeted figure was NOK126.5 million.²⁴ The budget for 2017 is NOK138.7 million.²⁵

We assume that 90% of the funding allocated by Nkom in 2014–17 is relevant to the model (the remaining 10% is related to projects using wireless technologies). We have also included the additional funding to these projects received from local authorities, based on data provided by Nkom.

²⁰ See https://www.regjeringen.no/globalassets/upload/krd/rapporter/rapporter2013/resultat_bredband fylkeskommunene.pdf, pages 6–7 and 16–17.

²¹ See <http://www.nkom.no/aktuelt/nyheter/bredb%C3%A5ndsst%C3%B8tteordningen-godkjent-av-esa>

²² See <http://www.nkom.no/teknisk/bredb%C3%A5nd/utbygging/tildelingar-av-breibandstilskot>

²³ See <http://www.nkom.no/teknisk/bredb%C3%A5nd/utbygging/tildelingar-av-breibandstilskot-2015>

²⁴ See http://www.nkom.no/om-nkom/_attachment/21586?_ts=152166d1fe3, page 8

²⁵ See <https://www.nkom.no/aktuelt/nyheter/fylkene-s%C3%B8ker-om-588-millioner-til-bredb%C3%A5ndsutbygging>

All of these contributions are summarised on the *B2StateAid* worksheet in the *Network Service Costing – Access* module. The contribution is included as a negative capex, annualised over 50 years (consistent with the assumed economic lifetimes of civil infrastructure) and a capex trend of 0%. It has not been possible to accurately map these projects to geotypes. These subsidies are therefore netted off and allocated to rural geotypes only (geotypes 5–7 and 13–16).

Annex A Overview of the offline calculations

This annex is intended to provide more detail about the revisable offline calculations whose outputs are used in the *Network Service Costing – Access* module. It is laid out as follows:

- Section A.1 provides details of the calculations contained in the ‘Geo-analysis Code’ workbook
- Section A.2 explains the calculations performed in the ‘Access Data’ workbooks
- Section A.3 describes the calculations performed in the copper cabling calculations workbook.

A.1 The ‘Geo-analysis Code’ workbook

The revisable offline calculations determine the assets needed to join all locations in a service area back to its MDF location. The module consists of the ‘Geo-analysis Code’ workbook and 26 ‘Access Data’ workbooks.

The ‘Geo-analysis Code’ workbook contains both the VB and the input parameters used by the VB. The VB calculates an efficient access network deployment to connect a given set of building locations to a given access node. The subroutines within the VB are described in Annex C.

The ‘Access Data’ workbooks store the building locations within each of 400 service areas that have been sampled, and the assumptions used for, and outputs of, the VB run for each sampled area.

The total derived asset volumes for each sampled area are then linked back to the ‘Geo-analysis Code’ workbook. These volumes are then aggregated by geotype, from which network dimensioning parameters are derived to be used in the network design calculations. This structure is outlined in Figure A.1.

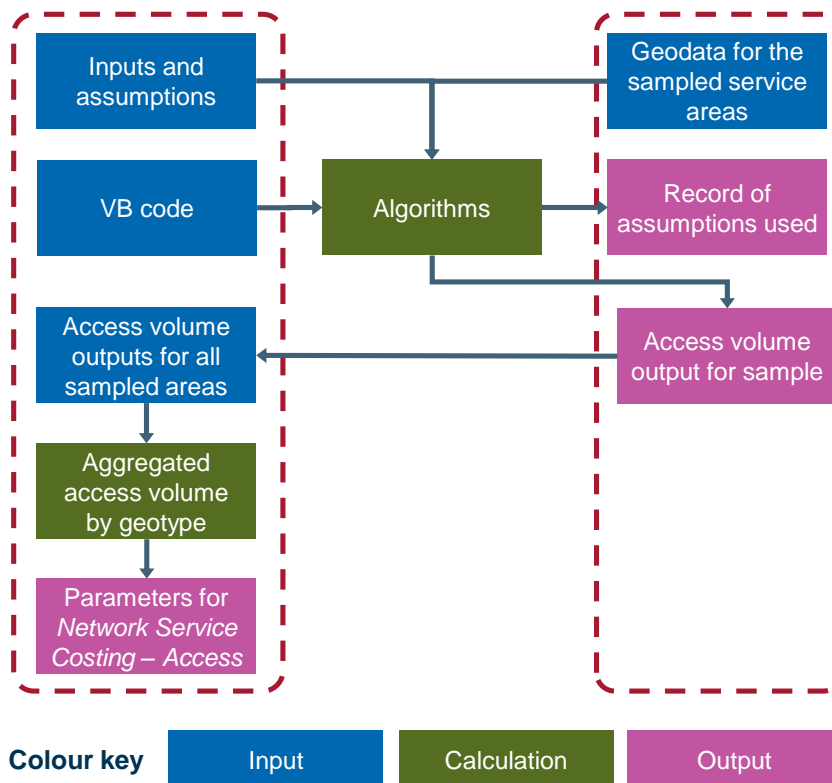


Figure A.1: Illustration of the structure of the ‘Geo-analysis Code’ workbook and ‘Access Data’ workbooks [Source: Analysys Mason, 2018]

The VB in the 'Geo-analysis Code' workbook can be viewed in the VB Editor in Microsoft Excel by pressing Alt+F11. To stop the code while it is running, press and hold Ctrl+Break. Press F5 to restart and F8 to step through the VB one line at a time. Run, pause and stop buttons can also be found on the VB toolbar, as shown in Figure A.2 below.

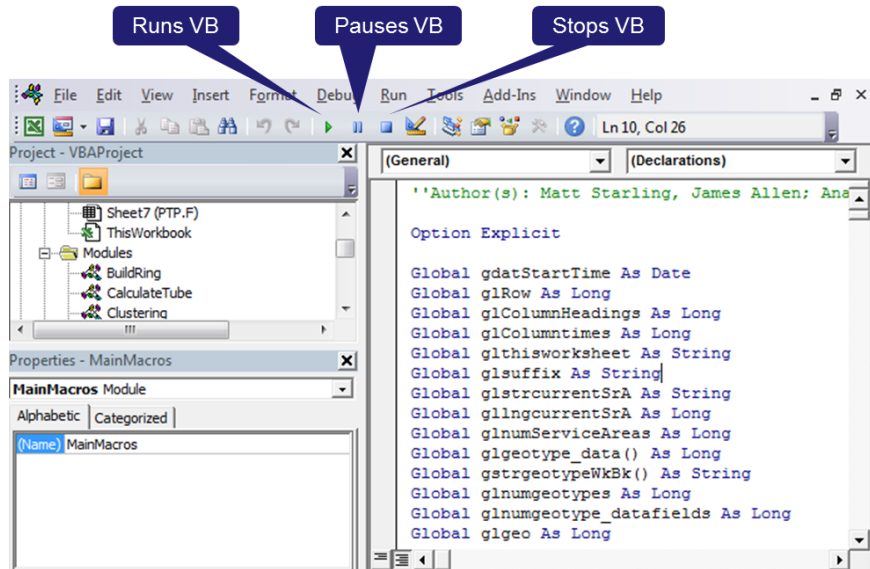


Figure A.2: Illustration of the VB Editor [Source: Analysys Mason, 2018]

Inputs for the geo-analysis in the 'Geo-analysis Code' workbook are stored on four separate worksheets, one for each of the three architectures plus a fourth one containing certain inputs that are common to all three architectures:

- *CTTH.F* for inputs related to the CTTH (and fibre for high-demand locations) architecture
- *PON.F* for inputs related to the FTTH/PON architecture
- *PTP.F* for inputs related to the FTTH/PTP architecture
- *INselected* for certain inputs that are common to all three architectures (mainly related to distance functions).

Inputs on the *CTTH.F*, *PON.F* and *PTP.F* worksheets cover aspects such as:

- node utilisation
- manhole and buried tubes/ducts
- lead-in cables
- standard cable (copper for CTTH, fibre for PTP and PON)
- higher-demand cable (fibre for CTTH/PON)
- node cluster constraints
- use of fibre rings
- use of tapering in cabling architecture
- proxy cost function coefficients for spanning trees.

Figure 3.4 below shows geo-analysis inputs on the *CTTH.F* worksheet.

Section	Parameter	Value	Notes
Service areas to process	This range of service areas	2	service_areas_to_process
	First service area	1	first_service_area
	Last service area	415	last_service_area
Deployment option	CTTH and fibre	CTTH.F	chosen_access_deployment_string, chosen_prefix, chosen_access_deployment
	Exclude flagged locations	0	exclude_flagged_demand, 1 = exclude flagged demand, 0 = include
Basic inputs	Use existing (real) PDP clustering	0	use_existing_real_network_PDP, 1 = use existing (real) network PDP
	Use existing (calculated) PDP clustering	0	use_existing_calculated_network_PDP, 1 = use existing (calculated) network PDP
	Use existing PDP clustering	0	use_existing_PDP_clustering, 1 = use an existing PDP clustering
	Use existing SDP clustering	0	use_existing_SDP_clustering, 1 = use existing SDP clustering, 0 = do not
Utilisations	SDP utilization	80%	Source: Analysys assumption
	PDP utilization	80%	Source: Analysys assumption
Manhole definitions	Maximum distance between SDPs	100 metres	
	Types of manhole	MH 3, MH 2, Spare	manhole_types_selected
Tube capacity definitions	Define possible tube combinations and associated manholes	MH 3, MH 2, MH 1	manhole_types, manhole_associated_to_tube_sol
	Define capacity of manholes in terms of number of links entering / exiting	MH 1, MH 2, MH 3	manhole_capacity

Figure A.3: Inputs illustrated on the *CTTH.F* worksheet [Source: Analysys Mason, 2018]

The architecture for which the VB is to be run is set on the *INselected* worksheet (see Figure A.4), which pulls in the relevant geo-analysis inputs.

Figure A.4: Main control panel in the 'Geo-analysis Code' workbook [Source: Analysys Mason, 2018]

Section	Parameter	Value	Notes
Service areas to process	This range of service areas	2	service_areas_to_process
	First service area	1	first_service_area
	Last service area	415	last_service_area
Deployment option	CTTH and fibre	CTTH.F	chosen_access_deployment_string, chosen_prefix, chosen_access_deployment

Various parameters for the VB can be set using this part of the *INselected* worksheet, e.g.:

- 'First service area' to 'Last service area' settings – A setting of '1' to '1' calculates outputs for just the first area, '1' to '415' calculates outputs for all areas, etc.

- ‘Use existing clustering outputs’ setting – If this is set to ‘1’, the VB will read in the cluster outputs previously stored in the ‘Access Data’ workbooks for each service area, and build the access network according to those clusters.
- ‘Excel version’ setting – It is recommended that the version of Excel being used is specified (2000/2003/2007/2010), otherwise the VB may stall.

To run the VB for the selected range of service areas, press the button ‘Derive access network volumes’ as shown above in Figure A.4.

The access network asset volumes are aggregated into a single line of several hundred cells for each service area. These 415 lines of asset volumes (on a per-sampled area) are linked back into the ‘Geo-analysis Code’ workbook, in a table (green cells) on the *SummAssets worksheet*, as shown below in Figure A.5.

Figure A.5: Summary table by service area in the ‘Geo-analysis Code’ workbook [Source: Analysys Mason, 2018]

Index	Workbook	Geotype	Service area in geotype	Service area	Number of locations	Units of demand	PDPs at MDF	PDPs	Cabinet linked by fibre	Cabinet linked by wireless	Cabinet linked by satellite	Locations served	Demand served	Standard to MDF	
												Standard cable	Higher demand cable	Standard cable	Higher demand cable
1	0b	1	1	ENGV	193	237	1	4	-	-	-	193	237	71	
2	0b	1	2	LAMY	1,165	2,233	1	27	-	-	-	1,165	2,233	18	
3	0b	1	3	DABA	67	83	1	1	-	-	-	67	83	93	
4	0b	1	4	STROM	697	1,144	1	15	-	-	-	696	1,096	84	
5	0b	1	5	LKV	1,890	1,345	1	68	-	-	-	1,912	5,767	56	
6	0b	1	6	GMK	592	1,035	1	15	-	-	-	590	837	90	
7	0b	1	7	VOVA	312	411	1	3	-	-	-	312	411	62	
8	0b	1	8	KRB	1,214	3,733	1	43	-	-	-	1,214	3,733	83	
9	0b	1	9	LSM	3,196	6,326	1	87	-	-	-	3,176	7,129	84	
10	0b	1	10	GROTEN	614	1,090	1	12	-	-	-	614	1,090	88	
11	0b	1	11	RAMD	328	612	1	6	-	-	-	327	515	66	
12	0b	1	12	STRAT	1,218	1,625	1	29	-	-	-	1,218	1,625	90	
13	0b	1	13	HAY	1,935	3,528	1	38	-	-	-	1,933	3,352	90	
14	0b	1	14	JUV	706	955	1	15	-	-	-	706	955	71	
15	0b	1	15	FURST	433	758	1	9	-	-	-	433	758	59	
16	0b	1	16	SORR	108	225	1	5	-	-	-	108	225	86	
17	0b	1	17	VHL	183	201	1	6	-	-	-	183	201	56	
18	0b	1	18	SB	3,726	8,393	1	100	-	-	-	3,720	8,498	74	

When the service area calculation is complete, external links in the ‘Geo-analysis Code’ workbook should be updated using ‘Edit → Links’ (this will ensure that the most recent calculated results are summarised in this table).

As shown in Figure A.6, the *SummAssets* worksheet contains a summary table which is aggregated to summarise outputs further by geotype.

Figure A.6: Summary table by geotype in the ‘Geo-analysis Code’ workbook [Source: Analysys Mason, 2018]

Geotype	Count service areas	Number of locations	Units of demand	PDPs at MDF	PDPs	Cabinet linked by fibre	Cabinet linked by wireless	Cabinet linked by satellite	Locations served	Demand served			
									Standard cable	Higher demand cable	Standard cable	Higher demand cable	
Geotype 1	1	46	1,396	53,555	123,412	46	1,349	1	-	53,405	150	110.2	
Geotype 2	2	35	735	24,555	47,823	35	688	12	-	24,501	54	42.8	
Geotype 3	3	26	252	8,516	10,931	26	223	3	-	7,873	2	10.7	
Geotype 4	4	20	148	3,195	4,086	20	128	-	-	3,195	-	4.0	
Geotype 5	5	12	56	743	1,063	12	41	3	-	742	1	9.6	
Geotype 6	6	4	14	153	285	4	10	-	-	152	1	1.8	
Geotype 7	7	8	26	229	299	8	18	-	-	229	-	2.0	
Geotype 8	8	2	132	5,826	9,458	2	125	5	-	5,820	6	3.0	
Geotype 9	9	14	580	22,105	34,654	14	504	62	-	22,091	14	33.3	
Geotype 10	10	36	675	20,173	26,385	36	596	43	-	20,164	9	26.0	



Ratios and distributions are derived relating to demand, nodes, route network and sheath deployments to be used as network design inputs in the *Network Service Costing – Access* module. These are calculated by geotype and are surrounded by an orange border, as shown in Figure A.7.

Figure A.7: Illustration of network design inputs for CTTH/fibre architecture in the ‘Geo-analysis Code’ workbook [Source: Analysys Mason, 2018]

Index	Workbook	Geotype	Service areas in geotype	Service area	Number of locations	Units of demand	PDPs at MDF	PDPs	Cabinet linked by fibre	Cabinet linked by wireless	Cabinet linked by satellite	Standard cable	Higher demand cable	Standard cable
CTTH and fibre calculation														
Demand density														
					1	2	3	4	5	6	7	8	9	10
476				Average number of copper lines per copper-fed lo	163	2.06	1.75	1.37	1.28	1.30	1.22	1.31	1.55	1.51
477				Average number of fibre lines per fibre-fed location	83.81	12.00	12.00	12.00	-	12.00	12.00	-	12.00	12.00
478				Average proportion of locations addressed directly	99.49%	99.72%	99.78%	92.52%	100.00%	99.87%	99.35%	100.00%	99.90%	99.94%
479				Average proportion of locations addressed directly	0.15%	0.28%	0.22%	0.02%	-%	0.13%	0.65%	-%	0.10%	0.06%
480				Average proportion of lines addressed directly by c	92.51%	89.30%	89.58%	98.65%	100.00%	90.69%	65.26%	100.00%	95.42%	96.30%
481				Average proportion of lines addressed directly by fi	7.49%	10.70%	10.42%	1.35%	-%	9.31%	34.74%	-%	4.58%	3.70%
Copper connection parameters														
483				Average proportion of copper lines directly connected to MDF		3.23%	5.62%	14.62%	20.19%	42.01%	40.86%	33.78%	1.51%	3.21%
490				Average proportion of copper lines served by PGS		0.01%	0.48%	0.13%	-%	1.14%	-%	-%	1.94%	2.71%
491				Average proportion of copper lines served by PDPs		96.76%	93.90%	85.25%	79.81%	56.85%	59.14%	66.22%	96.55%	94.08%
492														89.08%
Fibre connection parameters														
494				Average proportion of fibre lines directly connected to MDF		0.11%	0.04%	0.68%	-%	1.01%	1.01%	-%	-%	0.08%
495				Average proportion of fibre lines served via PDPs		1.02%	1.04%	0.68%	-%	-%	-%	-%	1.33%	1.01%
496														0.90%

Network design input calculations are determined separately for CTTH, FTTH/PON and FTTH/PTP architectures. The calculations for the two architectures that are not selected on the *INselected* worksheet are highlighted in grey.

Separate copies of the ‘Geo-analysis Code’ workbook and the ‘Access Data’ workbooks should be generated (one for each of the three architectures).

For the CTTH architecture, additional offline calculations must then be re-run in the CTTH cabling calculations workbook (described in Section A.3).

The values of the network design inputs calculated on each copy of the *SummAssets* worksheet should then be pasted separately into the relevant part of the *A2NwDsScen* worksheet in the *Network Service Costing – Access* module using ‘Edit >> Paste Special’ (with ‘values’ selected). As shown in Figure A.8, the relevant part of the worksheet is highlighted by a blue border.

Figure A.8: Illustration of network design inputs for CTTH/fibre architecture pasted in the Network Service Costing – Access module [Source: Analysys Mason, 2018]

Source	Geotype 1	Geotype 2	Geotype 3	Geotype 4	Geotype 5	Geotype 6	Geotype 7	Geotype 8	Geotype 9
Paste values from Geo-analysis CODE.xlsm here									
Average number of copper lines per copper-fed location	2.06	1.75	1.37	1.28	1.30	1.22	1.31	1.55	1.51
Average number of fibre lines per fibre-fed location	12.00	12.00	12.00	-	12.00	12.00	-	12.00	12.00
Average proportion of locations addressed directly by copper	99.72%	99.78%	92.52%	100.00%	99.87%	99.35%	100.00%	99.90%	99.94%
Average proportion of locations addressed directly by fibre	0.28%	0.22%	0.02%	-%	0.13%	0.65%	-%	0.10%	0.06%
Average proportion of lines addressed directly by copper	89.30%	89.58%	96.65%	100.00%	90.69%	65.26%	100.00%	95.42%	96.30%
Average proportion of lines addressed directly by fibre	10.70%	10.42%	1.35%	-%	3.31%	34.74%	-%	4.58%	3.70%
Copper connection parameters									
Average proportion of copper lines directly connected to MDF	3.23%	5.62%	14.62%	20.19%	42.01%	40.86%	33.78%	1.51%	3.21%
Average proportion of copper lines served by PGS	0.01%	0.48%	0.13%	-%	1.94%	-%	-%	1.94%	2.71%
Average proportion of copper lines served by PDPs	96.76%	93.90%	85.25%	79.81%	56.85%	59.14%	66.22%	96.55%	94.08%
Fibre connection parameters									
Average proportion of fibre lines directly connected to MDF	0.11%	0.04%	0.68%	-%	1.01%	1.01%	-%	-%	0.08%

A.2 ‘Access Data’ workbooks

Each of the 400 sampled service areas has been assigned to a geotype and has a corresponding worksheet in a particular ‘Access Data’ workbook. All of these worksheets are identical to each other. There are 26 workbooks in total, and an index of the sampled service areas can be found on the *SummAssets* worksheet. There is also an additional ‘Access Data’ workbook used to analyse the 15 exchange areas in Geotype 16.

The worksheet of the *y*th service area sampled in geotype *x* is named *SrA.Gx.y*.

For example, the first service area sampled from Geotype 1 has a worksheet named *SrA.G.1.1*. This worksheet is in the workbook 01a, while the last area sampled from Geotype 1 has a worksheet in the workbook ending in 01d. Figure B.9 shows an exhaustive list of the 26 ‘Access Data’ workbooks.

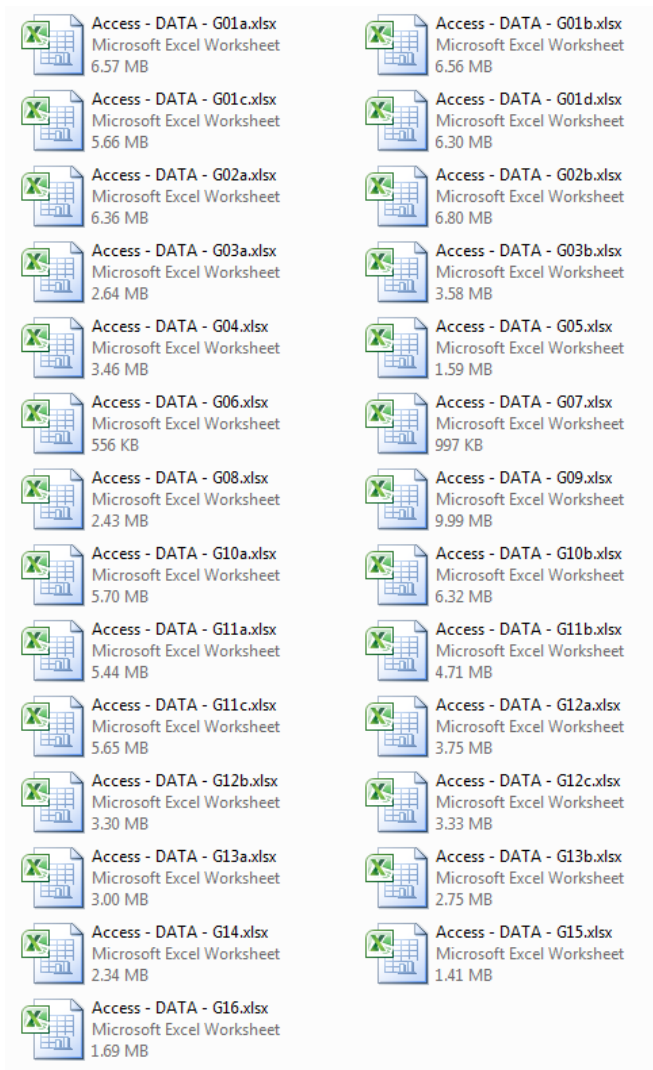


Figure A.9: 'Access Data' workbooks (the workbook for Geotype 16 is also shown) [Source: Analysys Mason, 2018]

Norwegian letters in the short codes of the service areas have been replaced with English letters where necessary, in order to avoid recognition issues between the various software programmes used in the modelling:

- Å has been replaced with 'AAA'
- Æ has been replaced with 'AAE'
- Ø has been replaced with 'OOE'.

A service area's worksheet stores co-ordinates of all locations in the service area requiring an access network connection. In particular, the numbered worksheets in the 'Access Data' workbooks store:

- the co-ordinates from the Bygningspunkter that require a connection to the access network
- the original co-ordinates (BL) and the corresponding points obtained from mapping onto the street network (RCP)
- the cluster control index, the identifier from the Bygningspunkter and the number of connections assumed to be required by the location
- the cluster indices from running the VB, as well as the access medium for the location and its type.

This information is illustrated in Figure A.10 below.

Figure A.10: Location of data stored in the 'Access Data' workbooks [Source: Analysys Mason, 2018]

Point index	Cluster control ID	Exclude this demand (E=TRUE, O=FALSE)	RCP x	RCP y	PBP x	PBP y	BL x	BL y	Final drop length (m)	Pairs required	Cluster index	Actu
41												
42	0: points could evolve S/A G11											
43	cluster control check, S/A G11											
44	first idx: S/A G11	first cluster control idx: S/A G11	first demand that: first RCP x: S/A G11	first RCP y: S/A G11	first PBP x: S/A G11	first PBP y: S/A G11	first BL x: S/A G11	first BL y: S/A G11	first final drop len:	first point cap S/A	first cluster ID: S/A	first act
45	1.00	3,390.00	-	322,349.79	7,198,935.07	322,349.79	7,198,935.07	322,352.32	7,198,931.34	5	100	64
46	2.00	3,390.00	-	323,331.04	7,200,305.97	323,331.04	7,200,305.97	323,353.28	7,200,324.88	42	100	5
47	3.00	3,390.00	-	322,497.09	7,198,950.78	322,497.09	7,198,950.78	322,500.93	7,198,946.18	6	100	72
48	4.00	3,390.00	-	322,185.58	7,198,735.52	322,185.58	7,198,735.52	322,171.74	7,198,749.41	20	200	57
49	5.00	3,390.00	-	323,385.78	7,200,533.15	323,385.78	7,200,533.15	323,406.19	7,200,519.94	24	100	14
50	6.00	3,390.00	-	322,504.28	7,198,958.72	322,504.28	7,198,958.72	322,525.11	7,198,948.83	23	100	72
51	7.00	3,390.00	-	323,193.80	7,200,749.43	323,193.80	7,200,749.43	323,177.95	7,200,750.64	16	100	10
52	8.00	3,390.00	-	323,166.91	7,199,880.00	323,166.91	7,199,880.00	323,162.45	7,199,890.98	18	100	33
53	9.00	3,390.00	-	323,314.30	7,200,458.04	323,314.30	7,200,458.04	323,293.21	7,200,462.38	22	200	18
54	10.00	3,390.00	-	322,240.52	7,198,944.80	322,240.52	7,198,944.80	322,273.71	7,198,944.68	33	200	61
55	11.00	3,390.00	-	322,183.86	7,198,546.74	322,183.86	7,198,546.74	322,208.18	7,198,562.07	21	200	52
56	12.00	3,390.00	-	322,273.16	7,198,705.85	322,273.16	7,198,705.85	322,261.27	7,198,718.79	18	100	58
57	13.00	3,390.00	-	322,335.56	7,198,764.14	322,335.56	7,198,764.14	322,348.18	7,198,755.74	15	200	60
58	14.00	3,390.00	-	322,344.48	7,198,777.57	322,344.48	7,198,777.57	322,331.01	7,198,786.51	18	200	60
59	15.00	3,390.00	-	322,376.14	7,198,741.84	322,376.14	7,198,741.84	322,322.81	7,198,732.03	12	100	60
60	16.00	3,390.00	-	322,332.78	7,198,833.68	322,332.78	7,198,833.68	322,421.57	7,198,830.14	23	100	62
61	17.00	3,390.00	-	322,267.04	7,198,700.31	322,267.04	7,198,700.31	322,279.34	7,198,686.93	18	200	58
62	18.00	3,390.00	-	322,289.96	7,198,724.74	322,289.96	7,198,724.74	322,300.81	7,198,712.01	17	100	57
63	19.00	3,390.00	-	323,253.61	7,200,534.14	323,253.61	7,200,534.14	323,268.68	7,200,532.01	15	100	18
64	20.00	3,390.00	-	323,350.97	7,200,776.32	323,350.97	7,200,776.32	323,343.05	7,200,775.12	8	100	71

For each sampled service area, the assumptions used in the previous run of the VB are stored at the top of its respective worksheet in the 'Access Data' workbook. An approximate timing of the previous run is also recorded, as shown in Figure A.11.

Named ranges are used to refer to any cells which are either read by the VB, or to which the VB writes outputs.

Figure A.11: Assumption data stored in the 'Access Data' workbooks [Source: Analysys Mason, 2018]

Assumptions	Capacity inputs and distance constraints	8	max.practical.SDP.cap.used.S/A.G11	Maximum number of primary higher dem #	8	max.num.primary.higher.demand.cab.Pros
5	Maximum practical SDP capacity pairs	8	max.practical.SDP.cap.used.S/A.G11	Maximum number of primary higher dem #	8	max.num.primary.higher.demand.cab.Pros
6	Absolute maximum SDP capacity pairs	10	max.absolute.SDP.cap.used.S/A.G11	Secondary network cable utilisation %	80%	secondary.cabling.utilisation.used.S/A.G11
7	Maximum permitted distance from SDP metres	40	max.dist.from.SDP.used.S/A.G11	Primary network cable utilisation %	90%	primary.cabling.utilisation.used.S/A.G11
8	Maximum practical PDP capacity pairs	30	max.practical.PDP.cap.used.S/A.G11	Distance constraint for installation of a metres	11,500	max.dist.for.PGS.used.S/A.G11
9	Absolute maximum PDP capacity pairs	100	max.absolute.PDP.cap.used.S/A.G11	Maximum distance of a micro ave link metres	30,000	max.wireless.link.dist.used.S/A.G11
10	Maximum permitted distance from PDP metres	400	max.dist.from.PDP.used.S/A.G11	Maximum number of relay stations that #	5	wireless.max.num.relay.stations.uses
11	Nature of secondary network	Fully tapered	secondary.methodology.used.S/A.G11	Backhaul capacity per residential sub #	20	backhaul.cap.per.res.sub.used.S/A.G11
12	Main non-tapered cable size #	20	main.non.tapered.cable.size.used.S/A.G11	Backhaul capacity per business sub #	20	backhaul.cap.per.bus.sub.used.S/A.G11
13	Maximum distance before additional llr metres	100	max.distance.between.SDPs.used.S/A.G11	SDP utilisation %	80%	SDP.utilisation.used.S/A.G11
14	Maximum distance in which cable can metres	500	max.dist.without.jointing.with.secondary.S/A.G11	PDP utilisation %	90%	PDP.utilisation.used.S/A.G11
15	Maximum distance between manholes metres	250	max.dist.primary.trench.between.manholes.used.S/A.G11	Maximum distance in which high dem metres	1,000	max.high.demand.cable.distance.no
16	Maximum distance in which cable can metres	500	max.dist.without.jointing.with.primary.S/A.G11	Maximum distance in which high dem metres	1,000	max.high.demand.cable.distance.no
17	Critical capacity for a standard cable c #	30	critical.capacity.used.S/A.G11	Tube utilisation: secondary cables %	60%	utilization.tube.secondary.cables.used.S/A.G11
18	Minimum demand at a location for it #	50	min.demand.to.use.higher.demand.cable.used.S/A.G11	Tube utilisation: primary cables %	80%	utilization.tube.primary.cables.used.S/A.G11
19	Maximum number of nodes in a higher #	20	max.nodes.in.higher.demand.ring.used.S/A.G11	Tube utilisation: PGS cables %	60%	utilization.tube.PGS.cables.used.S/A.G11
20	Methodology to connect higher demand	Connect higher de	higher.demand.cable.methodology.used.S/A.G11	Tube utilisation: high demand point-to %	60%	utilization.tube.higher.demand.cable.Pto
21	Higher demand pairs linking location pairs	12	higher.demand.cable.pairs.served.used.S/A.G11	Tube utilisation: high demand ring cab %	60%	utilization.tube.higher.demand.cable.ring.c
22	Higher demand cable area linking loca cm2	1	higher.demand.cable.area.served.used.S/A.G11	Tube cross-sectional area used S/A G11	79	tube.cross.sectional.area.used.S/A.G11
23	Maximum number of primary second #	8	max.num.secondary.cables.per.tube.used.S/A.G11	Average distance between poles metres	40	avg.distance.between.poles.used.S/A.G11
24	Maximum number of primary cables in #	5	max.num.primary.cables.per.tube.used.S/A.G11	Tube calculation methodology	Use cable cross-sections	tube.calculation.methodology.used.S/A.G11
25	Maximum number of point-to-point se #	8	max.num.higher.demand.PtoP.cables.per.tube.used.S/A.G11	Use real PDP clusters	FALSE	use.real.PDP.clusters.S/A.G11
26	Maximum number of higher demand ir #	8	max.num.higher.demand.rings.cables.per.tube.used.S/A.G11	Exclude flagged demand	FALSE	exclude.flagged.demand.S/A.G11
27	Minimum number of tubes needed for #	8	min.num.tubes.at.PDP.used.S/A.G11	Maximum number of buildings exceeded distance constr	-	max.buildings.exceeded.dist.constraint.uses
28	Maximum number of tubes that can be #	1	max.num.tubes.replace.with.aerial.used.S/A.G11	Splitter ratio	1	splitter.ratio.used.S/A.G11

Certain asset volumes are summarised in an output table to the right of the location data. As shown in Figure A.12, this summary table, starting in cell R45 of each data worksheet, records asset volumes by PDP cluster, including:

- PDP co-ordinates, classification of PDP, distance from the MDF, locations served, demand served
- route kilometres, cable sheath metres, cable pair metres, jointing
- average network secondary loop length, maximum secondary network loop length.



Figure A.12: Asset volumes stored by PDP cluster in the 'Access Data' workbooks [Source: Analysys Mason, 2018]

Description of asset volumes for access network in service area														
Table	Node index	NodeX	NodeY	Node Type	Crow-flies distance to MDF	Locations served		Demand served		Extra SDPs required in secondary network	Total FDP-SDP	Incremental secondary network	Incremental primary network	Incremental total
						Standard cable	Higher demand cable	Standard cable	Higher demand cable					
						199	-	237	-	-	1,667	4,614		534
						Standard cable (k)	Higher demand (k)	Standard cable (k)	Higher demand (k)	Additional SDPs (S)	FDP (SDP (m))	Secondary (m)	Primary (m)	Total (m)
1	322,350	7,198,935	MDF		58			71			455			453
2	323,286	7,200,664	PDP					6			207			1,703
3	323,248	7,200,163	PDP					1			308			814
4	322,956	7,199,592	PDP					6			334			343
5	322,222	7,198,665	PDP					3			362			694

Each node can be an MDF location, PDP or PGS

Figure A.13 shows another table, starting in cell BF45, which stores each of the links in the spanning tree derived for the service area, including:

- type of link, indices and co-ordinates of endpoints
- link length and whether or not this length is calculated using the p-function (0 means that the link lies along a straight road, meaning that crow-flies distance can be used)
- number of cables and tubes, by type, deployed within the link.

Figure A.13: Spanning tree links stored in the 'Access Data' workbooks [Source: Analysys Mason, 2018]

Data on spanning trees connecting address locations													
Connection type	Requires p-function	Road crossings	Edge index	v1	v2	v1.x	v1.y	v2.x	v2.y	Link length (m)	Cables lying in link		
											Secondary (standard cable)	Primary (standard cable)	Demanded
Within SDP	0	0	1	68	26	323530.31	7200688.07	323530.31	7200688.07	0	1	0	0
Within SDP	1	0	2	157	160	323273.39	7200657.73	323286.12	7200664.35	14.39749459	0	0	0
Within SDP	0	0	3	158	157	323273.39	7200657.73	323273.39	7200657.73	0	0	0	0
Within SDP	1	0	4	153	160	323308.11	7200671.86	323286.12	7200664.35	23.2370437	3	1	0
Within SDP	0	0	5	152	153	323417.18	7200596.3	323394.76	7200618.5	31.49637899	0	0	0
Within SDP	0	0	6	156	155	323319.57	7200623.05	323318.82	7200607.13	15.93785667	2	1	0
Within SDP	1	0	7	58	155	323322.71	7200586.24	323318.82	7200607.13	21.54624437	1	1	0
Within SDP	1	0	8	71	5	323382.51	7200533.9	323385.78	7200533.15	3.39707654	1	0	0
Within SDP	0	0	9	151	39	323334.34	7200513.29	323329.96	7200502.49	11.65437257	3	0	0
Within SDP	0	0	10	32	150	323236.45	7200437.32	323239.06	7200453.17	22.00533117	1	0	0
Within SDP	0	0	11	55	150	323247.14	7200488.06	323239.06	7200453.17	29.9984164	0	0	0
Within SDP	1	0	12	88	75	323288.52	7200388.87	323307.47	7200430.73	33.44582333	0	0	0

The deployment characteristics of each SDP cluster are stored in a similar table. As shown in Figure A.14, this table starts in cell CH45 and records details of the SDP clusters derived for the service area, including:

- index of the parent PDP, co-ordinates and index of the SDP, number of vertices, number of connections
- details related to the manhole required at the SDP location
- total 'as-the-crow-flies' distance from the building locations to the SDP, poles required within the SDP cluster (for use by the aerial cabling calculations in the Network Service Costing – Access module).

Figure A.14: SDP cluster data stored in the 'Access Data' workbooks [Source: Analysys Mason, 2018]

Node index (MDF, PDP, PGS)	Cluster index	SDP x coord	SDP y coord	Point representing SDP	Number of vertices in cluster	Is a PDP location	Capacities in cluster	Tubes out of node	Max tubes in one link	Count of links into node	Final manhole size	Non-primary tubes out of node
45	2	323573.75	720138.22	164	1	0	1	1	1	1	1 MH1	1
46	2	323541.09	7201255.62	163	1	0	2	2	1	2	2 MH1	2
47	2	323590.31	7200888.07	26	2	0	2	1	1	1	1 MH1	1
48	2	323444.07	7200985.1	65	1	0	1	3	1	3	3 MH2	3
49	2	323391.04	7200905.37	2	1	0	1	2	1	2	2 MH1	2
50	2	323303.59	7200828.26	162	1	0	1	2	1	2	2 MH1	2
51	2	323350.97	7200776.32	20	1	0	1	2	1	2	2 MH1	2
52	2	323303.81	7200760.56	161	1	0	1	1	1	1	1 MH1	1
53	2	323273.77	7200744.68	28	1	0	1	3	1	3	3 MH2	3
54	2	323193.8	7200749.43	7	1	0	1	1	1	1	1 MH1	1
55	2	323286.12	7200664.35	160	4	1	4	3	2	2	2 MH2	2
56	2	323484.76	7200698.5	163	2	0	2	2	2	2	2 MH4	2

Additional smaller tables summarise other aspects of the access network. These tables all start in row 7 of the worksheet, and provide details of the tubes and cabling required for the service area. Figure A.15 below shows the trench metres by number of tubes.

Number of tube	Associated manhole	Distance (m) of tube	Distance (m) of tube excluding	Distance (m) of tube primary only
28	MH 3	-	-	-
24	MH 3	-	-	-
20	MH 3	-	-	-
16	MH 3	-	-	-
12	MH 3	-	-	-
8	MH 2	-	-	-
6	MH 2	-	-	-
4	MH 2	-	-	-
2	MH 2	2,064	-	-
1	MH 1	4,751	6,281	2,597

Figure A.15: Trench metres by number of tubes (i.e. ducts) [Source: Analysys Mason, 2018]

Figure A.16 shows cable sheath by cable size, split by lead-in (within the SDP), secondary and primary, and total connections served by each final drop size.

Figure A.16: Summary of cable sheath and final drop cable size [Source: Analysys Mason, 2018]

Standard cables	Within SDP's direct feed	Secondary direct feed	Within SDP's Secondary	Primary	Minimum demand	Maximum demand	Standard cable size	Demand served	Locations	Final drop length
2	576	183	1,734	2,653	-	1	2	162	162	3,967
5	103	117	214	1,342	2	4	5	70	31	1,614
10	-	191	-	1,522	5	8	10	-	-	-
20	-	221	-	1,453	9	17	20	-	-	-
30	-	75	-	284	18	26	30	-	-	-
50	-	158	-	182	27	44	50	-	-	-
100	-	107	-	-	45	89	100	-	-	-
200	-	-	-	-	90	173	200	-	-	-
400	-	-	-	-	180	400	400	-	-	-

A single output row, as shown below in Figure A.17, summarises the assets required to deploy an access network to the service area. The row contains several hundred pieces of information and the cells link back into the SummAssets worksheet of the 'Geo-analysis Code' workbook.

Figure A.17: Summary line of assets stored in the 'Access Data' workbooks [Source: Analysys Mason, 2018]

Final total volumes for service area											
PDPs at MDF	PDPs	PGS - linked by fibre	PGS - linked by wireless	PGS - linked by satellite	Locations served Standard cable	Higher demand cable	Demand served Standard cable	Higher demand cable	Standar Direct to MDF	By PGS	By PDPs
1	4	-	-	-	199	-	237	-	71	-	166

Each 'Access Data' workbook also contains a *Links* worksheet, where relevant data for the chosen architecture is linked in from the 'Geo-analysis Code' workbook. The outputs from any sampled service area can be plotted from its assigned worksheet using MapInfo, as shown in a series of figures below. Figure A.18 shows a plot of locations, colour coded by their PDP cluster, while Figure A.19 shows a plot of a spanning tree. Figure A.20 shows a plot of a spanning tree where only links used by a fibre ring are visible.

Figure A.18: Plot of locations, colour-coded by their PDP cluster [Source: Analysys Mason, 2018]

Figure A.19: Plot of a spanning tree where line width increases with number of cables in the link [Source: Analysys Mason, 2018]

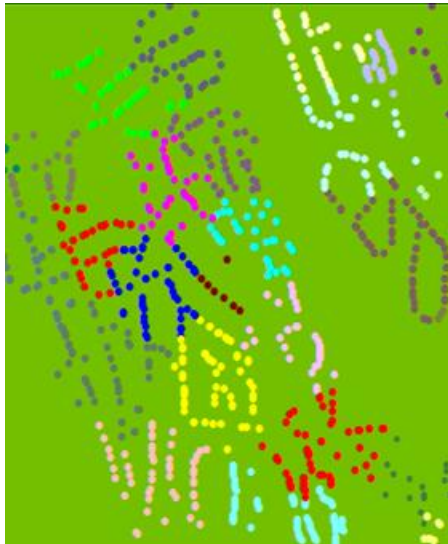
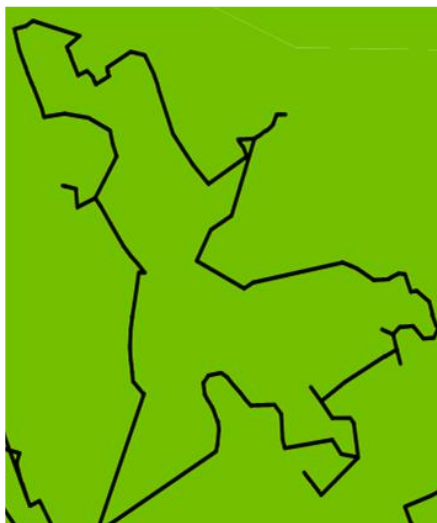


Figure A.20: Plot of a spanning tree where only a fibre ring is visible [Source: Analysys Mason, 2018]



A.3 Cabling calculations workbooks

The CTTH cabling calculations workbook is also used to calculate distributions of copper cable gauges in the CTTH network. Thicker copper gauges can be used to allow the CTTH network to support voice/xDSL along longer loops. Figure A.21 shows a plot of signal attenuation by gauge. We have assumed a mix of 0.4mm, 0.6mm and 0.9mm gauges deployed in the network.

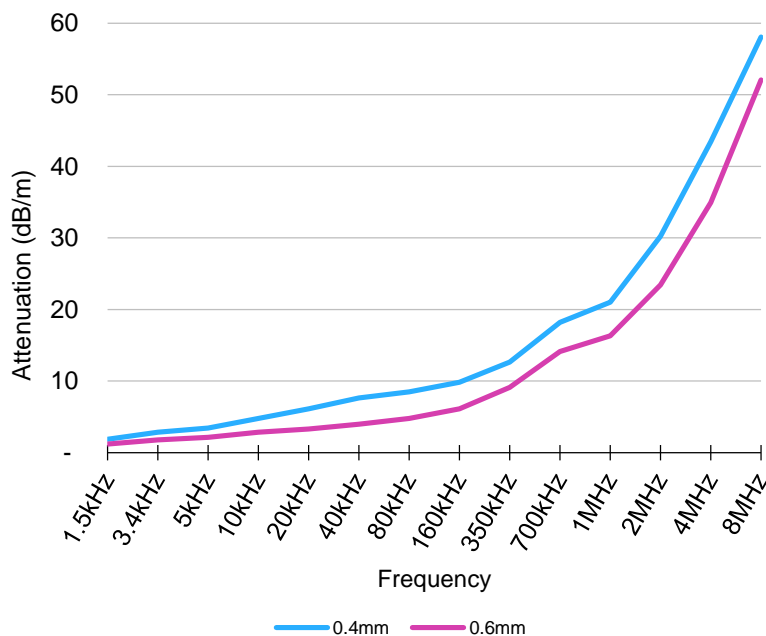


Figure A.21: Signal attenuation by gauge
[Source: Analysys Mason, 2018]

A calculation of the secondary/primary mix of gauges is undertaken for each PDP cluster from the sampled areas. A gauge distribution for each geotype is derived from a maximum signal attenuation per loop kilometre. The maximum signal attenuation is assumed based on:

- the longest loop in each PDP cluster
- ADSL service requirements using 0.4mm in the primary network
- ISDN service requirements otherwise.

The CTTH cabling calculations workbook is able to calculate distributions for the mix of gauges. In order to update this workbook following a re-run of the geo-analysis, the following steps should be taken:

- ensure that the 'Geo-analysis Code' workbook and the 'Access Data' and cabling calculation workbooks are all in the same directory
- open both the 'Geo-analysis Code' workbook and the cabling calculation workbook together
- on the *A1_Macro* worksheet of the cabling calculation workbook, set the first service area and last service area to be '1' and '400' respectively
- set cell F29 to be 'TRUE' (i.e. the primary and secondary networks are assumed to be separate)
- click on the button 'Paste in node data' and allow the macro to run, whereby it
 - copies the PDP cluster summary tables for each sampled service area onto the *A2_IN* worksheet

- copies relevant columns from the *A2_IN* worksheet into two tables on the *A3_Relevant* worksheet
- converts all distances in the two tables into kilometres.

The *A1_Macro* worksheet, ‘Paste in node data’ button, and parameters described above can be seen in Figure A.22.

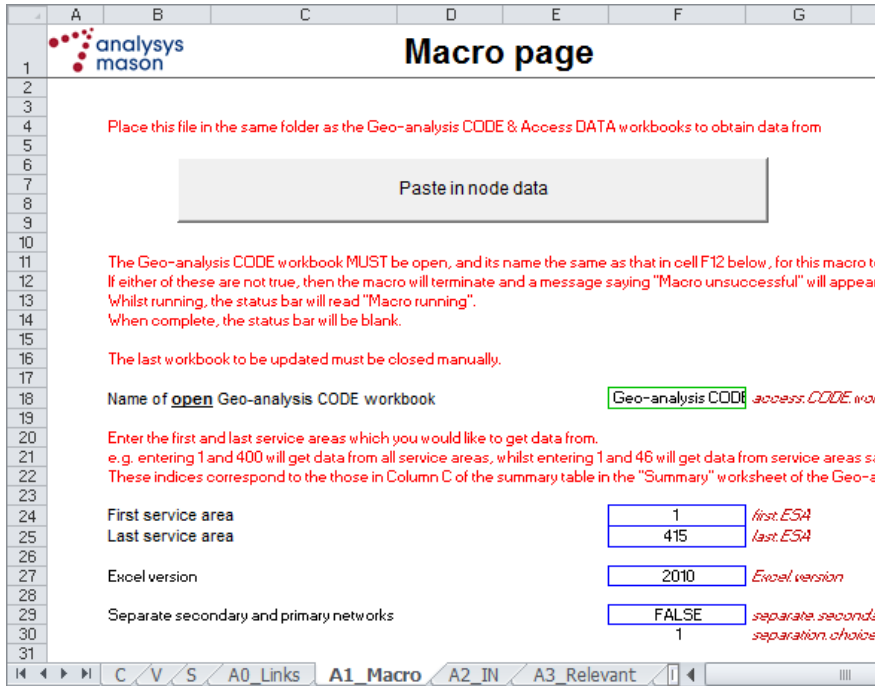
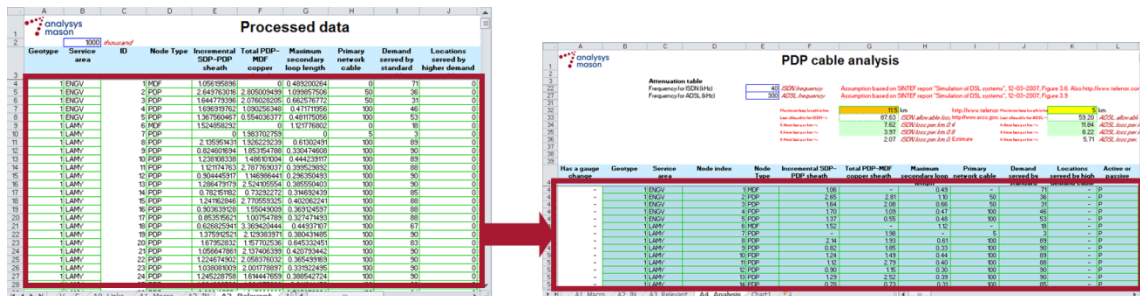


Figure A.22: Updating the cabling calculation workbooks [Source: Analysys Mason, 2018]

The data in columns A to K (starting on row 4) on the *A3_Relevant* worksheet should next be pasted into cell B41 of the *A4_Analysis* worksheet. This pasting operation is shown in Figure A.23. It should be ensured that there are enough rows in the table on the latter worksheet, and that all formulae in column A and columns N to AH are present in the rows used.

Figure A.23: Transfer of information to the *A4_Analysis* worksheet [Source: Analysys Mason, 2018]



The output of these calculations will determine both the mix of PDP types in the sampled areas and the cable sheath metres. The ‘Geo-analysis Code’ workbook should be updated with the results by updating the links from the cabling calculation workbook.

For the avoidance of doubt, this analysis is not required in the PON/PTP modelling, since fibre strands do not vary by gauge.

Annex B Assumptions used in the offline calculations

Some of the assumptions that can be used in the network deployments in the offline calculations can vary by geotype. However, for most assumptions, the same value is currently used across all geotype.

The assumptions used are given below in Figure B.1, Figure B.2 and Figure B.3 for the copper, PON fibre and PTP fibre networks, respectively. All of the assumptions tabulated below can be found in the 'Geo-analysis CODE' workbook.

B.1 The copper network

Figure B.1: Assumptions used in the copper network deployment [Source: Analysys Mason, 2018]

Parameter	Value currently assumed
Absolute maximum SDP capacity	10 lines
Assumed SDP utilisation	80%
Assumed secondary cabling utilisation	80%
Maximum distance between SDPs	100 metres
Maximum permitted distance from SDP centre	40 metres
Absolute maximum PDP capacity	100 lines
Assumed PDP/primary network utilisation	90%
Maximum permitted distance from PDP centre	Varies by geotype between 400 metres and 900 metres
Tapering	Fully tapered
Maximum distance in which cable can be pulled through the secondary network without jointing	500 metres
Maximum distance in which cable can be pulled through the primary network without jointing	500 metres
Maximum number of loops which can exceed maximum threshold	0
Maximum distance between manholes in primary routes between PDPs	250 metres
Maximum loop length threshold	11 500 metres
Cable sizes used between RCP and SDP (copper)	2, 5, 10, 20, 30, 50, 100, 200 and 400 pairs
Coefficients for the proxy cost function within the SDP clusters	$k_1=1, k_2=0, k_3=0.03, k_4=0$
Coefficients for the proxy cost function in secondary network connection (fully tapered)	$k_1=1, k_2=0.1, k_3=0.004, k_4=0$
Coefficients for the proxy cost function in primary network connections	$k_1=1, k_2=0.01, k_3=0.0005, k_4=0$
Tube diameter	10 cm
Tube utilisation	60%
Maximum tubes that can be converted to aerial	1

B.2 The fibre passive optical network

Figure B.2: Assumptions used in the passive optical fibre network deployment [Source: Analysys Mason, 2018]

Parameter	Value currently assumed
Absolute maximum SDP capacity	36 lines
Assumed SDP utilisation	85%
Splitter ratio	32
Assumed secondary cabling utilisation	85%
Maximum distance between SDPs	100 metres
Maximum permitted distance from SDP centre	50 metres
Absolute maximum PDP capacity	600 lines
Assumed PDP/primary network utilisation	90%
Maximum permitted distance from PDP centre	Varies by geotype between 500 metres and 1000 metres
Tapering	Fully tapered
Maximum distance in which cable can be pulled through the secondary network without jointing	1000 metres
Maximum distance in which cable can be pulled through the primary network without jointing	1000 metres
Maximum number of loops which can exceed maximum threshold	0
Maximum distance between manholes in primary routes between PDPs	1000 metres
Maximum loop length threshold	100 000 metres
Cable sizes used between RCP and SDP (fibres)	2, 6, 12, 24, 48, 72, 96, 120 and 312 pairs
Coefficients for the proxy cost function within the SDP clusters	$k_1=1, k_2=0, k_3=0.03, k_4=0$
Coefficients for the proxy cost function in secondary network connection (fully tapered)	$k_1=1, k_2=0.1, k_3=0.004, k_4=0$
Coefficients for the proxy cost function in primary network connections	$k_1=1, k_2=0.01, k_3=0.0005, k_4=0$
Tube diameter	1.4 cm
Tube utilisation	60%
Maximum tubes that can be converted to aerial	1

B.3 The fibre point-to-point network

Figure B.3: Assumptions used in the PTP fibre network deployment [Source: Analysys Mason, 2018]

Parameter	Value currently assumed
Absolute maximum SDP capacity	12 lines
Assumed SDP utilisation	85%
Assumed secondary utilisation	85%
Maximum distance between SDPs	100 metres
Maximum permitted distance from SDP centre	40 metres
Absolute maximum PDP capacity	300 lines
Assumed PDP/primary network utilisation	90%
Maximum permitted distance from PDP centre	Varies by geotype between 400 metres and 900 metres
Tapering	Fully tapered
Maximum distance in which cable can be pulled through the secondary network without jointing	1000 metres
Maximum distance in which cable can be pulled through the primary network without jointing	1000 metres
Maximum number of loops which can exceed maximum threshold	0
Maximum distance between manholes in primary routes between PDPs	1000 metres
Maximum loop length threshold	100 000 metres
Cable sizes used between RCP and SDP (fibres)	2, 6, 12, 24, 48, 72, 96, 192 and 312 pairs
Coefficients for the proxy cost function within the SDP clusters	$k_1=1, k_2=0, k_3=0.03, k_4=0$
Coefficients for the proxy cost function in secondary network connection (fully tapered)	$k_1=1, k_2=0.1, k_3=0.004, k_4=0$
Coefficients for the proxy cost function in primary network connections	$k_1=1, k_2=0.01, k_3=0.0005, k_4=0$
Tube diameter	5 cm
Tube utilisation	60%
Maximum tubes that can be converted to aerial	1

Annex C Description of Visual Basic

Visual Basic (VB) code has been developed, using Microsoft Excel, for certain calculations to dimension the access network for service areas from Telenor's access network, in order to derive network dimensioning inputs for the bottom-up (BU) modelling undertaken by Analysys Mason Limited ('Analysys Mason') for Nkom.

A technologically agnostic approach has been adopted in the naming conventions used within the VB. This ensures that it can be used to calculate dimensioning inputs for different architectures. An example is in the use of the terminology 'standard cable' and 'high demand cable':

- For a copper-to-the-home (CTTH) network, copper is used for the standard cables, while fibre is used to serve locations with higher demand (and is hence the 'high-demand cable').
- For a fibre-to-the-home (FTTH) network, fibre is used for both standard and, where needed (e.g. in a passive optical network (PON)), high-demand cables.

The VB determines an efficient access network deployment for a service area, given the location of the main (optical) distribution frame (M(O)DF) and a set of locations in the service area with associated levels of demand. Locations are grouped into clusters served by a secondary distribution point (SDP). SDP clusters are themselves grouped into clusters served by a primary distribution point (PDP). A number of architectures can be considered: CTTH with fibre for high demand; FTTH/PON; and point-to-point (PTP) FTTH. The VB is stored in the Geo-analysis Code workbook.

This annex outlines the structure of the VB. In addition, the VB itself has been annotated should users want to inspect it within the VB editor in Microsoft Excel. The VB begins with a start-up phase, described in Annex C.1, in which constants and assumptions are read in. There is then a main phase, which is split into eight sub-phases. These are described in more detail in Annex C.2.

C.1 Start-up phase

This stage is completed at the start of the calculation for any service area through various subroutines. For each service area, the relevant Access Data workbook is opened (if not already open), old assumptions are deleted and input arrays are populated.

Two subroutines – *SetupPermanentConstants* and *ReadInGeotypeData*, which read in inputs relevant to all service areas, are run at the start of the process.

For each service area to be processed by the algorithms, three subroutines – *SetupConstantsForThisSrA*, *DeleteOldSrAOutputs* and *Initialise* – are used to read in input data specific to the service area.

These subroutines are described in turn below.

C.1.1 Subroutine SetupPermanentConstants

Location: Found in the *CommonCode* module.

Purpose: Reads in various assumptions and constants that are fixed regardless of geotype, including the directory path, cable sizes and other network deployment assumptions, such as manhole definitions.

C.1.2 Subroutine ReadInGeotypeData

Location: Found in the *CommonCode* module.

Purpose: Reads in the indices for the service areas as stored in the *SummAssets worksheet* (i.e. the geotype and index of the service area).

For each service area to be calculated, the relevant Access Data workbook is opened if it is not already open. Old assumptions from previous calculations are then deleted and input arrays are populated. Throughout the process, the time taken at major stages in the process is recorded and stored.

C.1.3 Subroutine SetupConstantsForThisSrA

Location: Found in the *CommonCode* module.

Purpose: Resets all of the global variables and reads in the assumptions that vary by geotype on the *INselected* worksheet, including:

- clustering capacity and distance constraints
- p-function coefficients
- proxy cost function coefficients
- number of locations and the identity of the one that is the main distribution frame (MDF) location.

C.1.4 Subroutine DeleteOldSrAOutputs

Location: Found in the *CommonCode* module.

Purpose: Deletes the contents of all of the cells that were written to in the last calculation of the service area.

C.1.5 Subroutine Initialise

Location: Found in the *CommonCode* module.

Purpose: Reads in the location co-ordinates and demand requirements for the relevant service area from its worksheet in the Access Data workbook.

In particular, the array `gobjInputPoints()` is populated with the co-ordinates and demand at each location.

The Access Data workbooks include the functionality to flag locations as not being included in the calculation. Therefore, the calculations have the flexibility to only service a subset of the demand locations.

By default, all locations are included. However, if the user specifies to 'exclude flagged demand' then the VB will not read in those locations that are flagged to be excluded.

The VB also includes the functionality to use actual cabinet areas in the modelled network, by assigning each location with an identifier for its parent cabinet location. Furthermore, the location acting as the cabinet, and whether that cabinet contains active equipment (e.g. being equipped with FTTN/VDSL, labelled as 'A') can also be specified. A cabinet without active equipment is labelled as being passive, or 'P'.

C.2 Main phase

There are eight sub-phases in the main phase:

- standard cable clustering sub-phase, which is described in Annex C.2.1
- standard cable SDP cluster spanning tree sub-phase, which is described in Annex C.2.2
- standard cable SDP cluster connection sub-phase, which is described in Annex C.2.3
- standard cable PDP cluster connection sub-phase, which is described in Annex C.2.4
- high-demand cable determination sub-phase, which is described in Annex C.2.5
- backhaul determination sub-phase, which is described in Annex C.2.6
- result storage sub-phase, which is described in Annex C.2.7
- assumption storage sub-phase, which is described in Annex C.2.8.

C.2.1 Standard cable clustering sub-phase

This is run through the subroutine *AllClusteringMethods*, which is found in the *MainMacros* module. The deployment executes seven subroutines:

- *IdentifyMDF*
- *DivisiveClustering*
- *WriteClusterResults*
- *ClusterToPDPClusterLevel*
- *CalculateUnitsOfHighDemand*
- *IdentifyPDPs*.

These are explained in more detail below.

Subroutine IdentifyMDF

Location: Found in the *Clustering* module.

Purpose: This only calculates an MDF location for a service area if no MDF location is stated in the *INselected* worksheet. Currently, each service area uses the first location in the list of building locations as the location of the MDF. This first location has been provided by Telenor.

If a location is not stated for the MDF in the worksheet in the Access Data workbooks, then the location closest to the demand-weighted centre of the locations in the service area is used. There are three sets of objects that can be used for this calculation: locations, SDPs and PDPs. The current set-up uses individual locations in the absence of a MDF location.

Subroutine DivisiveClustering

This subroutine groups property boundary points (PBPs) into clusters, which are served by SDPs. This clustering is based on a capacity and a distance constraint and is top-down in design. Specifically, a single 'parent' cluster is created containing all of the locations, and 'child' clusters are created from the parent, causing it to shrink in size. This ceases when the parent cluster satisfies both the capacity and distance constraints.

A third constraint forbids certain locations from lying within the cluster. Each PBP is assigned to a 'control' cluster, with each control cluster having its own unique index. Each service area has a list of forbidden pairs of control clusters. The clustering algorithm works entirely on the basis that if two points have different control clusters, which are a forbidden control cluster pair, then the two points must lie in both different SDP clusters and different PDP clusters. In our base case, we assign each cabinet area a different control cluster identifier, with each possible pair of such identifiers being forbidden. This is how we force the VB to use the actual cabinet areas.

The following subroutines create the parent cluster.

► *Subroutine InitialiseClusterAllocations*

Location: Found in the *Clustering* module.

Purpose: Assigns each point to a single parent cluster.

► *Subroutine InitialiseParentCapacity*

Location: Found in the *Clustering* module.

Purpose: Calculates the total demand within the parent cluster.

► *Subroutine CalWeightedCentre*

Location: Found in the *Clustering* module.

Purpose: By default, this calculates the demand-weighted centre of the parent cluster. If it is supplied with points that all have zero demand, then it will calculate the geometric centre of all the points.

► *Subroutine CalSquareMaxDInP*

Location: Found in the *Clustering* module.

Purpose: This identifies the point furthest from the centre of the parent cluster in order to generate a child cluster. Having identified the point, it sets:

- the point as the first point in a new child cluster
- the demand of the child cluster as the demand at that point.

We note that we do allow individual points with demands greater than the SDP/PDP capacity to be clustered as clusters of one point, although this fails the capacity limit criterion.

The main loop of the algorithm creates new child clusters until the parent cluster satisfies the demand and distance constraint. New child clusters are created by:

- selecting the point in the parent cluster that is furthest from its demand-weighted centre, using the subroutine *ChooseFirstChildMember*, which is found in the *Clustering* module
- expanding the cluster by adding points from the parent. Each time a point is added:
 - all points in the parent cluster are shortlisted to those that are within twice the maximum permitted distance from the current child cluster demand-weighted centre and with a capacity that would not overflow the cluster capacity were it added
 - points that are found to have too much demand for the cluster (or are part of a forbidden control cluster pair with the rest of the child cluster) are not considered again for the cluster at all, but are kept within the parent cluster and are restored for consideration for the next child cluster

- the point among these that is the closest to the child cluster demand-weighted centre is selected and provisionally re-allocated
- the child cluster centre is re-calculated using *CalUnweightedCentre*, which is found in the *Clustering* module and calculates a geometric centre for the cluster
- the re-allocation is finalised, unless the cluster no longer satisfies the distance criterion with the re-calculated cluster centre, in which case it is rejected.

This loop uses the subroutine *AllocatePointToCluster* to move points between the parent and child clusters.

► *Subroutine AllocatePointToCluster*

Location: Found in the *Clustering* module.

Purpose: Allocates a selected point to a given child cluster provided it does not violate distance constraints. If the allocation is accepted, then the new cluster centres of both the parent and the child are also re-calculated.

When the parent cluster satisfies the demand and distance constraint, it is re-written as the final child cluster. A series of subroutines are then used to improve the quality of these clusters:

- *SimpleReassignment*
- *Swap*
- *FullOptimisation*
- *HighDemandSimpleReassignment*
- *HighDemandSwap*
- *SingleDemandSwap*.

A dictionary of points is used to accelerate the refinement processes using a *Scripting.Dictionary* object. This object is populated before the refinement begins.

These subroutines are re-used frequently throughout the VB for different clustering requirements and are each explained below. They can move any locations between clusters except for the MDF location when a service area is using the high-demand cable ring deployment. This very minor constraint allows the subroutines to be re-used for clustering PDPs into high-demand cable rings, which requires that every cluster contains the MDF.

These subroutines require particularly intensive use of distance calculations, particularly for distance comparisons (e.g. identifying whether a point P1 is closer to a point P2 or a point P3). We use a faster distance measure in each of these cases with the subroutine *CalcPfunctionDistanceComparisonOnly*.

► *Subroutine CalcPfunctionDistanceComparisonOnly*

Location: Found in the *CommonCode* module.

Purpose: For two points with co-ordinates (x_1, y_1) and (x_2, y_2) and a p–function with coefficients k and p , this subroutine outputs:

$$|x_1 - x_2|^p + |y_1 - y_2|^p$$

This subroutine does not take the p th root that would be required in deriving the actual p–function distance and therefore requires less time. Comparing two measures calculated with this form will give the same result as comparing two actual p–function distances, as functions of the form x^p are increasing functions for positive x .

In contrast, the subroutine *CalcPfunctionDistance* calculates the actual p–function distance between two points, executing the final stage of taking the p th root.

► *Subroutine CalcPfunctionDistance*

Location: Found in the *CommonCode* module.

Purpose: For two points with co-ordinates (x_1, y_1) and (x_2, y_2) and a p–function with coefficients k and p , this subroutine outputs:

$$k(|x_1 - x_2|^p + |y_1 - y_2|^p)^{1/p}$$

This function can also be used for the normal straight-line distance measure ('crow-flies'), by using $k=1$ and $p=2$.

► *Subroutine SimpleReassignment*

Location: Found in the *Clustering* module.

Purpose: This subroutine moves a point from one cluster to another under certain conditions.

To start with, the demand-weighted centres for each cluster are calculated and clusters with spare capacity are flagged.

The main Do...Loop continues moving through each point in turn until no more can be re-assigned. This can move through all of the points more than once. For each point:

- the cluster with the closest demand-weighted centre is identified
- it is moved to this identified cluster if and only if
 - the point is closer to this new cluster's demand-weighted centre than its current one
 - the new cluster has sufficient spare capacity
 - all points in the new cluster obey the distance constraint with respect to a cluster centre re-calculated using this new point

- the point is not in a control cluster that is forbidden with respect to the existing points in the identified cluster
- its old cluster is flagged to have spare capacity and the new cluster is checked to see whether it no longer has spare capacity.

► *Subroutine Swap*

Location: Found in the *Clustering* module.

Purpose: This subroutine swaps a point in one cluster with a point in another under certain conditions.

To start with, the demand-weighted centres for each cluster are calculated.

The main Do...Loop cycles through all points in turn, possibly multiple times, until no more points can be swapped. For each point P:

- the cluster with the closest demand-weighted centre is identified
- if the identified cluster is not P's current cluster and if moving P to the new cluster violates the maximum capacity constraints, then it tries to find a point Q in the new cluster which can be swapped with P so that all of the following are satisfied
 - the two new clusters both satisfy the cluster capacity constraint
 - the sum of the two distances between the points and the cluster centres of their new clusters is lower than the sum of the distances between the points and the cluster centres of their original clusters
 - both clusters obey the distance constraint with respect to their new cluster demand-weighted centre
 - the point is not in a control cluster that is forbidden with respect to the existing points in the identified cluster
- if such a Q is found, then it
 - temporarily revises the two clusters
 - re-calculates their demand-weighted centres
 - re-calculates the sum of the two distances between the points and the re-calculated cluster centres of their new clusters
 - checks if this new total distance is lower than the sum of the two distances between the points and the original cluster centres of their original clusters
- if this test is also successful, then the swap is made permanent; otherwise, P and Q are restored to their original clusters.

► *Subroutine FullOptimisation*

Location: Found in the *Clustering* module.

Purpose: This subroutine moves a point from one cluster to another if certain criteria are satisfied, though these criteria are different to those in *SimpleReassignment*. Specifically, it tries to minimise the total distance from the points in a cluster to their cluster centre.

First, the demand-weighted centres for each cluster are calculated.

Then, for each cluster, the sum of the distances between the points in a cluster and their demand-weighted cluster centre are calculated. This uses the subroutine *CalcTotalDist*, which can be found in the *Clustering* module. Clusters with spare capacity are also flagged.

The main Do...Loop cycles through all points in turn, possibly multiple times, until no more can be moved. For each point P:

- the cluster containing P is identified
- the total distance (d1) between all points in this cluster and the cluster centre is stored
- P is temporarily removed from its cluster and both the demand-weighted cluster centre and the total distance (d2) between the cluster points and the new cluster centre are re-calculated
- P is then restored to its cluster
- for each cluster with sufficient spare capacity to accommodate P, and which is not in a control cluster that is forbidden with respect to P, the total distance (d3) between all points in this cluster and its current cluster centre is stored
- P is then added into this cluster and the demand-weighted cluster centre and the total distance (d4) between the SDP locations and the new cluster centre are calculated
- the cluster which gives the largest reduction in total distance (i.e. which maximises $[d1-d2]-[d4-d3]$) is identified
- if no clusters give a reduction, then it proceeds to the next point
- otherwise P is moved to the identified cluster provided that it also satisfies the normal distance constraint using its new demand-weighted centre
- the original cluster is flagged as now having spare capacity
- the cluster that has received P is also checked to see if it still has spare capacity.

► *Subroutine HighDemandSimpleReassignment*

Location: Found in the *Clustering* module.

Purpose: This is similar to *SimpleReassignment*, except that it only considers points with high demand (i.e. more than one unit of demand).

First, the demand-weighted centres for each cluster are calculated. Points with a high demand (i.e. more than 1 unit of demand but not exceeding the maximum cluster capacity) are then identified.

Next, the main Do...Loop cycles through all points in turn, possibly multiple times, until no more can be re-assigned. For each high-demand point P:

- the cluster whose demand-weighted centre is closest to P is identified
- P is moved to this cluster if all the following are satisfied
 - P is closer to this new cluster's demand-weighted centre than its current one
 - the new cluster has sufficient spare capacity (using the absolute maximum capacity limit, not the normal cluster capacity limit)
 - all points in the new cluster obey the distance constraint with respect to the new cluster centre
 - the point is not in a control cluster that is forbidden with respect to the existing points in the identified cluster
- if these are satisfied, then the cluster centres for both clusters are re-calculated.

► *Subroutine HighDemandSwap*

Location: Found in the *Clustering* module.

Purpose: This is similar to *NormalSwap*, except that it only considers points with high demand (i.e. more than one unit of demand).

First, the demand-weighted centres for each cluster are calculated and high-demand points are identified.

The main Do...Loop cycles through all points in turn, possibly multiple times, until no more can be swapped. For each high-demand point P:

- the cluster whose demand-weighted centre is closest to P is identified
- if the cluster is not P's current cluster and if moving the point to the new cluster violates the maximum capacity constraints, then it tries to find a point in the new cluster that can be swapped with P so that all of the following are satisfied
 - the two new clusters both satisfy the cluster demand constraint, but using the absolute maximum capacity as the limit
 - the sum of the two distances between the points and their SDP cluster centres is improved compared with before

- both clusters obey the distance constraint with respect to their new cluster demand-weighted centre
- the point is not in a control cluster that is forbidden with respect to the existing points in the identified cluster
- if such a point is found, then the two clusters are revised and their demand-weighted centres are re-calculated
- otherwise, the points are returned to their original clusters.

► *Subroutine SingleDemandSwap*

Location: Found in the *Clustering* module.

Purpose: This is identical to *HighDemandSwap*, except that it only considers points with one unit of demand.

Subroutine WriteClusterResults

Location: Found in the *Clustering* module

Purpose: Writes the cluster indices for each location in the output worksheet for the service area, beside its co-ordinates.

The first standard cable clustering sub-phase for the deployment, which allocates locations to clusters served by an SDP, uses the following sequence of refinement subroutines:

- SimpleReassignment
- Swap
- FullOptimisation
- HighDemandSimpleReassignment
- HighDemandSwap
- SingleDemandSwap
- SimpleReassignment
- Swap.

Having completed the clustering of the points, the cluster indices are printed on the output worksheet for the service area.

Subroutine ClusterToPDPClusterLevel

Following the clustering of locations into SDP clusters, a second clustering sub-phase occurs by grouping SDP clusters into PDP clusters. In order to re-use the clustering subroutines described above, local copies of the arrays containing the SDP clustering data are created, allowing the original arrays to be re-used for the second level of clustering. This is accomplished by a subroutine called *CopyClusteringArrays*.

► *Subroutine CopyClusteringArrays*

Location: Found in the *CommonCode* module.

Purpose: Stores the values contained in:

- *glNumPoints*, which is the number of points to be clustered
- *gNumChildClusters*, which is the number of child clusters created
- *giClusterAssignedTo()*, which contains the cluster index for each point
- *giNumVerticesInCluster()*, which contains the number of locations in each cluster
- *giClusterCapacity()*, which contains the number of units of demand within each cluster
- *gobjInputPoints()*, which contains data specific to each location, including the co-ordinates and number of units of demand.

In particular, the SDP cluster for each location is stored in *giSDPCluster()*.

The location of the SDP that serves each SDP cluster is defined as the location in the cluster closest to its demand-weighted centre. The identity of this point is stored in the array *giClusterMainPoints()*. The array *gobjInputPoints()* is then re-populated with the data for all the SDP clusters.

The subroutine *DivisiveClustering*, described above, is then re-used to derive PDP clusters for the SDP clusters. These clusters are derived using only the points that are used as the SDPs for the SDP clusters. This implicitly ensures that locations in the same SDP cluster are in the same PDP cluster.

In this case, SDPs are grouped into clusters served by PDPs, using the subroutine *DivisiveClustering*. This clusters a set of locations based on a capacity and a distance constraint specific to PDPs. These constraints are obviously larger than those used for clustering into SDP clusters.

InitialiseClusterAllocations, *InitialiseParentCapacity*, *CalWeightedCentre*, *CalSquareMaxDInP* and the main Do...Loop follow as previously described above. However, a different sequence of refinements is used in this case, namely:

- *SimpleReassignment*
- *Swap*
- *FullOptimisation*
- *SimpleReassignment*
- *Swap*.

The resulting clustering data is then stored in separate arrays and the location-specific clustering data is restored to its original arrays using *CopyClusteringArrays*. In particular, the:

- number of SDPs in each PDP cluster is stored in *giNumClustersInPDPCluster()*
- total demand served by each PDP is stored in *giPDPClusterCapacity()*
- parent PDP of each SDP is stored in *giClusterToPDPCluster()*.

Subroutine CalculateUnitsOfHighDemand

Location: Found in the *Clustering* module.

Purpose: Calculates the demand served by high-demand cable in each PDP cluster, by identifying the points that are served by high-demand cable. This is stored in the array `giDemandServedByHighDemandCableByPDP()`.

Subroutine IdentifyPDPs

Location: Found in the *Clustering* module.

Purpose: PDP locations are identified as one of the SDP locations in the cluster. The location of the PDP for each PDP cluster is stored in `glPDPClusterMainPoints()`.

For the case of the PDP cluster containing the MDF, the PDP location is defined to be the MDF.

Otherwise, the demand-unweighted centre of all the locations in the PDP cluster is derived using the subroutine *CalUnWeightedPDPclusterCentre*, found in the *Clustering* module.

The SDP location that is closest to this demand-unweighted centre is then defined as the PDP location for that PDP cluster.

The subroutine *ReIdentifyPDP* is identical to *IdentifyPDP* in every respect, except that it recalculates the PDP location for a single PDP cluster, rather than every PDP cluster.

C.2.2 Standard cable SDP cluster spanning tree sub-phase

Having defined the clusters and locations of SDPs and PDPs, the subroutine *ConstructTreeFollowingClusterMainPointIdentification* derives the minimum spanning trees for each cluster. It begins with subroutines *GetMaxPointsInCluster* and *SetupArraysForSpanningTree*, which require information from across all the spanning trees.

Subroutine GetMaxPointsInCluster

Location: Found in the *SpanningTree* module.

Purpose: Identifies the maximum number of points in an SDP cluster across all SDP clusters.

Subroutine SetupArraysForSpanningTree

Location: Found in the *SpanningTree* module.

Purpose: Dimensions the key arrays for the minimum spanning tree process:

- *giUnattachedPoint()* – the list of locations in the cluster that are unattached at any point in the algorithm
- *giAttachedPoints()* – the list of locations in the cluster that are attached at any point in the algorithm
- *giVertexRoute()* – for any location, the location that it passes through in order to get back to the node location
- *gdDistanceMatrix()* – stores the distance between any two points in the cluster
- *gobjEdges()* – stores the vertices and lengths associated with each edge in the spanning tree.

Following these two subroutines, each SDP cluster is then treated individually. The following subroutines are used in order to create and store the calculations:

- *SetupPointsInCluster* – identifies the central point in the cluster
- *SetupGdDistanceMatrix* – calculates the required distances
- *ConstructTree* – constructs the minimum spanning tree for the cluster
- *StoreRoutes* – for each point P, identifies the point P passes through to get back to the node
- *GetTotalDistance* – calculates the total trench within the tree
- *GetSheathLength* – calculates the total standard cable sheath within the tree
- *GetStdCableLength* – calculates the total standard cable pair length within the tree
- *WriteNetworkResults* – writes the list of edges in the spanning tree onto the output worksheet.

Subroutine SetupPointsInCluster

Location: Found in the *SpanningTree* module.

Purpose: Calculates the number of points in the cluster and identifies the node for the cluster (i.e. the SDP location for the SDP cluster) and states this location as the central point *cp*.

Subroutine SetupGdDistanceMatrix

Location: Found in the *SpanningTree* module.

Purpose: For the deployment, calculates the straight-line distance between any two pairs of points and stores these distances in the array *gdDistanceMatrix()*. For any link, the subroutine *UseEuclidean* is used to establish whether it lies along a road or not. If the link lies on the road, then the distance is calculated as Euclidean ('as-the-crow-flies') distance, otherwise the *p*-function is used. The function *TestForRoadCrossing* is also used to identify whether a link crosses a road or not.

► *Subroutine UseEuclidean*

Location: Found in the *CommonCode* module.

Purpose: For two locations with building locations $B1 = (BL_{x1}, BL_{y1})$ and $B2 = (BL_{x2}, BL_{y2})$ respectively and PBP locations $PBP1 = (PBP_{x1}, PBP_{y1})$ and $PBP2 = (PBP_{x2}, PBP_{y2})$ respectively, this subroutine determines whether:

- the line B1-PBP1 and B2-PBP2 are parallel (within a given tolerance)
- the line B1-PBP1 and PBP1-PBP2 are perpendicular (within a given tolerance).

If both are true (and the length of the line PBP1-PBP2 is less than a value $MAXSTRAIGHTROADLENGTH=100$ metres), then *UseEuclidean* is set to true, meaning that the line PBP1-PBP2 is likely to follow a straight road and hence the 'as-the-crow-flies' distance can be used. Otherwise, *UseEuclidean* is set to false, meaning that the p-function should be used to calculate the length RCP1-RCP2.

► *Subroutine TestForRoadCrossing*

Location: Found in the *CommonCode* module.

Purpose: For two locations with road centre points $RCP1 = (RCP_{x1}, RCP_{y1})$ and $RCP2 = (RCP_{x2}, RCP_{y2})$ respectively and PBP locations $PBP1 = (PBP_{x1}, PBP_{y1})$ and $PBP2 = (PBP_{x2}, PBP_{y2})$ respectively, this subroutine determines whether the line RCP1-RCP2 and PBP1-PBP2 are parallel (within a given tolerance) and also whether the length of PBP1-PBP2 is less than a value of $MAXROADWIDTH=25$ metres.

If both are true, then *TestForRoadCrossing* is set to true, meaning that the line PBP1-PBP2 is likely to be a road crossing and is flagged as such. Otherwise, *TestForRoadCrossing* is set to false.

Subroutine ConstructTree

In order to derive the spanning tree for the cluster, the algorithm begins with the central point *cp* identified in *SetupPointsInCluster*. All other locations in the cluster are assumed to be unattached. Locations are then added to the tree incrementally. Each time a location is linked to the tree, it becomes attached and the lists of attached and unattached locations are updated using the function *IdentifyAttachedAndUnattachedPoints*.

► *Subroutine IdentifyAttachedAndUnattachedPoints*

Location: Found in the *SpanningTree* module.

Purpose: Moves through the entire set of points and enumerates them using two arrays, *giUnattachedPoint()* and *giAttachedPoints()*. *giUnattachedPoint(j)=k* means that point *k* is the *j*th point in the list that is unattached. Similarly, *giAttachedPoint(j)=k* means that point *k* is the *j*th point in the list that is attached.

In order to determine which location to join to the tree, the algorithm calculates the average cost per unit of demand of linking an unattached point P to an attached point Q using a trench and a cable on the existing tree. This is determined by the function *AverageCostPerLine*.

► *Subroutine AverageCostPerLine*

Location: Found in the *SpanningTree* module.

Purpose: Determines the extra capacity and the standard cable pair requirements (*c*) needed to serve the unattached point, as well as the length of extra trench distance (*d*) to link the attached and unattached point.

The cost of the new link is then calculated using the proxy cost expression:

$$k_1 \times d + k_2 \times c + k_3 \times d \times c$$

If the attached and unattached point return *TestForRoadCrossing* = TRUE, then a final term is added ($k_4 \times d$). The new cost per unit of demand for the entire tree is then calculated.

By changing the values of k_1 , k_2 and k_3 , different tree configurations can be derived, by changing the relative weight attributed to the cost components. Two examples are shown below in Figure C.1. In the first example, the algorithm effectively minimises the length of trench at all stages ('trench metre minimising'). In the second example, since only the $k_3 \times d \times c$ is nonzero, this is equivalent to minimise the quantity of copper/fibre deployed ('copper/fibre pair metre minimising').

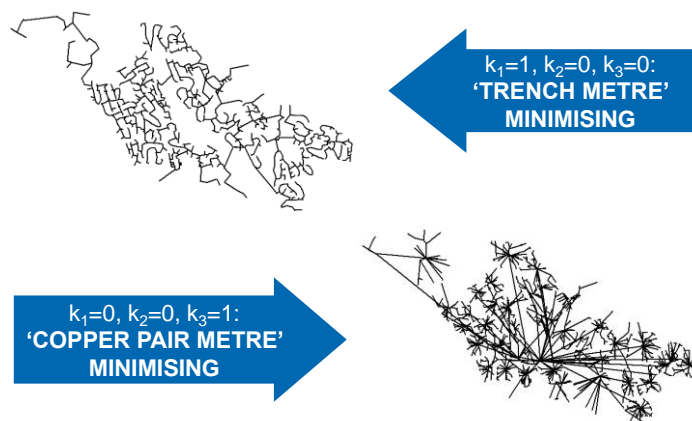


Figure C.1: Illustration of different trees resulting from different proxy functions [Source: Analysys Mason, 2018]

For each unattached point P, the edge to connect each attached point Q to the tree is considered. The edge that gives the lowest new average cost per unit of demand for the whole tree is stored in the array `objEdgeList()` using *AddToEdgeList*.

► *Subroutine AddToEdgeList*

Location: Found in the *SpanningTree* module.

Purpose: Having identified the best edge by which to join a particular point to the existing tree, this subroutine stores the vertices of this edge and its average cost per unit of demand.

Having stored the best edge to link each unattached point P to the tree in `objEdgeList()`, the edge that gives the overall lowest new average cost per line is then permanently added to the tree using *AddCheapestEdgeInListToObjEdges*.

► *Subroutine AddCheapestEdgeInListToObjEdges*

Location: Found in the *SpanningTree* module.

Purpose: Adds the best edge in `objEdgeList()`, in terms of average cost per line, to the list of edges for the minimum spanning tree. Then updates the array `giVertexRoute()` for this new edge in the tree, defined by:

`giVertexRoute(unattached location on new edge) = attached locations on new edge`

Finally, updates the total standard cable length required to link the location all the way back to the node.

The number of unattached points is reduced by 1 and the lists of attached and unattached points are updated using *IdentifyAttachedAndUnattachedPoints*. The loop in *ConstructTree* continues until all locations in the cluster are part of the spanning tree.

Subroutine StoreRoutes

Location: Found in the *SpanningTree* module.

Purpose: For each point P in the cluster, this stores the point Q that is passed back through in order to reach the SDP, with the array defined as `giRouteToCentre(P) = Q`.

Subroutine GetTotalTrenchDistance

Location: Found in the *SpanningTree* module.

Purpose: Calculates the total trench in the spanning tree by cycling through all points P in the cluster and calculating the distance between each point and its predecessor, back to the SDP.

Subroutine GetSheathLength

Location: Found in the *SpanningTree* module.

Purpose: Calculates the total cable sheath in the spanning tree by cycling through all points in the cluster and calculating the distance between each point and its predecessor, back to the SDP. This is multiplied by the sheath requirements for the link given the demand at each point. The total length of sheath is stored separately by number of pairs for the following four types:

- cable for passive ('P') cabinets (i.e. secondary cable in the PDP cluster for the MDF location)
- cable to active ('A') cabinets
- other secondary cable to passive ('P') cabinets
- other secondary cable to active ('A') cabinets.

Subroutine GetStdCableLength

Location: Found in the *SpanningTree* module.

Purpose: Calculates the total standard cable length in the spanning tree by cycling through all points P in the cluster and calculating the distance between each point and its predecessor back to the SDP. This is then multiplied by the standard cable pair requirements given the demand at each point. The total length of pair metres is again stored separately for active cabinets and passive cabinets.

Subroutine WriteNetworkResults

Location: Found in the *SpanningTree* module.

Purpose: Writes the points and their co-ordinates that define every edge in the spanning trees for the SDP clusters in the output worksheet for the service area. Then writes the number of tubes needed, by type, for each edge; determines how many extra manholes are required along these edges; and writes the SDP locations, their co-ordinates and their parent PDP in the output worksheet for the service area.

C.2.3 Standard cable SDP cluster connection sub-phase

This sub-phase is run through the *ConnectClusters* subroutine, which is found in the *SecondaryNetwork* module. This joins up all the SDP locations within a PDP cluster back to the PDP using the subroutine *RunAtClusterLevel*, which is also found in the *SecondaryNetwork* module. This subroutine is only used if there is more than one SDP location in the PDP cluster.

First, the largest number of SDP locations to be found in any PDP is calculated. Then, *RunAtClusterLevel* executes several subroutines:

- *SetUpClusterPairIndex*
- *IndexClusterWithinPDPCluster*
- *SortPairsOfClusters*
- *RoutePointsForCluster*
- *ApplyDijkstra* (contained within the previous subroutine *RoutePointsForCluster*).

Subroutine SetUpClusterPairIndex

Location: Found in the *SecondaryNetwork* module.

Purpose: Indexes pairs of SDPs in a PDP area so that each unordered pair occurs exactly once. The index uses triangular numbers: e.g. for four SDPs, (SDP1,SDP2) → 1, (SDP1,SDP3) → 2, (SDP1,SDP4) → 3, (SDP2,SDP3) → 4, (SDP2,SDP4) → 5, (SDP3,SDP4) → 6.

Subroutine IndexClusterWithinPDPCluster

Location: Found in the *SecondaryNetwork* module.

Purpose: This creates a new indexing *ClusterIndex()* of SDP clusters in a PDP cluster so that they are numbered from 1 to n . For example, if we are looking at the second PDP cluster and the first SDP cluster within this PDP cluster is SDP cluster 100, then *ClusterIndex(1)=100*. An inverse mapping *InverseClusterIndex()* is also stored, to enable movement between the two indices.

Following *IndexClusterWithinPDPCluster*, the SDP that is the PDP location is identified.

Subroutine SortPairsOfClusters

Location: Found in the *SecondaryNetwork* module.

Purpose: For each pair of SDP clusters in this PDP cluster:

- calculates how many unique pairs of points there are which have one point from each SDP cluster
- explicitly identifies these pairs of points, and for each pair, calculates the distance between the two points
- sorts the pairs of points in order of this distance, with the closest pair of points listed first.

Subroutine RoutePointsForCluster

This subroutine is found in the *SecondaryNetwork* module. Its purpose is to calculate, for each pair of SDP locations, the connection, possibly via other SDP locations, that has the lowest cost (according to our proxy cost function).

A linkage between two SDPs can be split into two components: a component that uses only additional trench and a component that uses only existing trench.

The proxy cost function for costing a part of a link that requires new trench assumes additional trench cost. This is calculated using $(M_1 + M_3) \times \text{new trench length } L_N$, where the cost multiplier $M_1 = k_1 + (k_3 \times \text{cabling capacity } C_D^{26})$ and $M_3 = k_4$ when the additional trench link returns *TestForRoadCrossing* = TRUE and $M_3 = 0$ otherwise.

The proxy cost function for costing a part of a link which uses only existing trench assumes no additional trench cost. The cost of this is calculated by using $M_2 \times \text{existing trench length } L_E$, where the cost multiplier $M_2 = (k_3 \times \text{cabling capacity } C_D)$.

These separate cost multipliers $M_1/M_2/M_3$ are calculated for each pair of SDPs and stored in the arrays *dCostMultiplier1()*, *dCostMultiplier2()* and *dCostMultiplier3()*, respectively. As shown above, these multipliers depend on the value of C_D , which itself depends on whether this part of the network is assumed to be tapered or non-tapered, as shown below in Figure C.2.

²⁶ In the case of the PON deployment, this is assumed to be the capacity divided by the splitter ratio.

Figure C.2: Calculation of jointing and C_D [Source: Analysys Mason, 2018]

Assumption of secondary network	C_D	Joints required
Fully tapered	Smallest cable size in the secondary network that accommodates the larger of the demands served by the two SDPs	Smallest cable size in the secondary network that accommodates the larger of the demands served by the two SDPs
Non-tapered	Number of pairs in the appropriate non-tapered cable size used in the secondary network	Equal to the larger of the demands served by the two SDPs

The remainder of *RoutePointsForCluster* then proceeds as follows, for each pair of SDP clusters:

- Identify the pair of points, one from each SDP cluster, which are the closest (at a distance d apart, calculated using the p-function).
- Calculate the sum of the distances D_T of each point in the pair back to their respective SDPs.
- Assume the proxy cost of linking the two SDP clusters together through these points to be $((M_1+M_3) \times d) + (M_2 \times D_T)$.
- For each pair of SDP clusters, identify the pair of points that gives the lowest proxy cost. This gives a fully meshed set of linkages between all SDPs.
- Apply a version of the Dijkstra algorithm using the subroutine *ApplyDijkstra*. This identifies a subset of these linkages that can link all SDPs back to the MDF at the lowest cost.

Subroutine *ApplyDijkstra*

Location: Found in the *SecondaryNetwork* module.

Purpose: Applies the Dijkstra algorithm to derive a least proxy cost route between any SDP cluster and the PDP node, using the calculated mesh of linkages. Sets *Incoming()* for each SDP, by default, to be its own demand (in the case of the PON deployment, this is divided by the splitter ratio). Assumes, provisionally, that all SDPs are connected directly to the PDP. Starts the algorithm with the PDP. For every other SDP, recalls the requirements for linking it to the PDP:

- extra trench
- cost of linking the two SDPs
- cabling cost of linking the two SDPs (i.e. excluding trench cost)
- joints required, using *GetJointingCosts*
total sheath length between them.

Executes the following loop while there are still unconnected SDPs, starting at the PDP:

- for a given connected SDP i , looks through the unconnected SDPs and determines which SDP (j) is the most cost-effective to link directly to SDP i
- updates the array $I_{\text{Incoming}}(i)$, which is defined as the total demand passing through the SDP on the way back to the PDP, to include the demand at j
- for each unconnected SDP, tests to see if its currently identified path to the PDP has a lower proxy cost than if it were to go through i . If the proxy cost is lower, then sets its provisional route back to the PDP to be via i and update $I_{\text{Incoming}}()$ accordingly
- for each unconnected SDP k , the test:
 - calculates all the extra jointing costs of going through SDP i (possibly via other SDPs) back to the PDP, rather than direct
 - determines whether $([\text{total cabling cost of linking } k \text{ to PDP via } i] + [\text{extra jointing costs of linking } k \text{ to PDP via } i] + [\text{the cost of linking } k \text{ to SDP } i]) < \text{cost of linking } k \text{ to the PDP directly}$. If this is true, then it sets the provisional link for k to be via SDP i
- sets i to be the SDP that was just connected (j) and return to the start of the loop.

When all SDPs have been connected back to the MDF, aggregates:

- extra trench to join all SDP clusters in the PDP cluster to the PDP location
- demand-related jointing required
- number of branching kits required
- distance related jointing required (non-tapered case only)
- incremental standard cable sheath required
- incremental standard cable sheath by cable size
- incremental standard cable required
- the routes that SDPs take back to their parent PDP, in `giPreviousClusterBackToPDP()`.

This subroutine also refers to *GetJointingCosts*, which is explained below.

► *Subroutine GetJointingCosts*

Location: Found in the *SecondaryNetwork* module.

Purpose: This identifies the jointing required for a particular link from an SDP i back to the PDP. The calculation depends on whether the network is assumed to be fully tapered or non-tapered:

- In the tapered case, we revise the cabling required on each link required on the path from i back to the PDP based on the cable sizes available to us. The jointing is then aggregated at each SDP on the path that i takes back to the PDP, each time adding on the demand at the SDP and the downstream cable capacity.

- In the non-tapered case, we revise the cabling required on each link required on the path from *i* back to the PDP based on the main and minor cable sizes assumed. The jointing is then aggregated at each SDP on the path that *i* takes back to the PDP, each time adding on the demand at the SDP. A full joint of the cable is only included at regular distance intervals, rather than at every SDP.

The final calculation of jointing is done by the very similar subroutine called *GetJointingAtSDPExcludingDemandWithinSDPitself*, which does not include the pairs jointed onto the SDP from the PBPs within the cluster (these joints are captured elsewhere).

The final step in *ApplyDijkstra* is to calculate the sheath requirements for each link within the PDP cluster, using the subroutine *CalculateTubeByType*.

► *Subroutine CalculateTubeByType*

Location: Found in the *CalculateTube* module.

Purpose: It identifies the number of sheaths by cabling type within each SDP–SDP link in the PDP clusters, as preparation for the derivation of the number of tubes within each link in the subroutine *WriteTubeOutputs*. The total cable cross-sectional area by cabling type within each link is also calculated.

If the cabling within the SDP–PDP network is assumed to be tapered, then one sheath is assumed to be required within each link.

If the cabling within the SDP–PDP network is assumed to be non-tapered, then the sheath requirements are derived through the subroutine *GetNonTaperedSheath*.

For each SDP–SDP link and each edge within these links, the number of sheaths required is calculated and stored as intra-PDP (standard cable) tube.

C.2.4 Standard cable PDP cluster connection sub-phase

The latter part of *ConnectClusters* is also used to drive the connection of PDPs to the MDF. First, the largest number of SDP locations found in any PDP is calculated and the arrays *lClusterIndex()*, *lInverseClusterIndex()*, *lClusterPairIndex()* are resized.

RunAtPDPClusterLevel, which is found in the *PrimaryNetwork* module, then runs the following subroutines:

- *SetUpClusterPairIndex*
- *SortPairsOfPDPClusters*
- *RoutePointsForPDPCluster*
- *ApplyDijkstraForPDPClusters* (within the previous subroutine *RoutePointsForPDPCluster*).

Subroutine SetUpClusterPairIndex

Location: Found in the *PrimaryNetwork* module.

Purpose: This sets up an index for pairs of PDP clusters, so that each unordered pair occurs exactly once. The index uses triangular numbers: e.g. for four PDPs, (P1,P2) → 1, (P1,P3) → 2, (P1,P4) → 3, (P2,P3) → 4, (P2,P4) → 5, (P3,P4) → 6.

Subroutine SortPairsOfPDPClusters

Location: Found in the *PrimaryNetwork* module.

Purpose: For each pair of PDP clusters in the service area:

- calculates how many unique pairs of SDPs there are which have one SDP from each PDP cluster
- explicitly identifies these pairs of SDPs and, for each pair, calculates the distance between the two SDPs using the p-function
- sorts the pairs of SDPs in order of this distance, with the closest pair of SDPs listed first.

Subroutine RoutePointsForPDPCluster

Location: Found in the *PrimaryNetwork* module.

Purpose: Finds the route with the lowest cost for connections between PDP clusters and then connections to the MDF.

This assumes that:

- if the route for a PDP location back to the MDF goes through other PDP clusters, then it passes through their PDP locations
- each PDP-MDF link is a discrete cable.

The proxy cost function when costing linkages with new trench assumes additional trench cost – uses a cost multiplier of $M_1 = k_1 \times + (k_3 \times \text{PDP-MDF cabling capacity } C_D)$, to multiply by the new trench length L_N .

The proxy cost function when costing linkages through existing trenches assumes no additional trench cost – uses a cost multiplier of $M_2 = (k_3 \times \text{PDP-MDF cabling capacity } C_D)$, to multiply by the existing trench length L_E .

When costing the links between any two PDP locations, for each unique pair of PDP clusters:

- the pair of SDPs (with one from each PDP cluster) which are the closest (a distance d apart, calculated with the p-function) is identified
- the sum of their distances back to their respective PDPs, D_T is calculated
- the proxy cost of linking the two PDPs clusters together through these SDPs is then assumed to be $(M_1 \times d) + (M_2 \times D_T)$.

For comparing the costs of linking two PDPs, since the cable capacity between a PDP and the MDF is constant, jointing proxy costs are not included in our sum, so k_2 is not included above.

For each pair of PDP clusters, the pair of SDPs which gives the lowest linking proxy cost is identified.

The jointing cost for each of these best linkages is then added on. This gives us a fully meshed set of linkages between all PDPs. These linkages are stored in the array `C2CEdgePDP()`.

Subroutine ApplyDijkstraForPDPClusters (within subroutine RoutePointsForPDPCluster)

Location: Found in the *PrimaryNetwork* module.

Purpose: Applies the Dijkstra algorithm to derive a route of lowest proxy cost between any PDP and the MDF, using the linkages identified in subroutine *RoutePointsForPDPCluster*.

For every PDP other than the MDF, recalls the requirements for linking it to the MDF:

- extra trench
- cost of linking them
- cabling cost of linking them (i.e. excluding trench cost)
- (effectively) total sheath length between them.

Assumes, provisionally, that all PDPs are connected directly to the MDF.

Starting with the MDF, executes the following loop while there are still unconnected PDPs:

- for a given (connected) PDP i , looks through the remaining unconnected PDPs and decides which PDP (j) is the most cost-effective to link directly to PDP i
- for each unconnected PDP k , tests to see if there is a cheaper proxy cost in linking it back to the MDF by going through i , or via the current provisional path, by
 - calculating all the extra jointing costs of going through PDP i (possibly via other PDPs) back to the MDF, rather than its existing path
 - if $([\text{total cabling cost of linking } k \text{ to MDF via } i] + [\text{extra jointing costs of linking } k \text{ to MDF via } i] + [\text{the cost of linking } k \text{ to PDP } i]) < \text{cost of linking } k \text{ to the MDF directly}$, then set the link for k to be via PDP i
- sets i to be the PDP that was just connected (j) and returns to the start of the loop.

When all PDPs have been connected, calculates:

- total extra trench required to join all PDPs to the MDF
- incremental standard cable sheath required to link the PDP location back to the MDF, for each PDP cluster
- for each PDP, the previous PDP on its way back to the MDF, stored in `glPreviousPDPCentre()`.

C.2.5 High-demand cable determination sub-phase

Having completed the trench network for the standard cable network, the algorithm then seeks to overlay a high-demand cable network to serve the locations of high demand (if any). There are two paths to follow for this section, depending on whether the high-demand cable implementation uses a series of high-demand cable rings or point-to-point connections. These are handled by subroutines *IncludePDPsInHighDemandRingForHighDemand* and *LinkHighDemandCablePointsDirectlyToPDP* respectively, which are both found in the *BuildRing* module.

Subroutine IncludePDPsInHighDemandRingForHighDemand

For the deployment, this subroutine derives a series of high-demand cable rings passing through some or all of the PDP locations. The extra trench and cables required to create these rings is derived. The incremental high-demand cable sheath and cable required to link the high-demand cable-fed locations back to their parent PDP and on to the high-demand cable ring are also calculated.

For each PDP cluster, the number of SDPs is identified. The PDP clusters that are to be included within the high-demand cable rings are then identified: this may be all of them, or it may only be those that serve high-demand cable-fed locations. Those PDPs to be included are flagged using the array `gBolPDPClusterInAHighDemandRing()`.

The subroutine *ClusterNodesForHighDemandRing* groups the identified PDPs into a set of clusters, each one to be served by a ring.

► *Subroutine ClusterNodesForHighDemandRing*

Location: Found in the *BuildRing* module.

Purpose: The data contained within the arrays used in the clustering algorithms is first backed up into local arrays. In particular, the data contained within `gobjInputPoints()` is stored in `objgIndividualPoints_HighDemandRing()`.

The clustering arrays are then re-populated with the data for the PDPs to be put into a high-demand cable ring.

Using the maximum number of nodes that can be in a high-demand cable ring (`glMaxNodesInHighDemandRing`), the number of rings required is then

calculated. This in turn sets the capacity constraint for the high-demand cable ring clustering, by attempting to achieve a balance in the number of PDPs in each ring.

The subroutine *DivisiveClustering*, found in the *Clustering* module, is then used to cluster the PDPs into high-demand cable rings. An effectively infinite distance constraint is used and the design of the clustering algorithms means that the MDF always lies in each of the clusters.

The allocation of each PDP to a high-demand cable ring is then stored in *giPDPClusterToHighDemandRing()* and the clustering arrays are restored to their original values.

Each high-demand cable ring is then mapped onto the array *giHighDemandRingToPDPMapping()*, defined by:

$$giHighDemandRingToPDPMapping(j,k) = kth \text{ PDP in the } i\text{th high demand cable ring}$$

The first PDP in each ring is always defined to be the MDF.

For each ring, the total number of high-demand cables that the ring serves across all of the PDP locations (barring the MDF) is calculated. This assumes a fixed number of high-demand cables (*giHighDemandCablePairsSecondary*) for each location served by high-demand cable. This number is stored in *giTotalHigherDemandOnRing()*.

The subroutine *RunAtHighDemandRingLevel* then identifies the lowest cost linkages between each pair of PDP locations, assuming the existing trench network is used for the standard cable served locations.

► *Subroutine RunAtHighDemandRingLevel*

Location: Found in the *PrimaryNetwork* module.

Purpose: This runs several subroutines similar to those run in the standard cable PDP connection sub-phase. These subroutines are:

- *SetUpClusterPairIndex*
- *SortPairsOfPDPClusters*
- *RoutePointsForHighDemandRing*, as explained below.

► *Subroutine RoutePointsForHighDemandRing*

Location: Found in the *PrimaryNetwork* module.

Purpose: Finds the route of lowest proxy cost for connections between any two PDP clusters.

The proxy cost function when costing linkages with new trench assumes additional trench cost – uses a cost multiplier of $M_1 = k_1 + (k_3 \times \text{SDP-PDP cabling capacity } C_D)$, to multiply by the new trench length L_N .

The proxy cost function when costing linkages through existing trenches assumes no additional trench cost – uses a cost multiplier of $M_2 = (k_3 \times \text{SDP-PDP high demand cabling } C_D)$, to multiply by the existing trench length L_E .

A single estimate of the total high-demand cable used in any PDP–PDP link is made by taking the maximum of the cable sizes required on the high-demand cable rings, estimated using *ProxyCableToUseInHighDemandRing* (described below). This is only used within the proxy cost functions.

When costing the links between any two PDP locations, for each unique pair of PDP clusters:

- identifies the pair of SDPs (with one from each PDP cluster) which is the closest (a distance d apart, calculated with the p -function)
- calculates the sum of their distances back to their respective PDPs, D_T .

The proxy cost of linking the two PDPs clusters together through these SDPs is then assumed to be $(M_1 \times d) + (M_2 \times D_T)$.

For each pair of PDP clusters, identifies the pair of SDPs which give the lowest linking proxy cost. This gives us a fully meshed set of linkages between all PDPs. These linkages are stored in the array *C2CHighDemandRing()*.

► *Subroutine ProxyCableToUseInHighDemandRing*

Location: Found in the *BuildRing* module.

Purpose: This identifies a single high-demand cable size to use for the proxy cost function used to determine the lowest cost paths between any pair of PDP locations.

For each high-demand cable ring, the smallest high-demand cable size that can accommodate the total capacity on that ring is identified. If no single cable size has enough capacity, then the combination of the two largest cable sizes that gives enough capacity is identified. The largest cable requirement across all high-demand cable rings is then used as the single estimate of the required cable size.

For each high-demand cable ring, the following subroutines are then run to determine the best ring formation for the PDPs in the ring:

- *RunTheTSPAlgorithm*
- *UpdateHighDemandCableAndTrenchArrays*
- *TotalTrenchForThisHighDemandRing*
- *TotalCableForThisHighDemandRing*.

► *Subroutine RunTheTSPAlgorithm*

Location: Found in the *RunTSP* module.

Purpose: This uses a Travelling Salesman Problem (TSP) algorithm to derive the most efficient ring structure to join a set of points. Versions of the relevant VB are contained in:

- the modules *InitialiseTSP*, *RunTSP* and *ShortestRing*
- the class modules *clsClusterPair*, *clsRing*, *clsTSPData* and *clsTSPInputData*.

► *Subroutine UpdateHighDemandCableAndTrenchArrays*

Location: Found in the *BuildRing* module.

Purpose: For a given high-demand cable ring, this stores particular data about the high-demand cable ring, including:

- the next PDP in the ring for each given PDP
- whether or not, for each link in the ring, the trench already exists from the standard cable deployment
- the PDP that is first on the ring after the MDF.

► *Subroutine TotalTrenchForThisHighDemandRing*

Location: Found in the *BuildRing* module.

Purpose: Calculates the extra trench required to connect the PDPs in a given high-demand cable ring.

► *Subroutine TotalCableForThisHighDemandRing*

Location: Found in the *BuildRing* module.

Purpose: Calculates the total high-demand cable sheath and cable lengths required to connect the PDPs in a given high-demand cable ring.

For the given high-demand cable ring, the smallest high-demand cable size that can accommodate the total capacity on that ring is identified. If no single cable size has enough capacity, then the combination of the two largest cable sizes that gives enough capacity is identified.

Having calculated the trench and cable requirements for the high-demand cable rings, *IncludePDPsInHighDemandRingForHighDemand* then calculates:

- the high-demand cable sheath needed to join each high-demand cable-fed location back to its parent PDP, by using the same path followed by the standard cable network (each high-demand cable-fed location has a nominal unit of demand served by the standard cable network)
- the high-demand cable length needed to join each high-demand cable-fed location back to its parent PDP on a PDP-by-PDP basis, by multiplying the total PBP–SDP and SDP–PDP high demand cable sheath lengths by their respective assumed high demand cable sizes
- the high-demand cable-specific tube required, using *CalculateHighDemandCableTubeByType* for links back to the PDP and *CalculateTubesForHighDemandCableBackFromPDP* for links from the PDP back to the MDF.

Subroutine LinkHighDemandCablePointsDirectlyToPDP

Location: Found in the *BuildRing* module.

Purpose: This calculates the high-demand cable sheath and cable length requirements for joining each high-demand cable-fed location back to its parent MDF via its parent SDP and PDP. This uses the path determined by the nominal unit of demand assigned to each high-demand cable-served location in the standard cable network.

This function does not need incremental trench, since the existing trench network is assumed to be used as the path back to the MDF.

For the deployment:

- the number of SDPs in each PDP cluster are calculated
- high-demand cable-fed locations are flagged in the array *bolPointFedByFibre()*
- SDPs served only by high-demand cable are flagged by *bolSDPServedByFibre()*
- the high-demand cable sheath needed to join each high-demand cable-fed location back to its parent MDF is calculated by using the same path followed by the standard cable network
- the high-demand cable length needed to join each high-demand cable-fed location back to its parent MDF is calculated for each PDP cluster, by multiplying the total PBP–SDP, SDP–PDP high-demand cable sheath lengths by their respective assumed high-demand cable sizes
- the PDP–MDF high-demand cable sheath length is assumed to be the same as that for the analogous connection in the standard cable network
- the PDP–MDF high-demand cable length is assumed to be the high-demand cable sheath length multiplied by the assumed high-demand cable size in the SDP–PDP part of the network
- a discrete cable is assumed for each high-demand cable-fed location all the way back to the MDF (PTP architecture)

- the amount of high-demand cable-specific tube required is calculated using *CalculateHighDemandCableTubeByType* for links back to the PDP and *CalculateTubesForHighDemandCableBackFromPDP* for the links from the PDP back to the MDF.

► *Subroutine CalculateHighDemandCableTubeByType*

Location: Found in the *CalculateTube* module.

Purpose: This calculates the tube required for the entire route for each high-demand cable from the high-demand cable-fed PBPs back to the PDP.

► *Subroutine CalculateTubesForHighDemandCableBackFromPDP*

Location: Found in the *CalculateTube* module.

Purpose: Where PTP high-demand cable is used, this calculates the tube required for the entire route for each high-demand cable-fed PBP from its parent PDP back to the MDF.

Where high-demand cable rings are used, this calculates the tube required for the entire route for each PDP-PDP link in the ring(s).

C.2.6 Backhaul determination sub-phase

Having calculated the standard cable and high-demand cable networks for a deployment in the service area, the backhaul requirements for each access node are then derived. For example, PDPs may be too far from the MDF to be linked by standard cable, in which case a pair gain system (PGS) is installed and a fibre/wireless link replaces the standard cable link. This is accomplished by the subroutine *DetermineBackhaulForStandardCableServedAreas*.

Subroutine DetermineBackhaulForStandardCableServedAreas

Location: Found in the *MainMacros* module.

Purpose: First, this subroutine analyses the cable between the standard cable nodes and the MDF, in order to remove double-counted cables. This is accomplished using the subroutine *RemoveDoubleBackPrimaryCable* (described below).

Next, it identifies whether each PDP node should be a PGS and, if so, whether it should have fibre, wireless or satellite backhaul. It runs through each PDP in turn:

- the MDF cannot be an PGS, so it is labelled as an MDF
- for all other PDPs, the maximum loop length across all of the locations in the PDP cluster (from PBP to MDF) is calculated

- if this distance is less than a maximum threshold for using a PGS (`gdMaxCableDistanceBeforeUsingPGS`), then a PDP is still used and the jointing required between the PDP and the MDF is derived and stored in `gdPrimaryJointing()`
- if the distance is higher than the threshold, then a PGS is required (meaning that the node is assumed to be active regardless of whether it has been identified as active or passive). The type of backhaul link is then determined as follows
 - if the network either includes all PDPs in a high demand cable ring, or links all PDPs with high demand cable-fed locations into high demand cable rings and the PDP has high demand cable-fed locations, then it will already have a backhaul link via the high demand cable ring. Therefore, the PDP–MDF link is removed, provided that it does not form part of the high demand cable ring
 - for the deployment, PGS are otherwise assumed to be linked to the MDF by fibre, unless a wireless link would be found to be cheaper. Moreover, if the wireless link is found to require more than a certain number of relay stations, then a satellite link is used. In the current version, the costs of a wireless link are assumed to be zero, meaning that a fibre-fed PGS is never deployed (only a wireless or satellite link is ever used).

Having completed the backhaul determination, the nature of each location in the service area can then be finalised using the subroutine *DetermineLocationType* (described below).

► *Subroutine RemoveDoubleBackPrimaryCable*

Location: Found in the *PrimaryNetwork* module.

Purpose: For each PDP cluster in turn, this subroutine considers the route that the cable takes from the PDP back to the MDF. Specifically, it:

- counts the number of times that the cable passes through each link in the route network
- reduces this count where it is more than one to remove instances where the cable doubles back on itself
- adjusts the recorded length of the cable for the PDP in `gdSheathLengthToConnectPDPClusters()` accordingly.

► *Subroutine DetermineLocationType*

Location: Found in the *OutputResults* module.

Purpose: This subroutine identifies all SDP locations, labelling all other locations as PBPs, and then overwrites the main node locations, namely the MDF, the PDPs and the PGS.

C.2.7 Result storage sub-phase

The remaining outputs of the network asset volumes are printed to the output worksheet for the service area by the subroutine *OutputTheResults*.

Subroutine OutputTheResults

Location: Found in the *OutputResults* module.

Purpose: This subroutine prints the remaining network volumes to the output worksheet for the service area in the relevant Access Data workbook.

Specifically, the subroutine:

- calculates the average secondary loop length for each PDP cluster
- prints the network volumes for the cluster containing the MDF
- prints the aggregated volumes for the service area, including
 - trench between PDPs and the MDF
 - high-demand cable sheath for the high-demand cable rings
 - high-demand cable length for the high-demand cable rings
 - number of high-demand cable rings
 - number of relay stations
- prints the network volumes for every other PDP cluster separately, including whether the cabinet contains active equipment or is just passive
- prints the identity of the next PDP on the high-demand cable ring for each PDP, if applicable
- prints the high-demand cable links from the MDF if there is more than one high-demand cable ring (the line for the MDF cluster can only indicate one of these links)
- prints the PDP indices for each SDP cluster
- prints the edges in the spanning trees at the SDP–PDP and PDP–MDF level of the network, using *WriteConnectClustersResults*, as well as the index of the parent PDP and whether that PDP contains active equipment or is just passive
- prints the incremental trench for the high-demand cable rings, using *WriteHighDemandRingResults* (described below)
- calculates the tube requirements for the high-demand cable using *CalculateHighDemandCableTubeByType* (described below) and *CalculateTubesForHighDemandCableBackFromPDP* (described below)
- prints the tube requirements for each link in the route network, using *WriteTubeOutputs* (described below)

- identifies each location as being served by either standard cable or fibre (the VB writes these outputs to those locations that have been included) and also whether its parent cabinet contains active equipment or is just passive
- estimates the cable lengths by cable size, using *CalculateTotalSheathLengthByCableSize*; this is specified separately for cabinets that contain active equipment or are just passive.

► *Subroutine WriteHighDemandRingResults*

Location: Found in the *BuildRing* module.

Purpose: Identifies the incremental trench links required for the high-demand cable rings and calculates the additional manholes required (if any) on these links.

► *Subroutine WriteConnectClustersResults*

Location: Found in the *PrimaryNetwork* module.

Purpose: For each edge in the spanning trees deployed from SDPs to PDPs and PDPs to the MDF, prints properties of the edge to the worksheet in the Access Data workbook.

► *Subroutine CalculateHighDemandCableTubeByType*

Location: Found in the *BuildRing* module.

Purpose: Identifies the number of high-demand cables passing through each link in the secondary network, by cable type.

► *Subroutine CalculateTubesForHighDemandCableBackFromPDP*

Location: Found in the *BuildRing* module.

Purpose: Identifies the number of high-demand cables passing through each link in the primary network, by cable type.

► *Subroutine WriteTubeOutputs*

Location: Found in the *CalculateTube* module.

Purpose: For each link in the trench network, the number of tubes required by type are calculated, determined by how many cables of each type there are passing through the link and the capacity of each type of tube (in terms of either a maximum number of cables per tube, or a maximum cross-sectional area of cabling per tube).

The number of tubes that are provisioned (based on the allowed multiples) is also determined for each link. This is separately calculated assuming an integrated

primary/secondary route network, as well as separate secondary-only and primary-only networks. The length of each link, using either 'as-the-crow-flies' distance or p-function, is also derived.

Finally, the type of manhole required at each SDP location is also determined.

► *Subroutine CalculateTotalSheathLengthByCableSize*

Location: Found in the *OutputResults* module.

Purpose: This estimates the cable lengths by cable size within the SDP clusters:

- for each level of demand, the number of sheaths of each cable size used to serve that demand is stored in the array `glCableRequirementsByDemand()`
- across all locations, the sheath requirements for each cable size are then aggregated in the array `gdSheathLengthByCableSize()`
- the total length required of each cable size is then printed in the output worksheet for the service area
- the sheath length by cable size within the secondary network is also printed to the worksheets in the Access Data workbook, having been pre-calculated in *ApplyDijkstra*.

C.2.8 Assumption storage sub-phase

The assumptions used within the calculation are printed onto the output worksheet for the service area, using the subroutine *RecordAssumptions*.

Subroutine RecordAssumptions

Location: Found in the *CommonCode* module.

Purpose: This prints all of the assumptions used in the calculation of access network asset volumes including:

- capacity and distance constraints for the nodes used in the network
- technical constraints for the high-demand cable rings and standard cable jointing
- cables used in the non-tapered secondary network (if applicable)
- coefficients for the p-function used
- coefficients for the proxy cost function
- cost assumptions used (for the high-demand cable and wireless backhaul cost comparisons for PGS backhaul).

Finally, in order to reduce congestion in the computer's memory, the subroutine *EraseArrays* (found in the *MainMacros* module) uses the Erase statement to clean global arrays populated separately for each service area, releasing the allocated memory.

Annex D Changes to the vAcc2.0D model

There was only one written consultation response, from Telenor, containing three separate comments. A redacted version of this response was published on Nkom's website.²⁷ Their comments were considered in a separate document published by Nkom in February 2016.²⁸

Telenor provided a further response to this document, which was also published on Nkom's website.²⁹ These comments were considered in a separate document published by Nkom in November 2016.³⁰

We have made a number of adjustments to the access model in response to both Nkom's feedback and our own further review of the model. Revisions have been made in the *Network Service Costing-Access* module unless otherwise stated.

D.1 Modelling the copper network based on the number of buildings in 2009

In the v1.7 model, it was assumed that no additional copper network was deployed after 2009 (i.e. the size of the copper network was dimensioned based on the number of buildings in 2009).³¹ This assumption was unintentionally removed from the *Network Service Costing – Access* module when the vAcc2.0D model was developed. This assumption was reinstated in the vAcc2.2 model, by setting the increase in the number of connected buildings to be zero beginning in 2010 for the copper calculation. This is implemented on the *A3NwDsFrcst* worksheet.

D.2 New model switches

We have added the ability to the vAcc2.2 model to:

- Choose a single depreciation method for all assets using a single input parameter. A new input cell on the *A1Ctrl* worksheet selects whether or not the global depreciation method is applied to all assets. If the switch is set such that the global method is not used, then the model uses the individual depreciation methods for each asset as input in the *A4AssetIn* worksheet as before.

²⁷ See http://www.nkom.no/marked/markedsregulering-smp/kostnadsmoeller/lric-fastnett-aksess/_attachment/21187?_download=true&_ts=151578a794f

²⁸ See https://www.nkom.no/marked/markedsregulering-smp/kostnadsmoeller/lric-fastnett-aksess/_attachment/22394?_download=true&_ts=152cb586297

²⁹ See http://www.nkom.no/marked/markedsregulering-smp/kostnadsmoeller/lric-fastnett-aksess/_attachment/23045?_download=true&_ts=153cbb79b71

³⁰ See https://www.nkom.no/marked/markedsregulering-smp/kostnadsmoeller/lric-fastnett-aksess/_attachment/25893?_download=true&_ts=158484a7d96

³¹ See the v1.7 Network Design – Access module, cells A1Ctrl!D67:D82 (can be downloaded at http://www.nkom.no/marked/markedsregulering-smp/kostnadsmoeller/lric-fastnett-aksess/_attachment/3963?_download=true&_ts=13a885c7d51)

- Set the current regulatory asset lifetimes equal to the economic lifetime for each asset. This is done with a switch in cell D130 of the *AICtrl* worksheet which drives the selected values on the “A4AssetIn” worksheet

D.3 Households forecast

Line 10 of the *A2 Market demand* worksheet in the Market module indicates a large increase in the number of households in Norway between 2012 and 2013. This represents a year-on-year household growth of just over 4% whilst most other years show a growth of between 1% and 2%. The higher figure is largely due to a change in methodology employed by SSB. Prior to 2013, students that were registered at their parents' address we considered part of that household, even if they spent the majority of the year living elsewhere (i.e. at an address closer to where they study).³² The new methodology employed by SSB places all students who are known to live away from their parents' home in other households through a combination of known addresses and statistical modelling³³. This contributes to an increase in the overall number of households.

Since the historical data was effectively underestimating the number of households, we find it appropriate to retain this forecast.

D.4 Change to DTT forecast

In the vAcc2.0D model, the proportion of Pay TV connections which were served by DTT was forecast to increase between 2014 and 2020 despite the fact that the proportion has consistently fallen since 2010. The forecast has been updated in the *Market* module of the vAcc2.2 model to continue the decreasing share of DTT to 2020. A comparison of the old and new forecasts is shown below.

³² 2013 data refers to statistics published on 1 January 2014

³³ See <https://www.ssb.no/en/befolkning/statistikker/familie/aar/2014-12-12?fane=om#content>

Figure D.3: Pay-TV connections served by DTT
[Source: vAcc2.0D model, 2018]

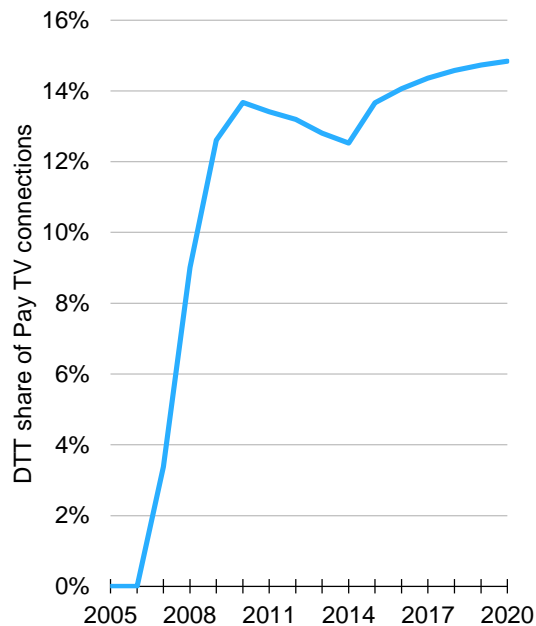
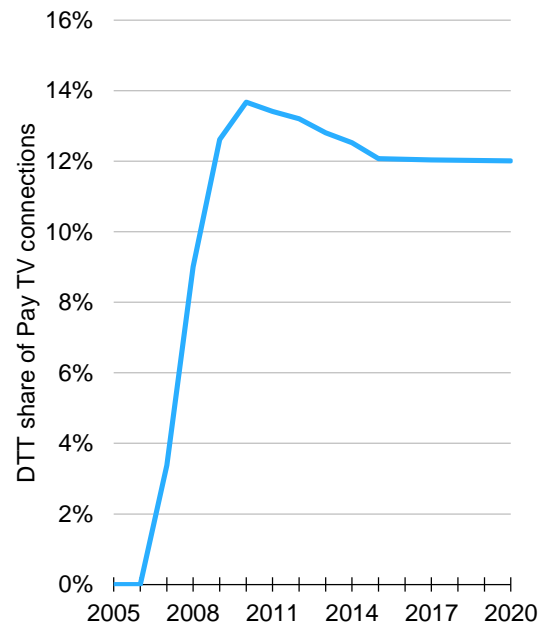


Figure D.4: Pay-TV connections served by DTT
[Source: vAcc2.2 model, 2018]



This revision has no impact on any cost results from Nkom's LRIC models, since only the forecast of IPTV connections is relevant to the traffic and subscriber forecasts for the modelled networks.

D.5 Amendments to cost trends

These are also described in Section 6.3.5.

The cost trend for copper cabling from 2010 onwards has been re-calculated using data from the indexmundi website using the time series from 2010 onwards. This has led to the revised value of 0% in the vAcc2.2 model. The cost trend for trenches from 2010 onwards has been similarly updated to 0.1%.

The cost trend for distribution points from 2010 onwards has been updated based on a benchmark of other cost models to a value of 0%.

The calculation that applies cost trends on the *B7Capex* worksheet has also been corrected.

D.6 Update to demand

As described in Section 4, the demand parameters have been further updated to include 2015 and 2016 actuals, as well as revisiting the forecasts if required.

D.7 Other corrections

- In the *Market* module of the vAcc2.0D model, the calculation of the “Share of the fibre market of other relevant NGA connections” was inconsistent with that on the *PUBLIC_TN* worksheet. The two calculations have now been fully aligned
- The switch to de-activate reuse of assets on the *AICtrl* worksheet was not being applied for the FTTN/VDSL case. This has been corrected
- A 25-year purchasing schedule was added on the *A6ReUse* worksheet for use by assets with 25-year lifetimes
- PGS cabinets were not being deployed on the *BIFullNw* worksheet in the vAcc2.0D model when FTTN/VDSL was activated. This has been corrected so that FTTN/VDSL active cabinets are deployed at these locations as well. The calculation of jointing enclosures has also been corrected to ensure the corresponding enclosures have been calculated
- GPON: ONT connections were being erroneously deployed when the vAcc2.0D model was dimensioning a PTP FTTH network: these have been removed
- We have added a calculation for calculating the costs of shared LLU on the *C2CostByService* worksheet. This uses the LRAIC+ for full LLU and full SLU and a shared cost percentage figure to calculate the total cost which should be borne by shared services (assumed to be 50%)
- The routing factors for SLU services and PGS-related assets have been corrected on the *B4RF* worksheet
- The WACC has been updated based on a new calculation by Thore Johnsen
- The inflation time series has been updated based on the most recent actuals and forecasts by Norges Bank
- The State Aid value linked into the *A4AssetIn* worksheet has been corrected so that it (i) it is now also included for the FTTN/VDSL case and (ii) is flat in nominal terms.

D.8 Amendments to the calculations of the RAB

Following additional feedback from Telenor in response to the document published in February 2016 (see Annex D), we have made some adjustments to the *A6Reuse* and *A7ResidualValueCopper* worksheets. These changes were made to the vAcc2.0F model to derive the vAcc2.2 model.

The adjustments define a RAB for the relevant assets (the whole network in the case of copper and the RCEA in the case of NGA networks). This RAB is defined as beginning in a chosen year (specified on the *AICtrl* worksheet; in the case of the vAcc2.2 model defined to be 2017). Indexation is then applied to the residual value of the RCEA going forward. Whether the residual value is

calculated using HCA, CCA OCM or CCA FCM is still a choice (set to be HCA in the vAcc2.2 model) on the *A1Ctrl* worksheet.

The residual value is then depreciated going forward using either a tilted annuity or CCA FCM depreciation. Therefore, in the vAcc2.2 model, we take the HCA NBV as the starting point for the RAB, but then depreciate this value over the remaining lifetime using either CCA FCM or tilted annuity depreciation.

The calculation works as follows for each asset (assuming a 2017 start date for the RAB):

- (1) Take the calculated year-beginning 2017 HCA NBV as the opening RAB value
- (2) Derive the remaining economic lifetime as of the year-beginning 2017
- (3) Calculate the 2017 return of capital (depreciation) using the opening RAB value and the remaining economic lifetime
- (4) Increase the 2017 opening RAB value using inflation and subtract the 2017 return of capital to get the 2017 closing RAB (and therefore 2018 opening RAB)
- (5) Reduce the remaining lifetime by 1 year to get the remaining economic lifetime in 2018
- (6) Repeat steps (3)–(5) for each asset for future years until its remaining lifetime reaching zero.

The RAB is therefore being indexed each year based on inflation and the return of capital can be shown to fully recover the residual NBV within the remaining lifetime in present value terms. This is since:

$$\text{Opening RAB (year } n+1) = \text{Opening RAB (year } n) \times (1 + \text{nominal WACC}) - \text{Capital charge (year } n)$$

This is the same as indexing the RAB using inflation, since

$$\text{Opening RAB (year } n+1) = \text{Opening RAB (year } n) \times (1 + \text{nominal WACC}) - \text{Capital charge (year } n)$$

$$= \text{Opening RAB (year } n) \times (1 + \text{inflation}) - [\text{Capital charge (year } n) - \text{Opening RAB (year } n) \times \text{real WACC}]$$

$$= \text{Opening RAB (year } n) \times (1 + \text{inflation}) - [\text{Capital charge (year } n) - \text{ROCE (year } n)]$$

$$= \text{Opening RAB (year } n) \times (1 + \text{inflation}) - [\text{Capital charge (year } n) - \text{Depreciation (year } n)]$$

For each RCEA, the total capital charge for the selected year (i.e. return of capital, plus return on capital employed, or ROCE) that has been calculated on the *A6Reuse/A7ResidualValueCopper* worksheets is then assumed to be recovered in that selected year.

Annex E Responses to feedback on the vAcc2.2 model

A total of seven consultation responses were received from four industry parties (Broadnet, Get TDC, NextGenTel and Telenor). This included consultation responses from Broadnet, NextGenTel and Telenor, with additional comments on those hearing responses from all three parties plus comments from Get TDC. A redacted version of each of these responses can be found on Nkom's website.³⁴ Within these responses, some of the material was in relation to the cost models, which we summarise below by topic. The feedback related to the modelling can be grouped into five issues:

- use of historical cost accounting (HCA) to determine the depreciated value of the copper assets in the Regulated Asset Base (RAB)
- behaviour of results from the copper network calculation
- outputs of the bitstream modelling
- outputs of the SLU modelling
- other comments related to the modelling.

We consider each of these issues in turn below.

E.1 Use of HCA to determine the depreciated value of the copper assets in the RAB

Telenor provided feedback on this issue from Section 4.4.1.1 of its response. We set out the relevant text from Telenor's response below, before providing our response.

E.1.1 Feedback from Telenor

Telenor finner Nkoms metode for å fastsette pristak for kobberaksess problematisk. Først og fremst gjelder dette bruk av historisk kost for å fastsette verdi av gjenbrukbar infrastruktur.

Som fremholdt i konsultasjon rundt LRIC-modellen og i senere kommunikasjon anser Telenor Nkoms valg av historisk kost som metode for å fastsette verdi av gjenbrukbar infrastruktur¹² for å bryte med EUs anbefaling for hvordan modeller for faste aksessnett skal utformes¹³. Dette valget er videre uheldig i og med at det fører til (fortsett) underkompensasjon av Telenors aksesslinjer, samt ukorrekte prissignaler i markedet.

EU Rekommandasjonen er klar på at metoden for å fastsette verdi av gjenbrukbar infrastruktur i Regulatory Asset Base (RAB) skal være gjenanskaffelseskost, og spesifiserer også at indeksmetoden skal anvendes for å beregne gjenanskaffelseskost¹⁴. Dette anerkjenner også Nkom (Varsel Marked 3a, punkt 495).

³⁴ See <https://www.nkom.no/marked/markedsregulering-smp/anbefaling-2016/marked-3a>

Nkoms velger likevel å avvike fra Rekomendasjonen. Dette begrunnes i at Telenor har historisk blitt regulert på historisk kost, og at en overgang til gjenanskaffelseskost vil medføre en overkompensasjon for Telenor.

Nkom, postulerer videre at hensynet til å unngå dette veier tyngre enn ulempene ved regulering basert på historisk kost, i første rekke fraværet av korrekte Build/Buy prissignaler. Det er flere problemer med premissene for denne argumentasjonen, som diskuteres i seksjonen under.

4.4.1.1.1. Historisk bruk av HCA-regulering i aksessnettet

I Varsel om vedtak marked 3a, punkt 480, redegjør Nkom for den historiske prising og reguleringen av Telenors LLU produkt, og kan oppsummeres som følger:

- 2000-2006: Pris/regulering basert på gjenanskaffelseskost
- 2006-2009: Pris/regulering basert på historisk kost
- 2009-: Pris/regulering satt ut fra «helhetsvurdering, men med hovedvekt på informasjon fra kostnadsregnskapet fra Telenor».

Ut i fra dette konkluderer Nkom at LLU har blitt priset på historisk kost siden 2006, og Nkoms konsulent Analysys Mason konkluderer at LLU-prisen i perioden har vært på eller høyere enn historisk kost i mesteparten av perioden.

Telenor deler ikke helt dette synet. Kun i perioden 2006-2009 var Telenors LLU faktisk regulert til historisk kost. I perioden 2009 frem til i dag har den blitt fastsatt utfra Nkoms subjektive vurdering, og samsvaret med historisk kost er vagt.

Perioden da LLU var priset ut ifra historisk kost var svært kort, også kortere enn perioden da gjenanskaffelseskost var basis for prisingen. Dette må sees i sammenheng med de svært lange levetidene til de underliggende infrastrukturaktiva som er typisk 30 eller 50 år. Således representerer prisene fra perioden da historisk kost var i bruk kun en liten andel av kostnadsinndekningsperioden. Dette gjelder også om man aksepterer argumentet at prisene også i perioden 2009-17 var basert på historisk kost.

Varigheten av bruk av historisk kost er imidlertid mindre viktig enn hvor i livssyklusen infrastrukturaktivaene befant seg da historisk kost ble anvendt, som vist i neste seksjon.

4.4.1.1.2. Overkompensasjon av netteier ved overgang fra historisk kost til gjenanskaffelseskost

(1) Det sentrale elementet i Nkoms argumentasjon for å avvike fra EU rekommandasjonen er at det vil oppstå en overkompensasjon av Telenor dersom gjenanskaffelseskost i stedet for historisk kost tas i bruk i prisreguleringen.

(2) Nkom viser her til notat fra Analysys Mason, som demonstrerer at nåverdien av kostnadsinndekning er den samme under historisk kost (HCA) og gjenanskaffelseskost (CCA). Notatet viser videre at i et eksempel med et typisk infrastrukturelement vil verdien

under CCA være større enn under HCA midt i livssyklusen, og følgelig vil en endring fra HCA til CCA på dette tidspunktet medføre et «windfall» eller en overkompensasjon til netteier.

(3) Telenor er enig i at CCA og HCA gir samme nåverdi av kostnadsinndekning dersom aktivaene holdes gjennom hele sin livssyklus. Under HCA vil kostnadsdekningen tidlig i livssyklusen være relativt større, og i slutten av livssyklusen være relativt mindre enn tilfellet er for CCA. I sum vil nåverdiene for de to være like.

(4) Dermed er det slik at dersom en netteier får kompensert i form av HCA for et aktivum i første delen av aktivumets livssyklus, og CCA i siste del, vil netteieren bli overkompensert.

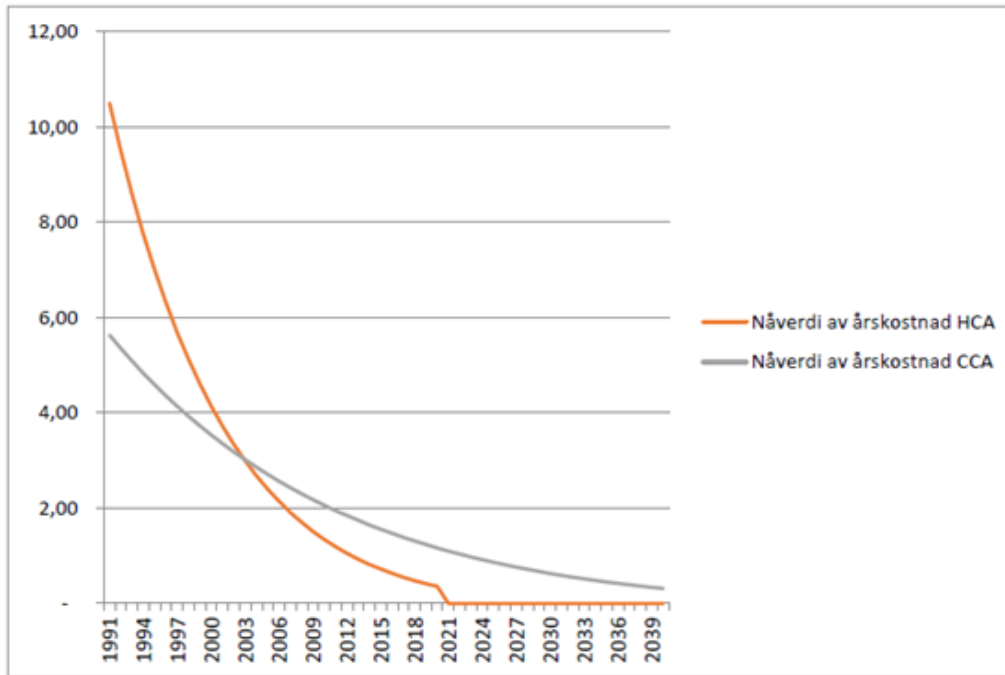
(5) Imidlertid er ikke dette beskrivende for situasjonen rundt prising av LLU i Norge. Premisset om at netteier har fått en høy kompensasjon gjennom HCA i fortiden er ikke til stede. De underliggende infrastrukturaktiva er i høy grad modne, og har i gjennomsnitt blitt installert lenge før LLU produktet ble tilgjengelig i Norge i 2000. Vi har derfor i hele perioden med et tilgjengelig LLU produkt befunnet oss i slutten av infrastrukturaktivaenes (gjennomsnittlige) livssyklus. Altså den delen av livssyklusen der HCA kompenserer mindre enn CCA.

(6) Følgelig har ikke Telenor mottatt den høye kompensasjon i fortiden som ville medføre at en overgang fra HCA til CCA gå overkompensasjon. Denne skulle eventuelt ha blitt hentet i perioden før LLU kom som et produkt.

(7) Dette kan illustreres i det følgende:

(8) Som eksempel bruker vi en noenlunde representativ hypotetisk komponent i infrastrukturnettverket som ble anskaffet i 1990 til pris 100. Pristrend er 4% per år, og WACC er 8%. Under HCA er livslengden 30 år; under CCA er den 50 år.

(9) Grafene under viser kostnadsdekning per år for denne komponenten per år under henholdsvis HCA og CCA.



(10) Som det går frem av grafen, så er det kun i de første 12 årene av komponentens livssyklus HCA gir høyere kompensasjon enn CCA. I dette tilfellet innebærer det perioden da LLU enten ikke var tilgjengelig eller ble solgt under CCA-orienterte priser.

(11) Da HCA-orienterte priser ble innført i 2006 og i senere år har dette gitt mindre kompensasjon enn CCA. I denne situasjonen, som er typisk for komponentene i Telenors infrastruktur, gir det ikke mening om å snakke om en overkompensasjon ved overgang til CCA fra HCA.

(12) At Telenors infrastruktur befinner seg og har befunnet seg i slutten av livssyklusen lar seg vise i aldersinformasjon for Telenors infrastrukturaktiva tilsendt Nkom i forbindelse med utvikling av LRIC-modellen i 2015.

(13) Dette demonstreres ytterligere gjennom kostnadsresultatene fra Nkoms LRIC-modeller i de årene disse har vært tilgjengelige (fra 2010), som uten unntak har gitt høyere resultater enn det HCA orienterte kostnadsregnskapet og de regulerte LLU-prisene.

(14) Dette gjelder også i perioden 2006-2009, siden LRIC modellene gir resultater også for tidligere år.

(15) Argumentet om at Telenor vil motta overkompensasjon ved bruk av CCA i nåværende regulering er derfor ikke gyldig.

(16) Det stemmer fortsatt at en overgang mellom HCA og CCA medfører et brudd, og at nåverdien kostnadsinndekningen sett fra anskaffelsesåret vil øke ved overgang til CCA. Dette representerer imidlertid ikke en overkompensasjon/windfall. Tvert imot representerer det en

delvis reversering av underkompensasjonen som fulgte det forrige metode-skiftet - nemlig overgangen til HCA-orientert prisregulering fra 2006 og utover.

(17) Ettersom verdsettelsesmetode som underbygger prisingen allerede har blitt endret flere ganger i løpet av LLU-produktets eksistens, vil ikke bruk av HCA i fremtidig regulering medføre noen bedret konsistens.

E.1.2 Response by Analysys Mason to Section 4.4.1.1.1

There are two paragraphs where we provide comment.

Telenor deler ikke helt dette synet. Kun i perioden 2006-2009 var Telenors LLU faktisk regulert til historisk kost. I perioden 2009 frem til i dag har den blitt fastsatt utfra Nkoms subjektive vurdering, og samsvaret med historisk kost er vagt.

Regarding this point, we have reviewed the annual regulatory accounts submitted by Telenor over the period 2006–2016 in relation to Telenor’s subscriber-related operatøraksess products, of which LLU is a part. ✗.

We would therefore consider this as good evidence that Telenor was not undercompensated for LLU in the period 2009 to the present day.

Perioden da LLU var priset ut ifra historisk kost var svært kort, også kortere enn perioden da gjenanskaffelseskost var basis for prisingen. Dette må sees i sammenheng med de svært lange levetidene til de underliggende infrastrukturaktiva som er typisk 30 eller 50 år. Således representerer prisene fra perioden da historisk kost var i bruk kun en liten andel av kostnadsinndekningsperioden. Dette gjelder også om man aksepterer argumentet at prisene også i perioden 2009-17 var basert på historisk kost.

Section 6 of our December 2017 report on copper modelling³⁵ states that, implicitly, all products using the copper access network should use the same basis of cost recovery. Moreover, the cost recovery over the last 50 years or so is relevant.

In that time, a replacement cost (not just a CCA) regime was only in place for the period 2000–2006. Telenor’s regulatory accounts have largely been based on HCA, and its statutory accounts over that time will have also been based on HCA. Therefore, prior to 2000, cost recovery must have been according to HCA principles, meaning that, for the vast majority of the lifetime of the network, HCA principles have been applied.

³⁵ Analysys Mason (2017), *Modelling the costs of copper networks in the Norwegian context*. Available at https://www.nkom.no/lover-og-regler/forskrifter/_attachment/31907?_ts=160f938e58d, Section 3.

E.1.3 Response by Analysys Mason to Section 4.4.1.1.2

Telenor makes several claims throughout this section. We consider these individually in the following subsections.

► *Paragraph 4*

Dermed er det slik at dersom en netteier får kompensert i form av HCA for et aktivum i første delen av aktivumets livssyklus, og CCA i siste del, vil netteieren bli overkompensert.

We agree with Telenor on this point. This is an example of the kind of ‘windfall gain’ that we are trying to avoid. However, this statement is not true if the net book value (NPV) is preserved at the point that the change in the depreciation method occurs, as in our modelling approach.³⁶

We also note that, as stated in Section 6.4 of the model documentation and Section 5 of our December 2017 report on copper modelling, the change in depreciation method proposed is from HCA to tilted annuity within the RAB, and not from HCA to CCA.

► *Paragraphs 5 and 6*

Imidlertid er ikke dette beskrivende for situasjonen rundt prising av LLU i Norge. Premisset om at netteier har fått en høy kompensasjon gjennom HCA i fortiden er ikke til stede. De underliggende infrastrukturaktiva er i høy grad modne, og har i gjennomsnitt blitt installert lenge før LLU produktet ble tilgjengelig i Norge i 2000. Vi har derfor i hele perioden med et tilgjengelig LLU produkt befunnet oss i slutten av infrastrukturaktivaenes (gjennomsnittlige) livssyklus. Altså den delen av livssyklusen der HCA kompenserer mindre enn CCA.

Følgelig har ikke Telenor mottatt den høye kompensasjon i fortiden som ville medføre at en overgang fra HCA til CCA gå overkompensasjon. Denne skulle eventuelt ha blitt hentet i perioden før LLU kom som et produkt.

We are not concerned with just the period when the LLU product was available, but rather with cost recovery across the whole lifetime of the access network. At any time, different services using the same parts of the network in the same way should have to use the same basis of cost recovery. This is not just a practical point. If the internal and external use of these assets were costed differently (e.g. if Telenor’s retail products were charged less for the use of the asset than for LLU), then this would be a significant breach of non-discrimination.

As described in our response to Section 4.4.1.1.1, before 2000, services will have been implicitly costed using HCA principles, as Telenor itself indicates in the last sentence of paragraph 6.

³⁶ We note that this point regarding how costs must be recovered when changing depreciation during an asset cycle (by calculating the residual value of the asset first) has also been referenced in the recent pricing process for copper unbundling in France. See the report by WIK, available from: http://www.wik.org/fileadmin/Studien/2016/Final_Report_Pricing_to_Iliad_Bouygues_2016_07_07.pdf, page 27.

► Paragraphs 7, 8, 9 and 10

Dette kan illustreres i det følgende:

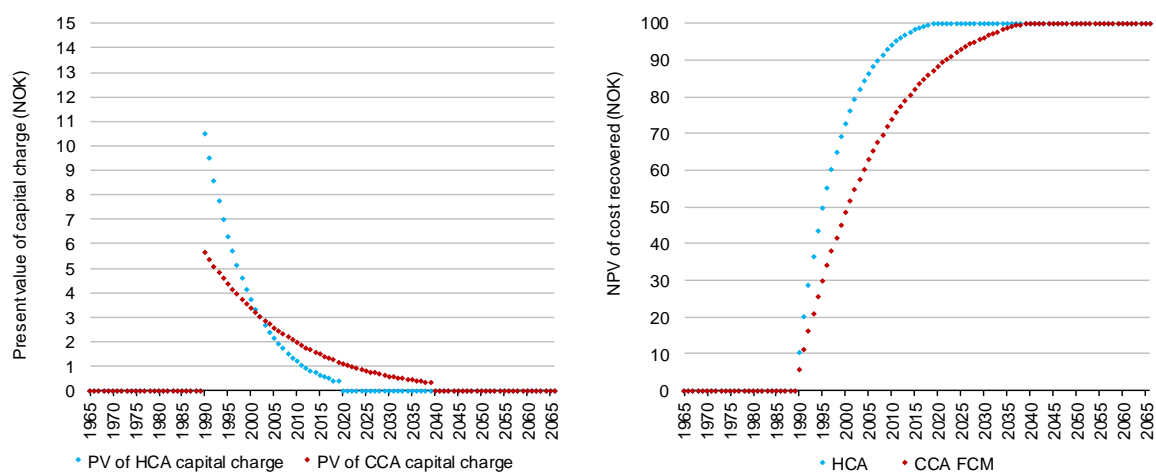
Som eksempel bruker vi en noenlunde representativ hypotetisk komponent i infrastrukturnettverket som ble anskaffet i 1990 til pris 100. Pristrend er 4% per år, og WACC er 8%. Under HCA er livslengden 30 år; under CCA er den 50 år.

Grafene under viser kostnadsdekning per år for denne komponenten per år under henholdsvis HCA og CCA.

Som det går frem av grafen, så er det kun i de første 12 årene av komponentens livssyklus HCA gir høyere kompensasjon enn CCA. I dette tilfellet innebærer det perioden da LLU enten ikke var tilgjengelig eller ble solgt under CCA-orienterte priser.

We have replicated Telenor's calculation for its stylised asset purchased in 1990. Figure E.1 below shows a comparison of the discounted capital charges (present value or PV) as shown by Telenor (left chart) and the NPV of total costs recovered (right chart).

Figure E.1: Reproduction of Telenor's calculation using a hypothetical asset bought in 1990 [Source: *Analysys Mason, 2018*]



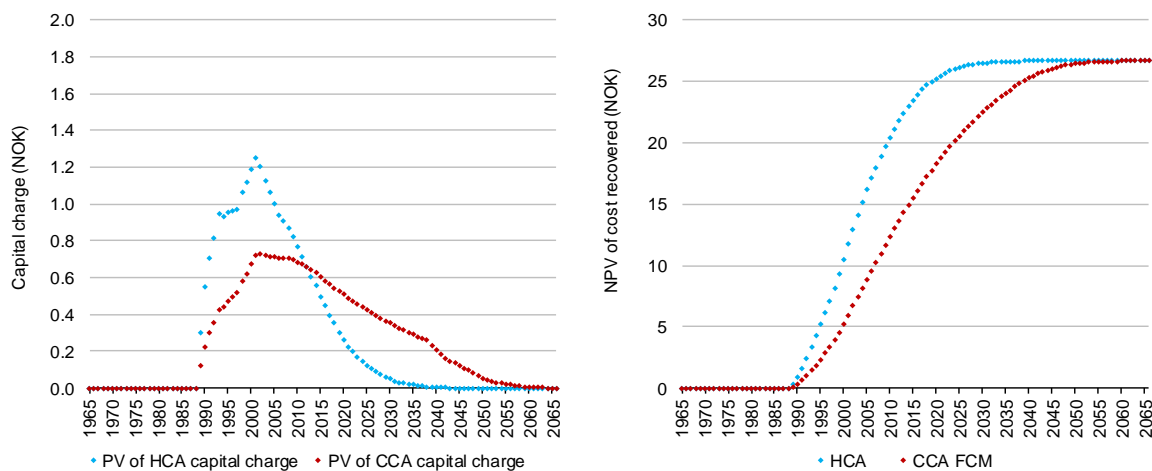
As described in Section 3 of our December 2017 report on copper modelling, the NPV of the total costs recovered is more relevant in economic terms than the individual PVs (i.e. discounted values) recovered in each year. As can be seen above in Telenor's example, even though the PV of the in-year CCA capital charges starts to exceed that for HCA in 2002, the NPV of costs recovered derived using HCA remains higher than that for CCA until the very end of the asset lifecycle (meaning that a move from HCA to CCA without taking this into account causes a windfall gain).

Telenor's example is not 'fairly representative' as it claims, since in reality the assets were purchased over time. Figure E.2 below indicates the capital charges and NPV of the total costs recovered for a set of assets purchased according to the asset age distribution provided by Telenor. In particular,

assuming a lifetime of 30 years and a RAB beginning in 2018, all assets purchased before 1988 are assumed to be fully depreciated according to the accounts, and therefore can be disregarded.³⁷ Consequently, the charts below only consider those assets purchased from 1988 onwards.

While the PV of the CCA capital charges only overtakes that for HCA in 2013, again the NPV of the total costs recovered always remains ahead of CCA until the very end of the asset lifecycle, due to the positive cost trends. Therefore, as we described in our December 2017 report on copper modelling, in these circumstances of a positive cost trend there will always be a windfall.

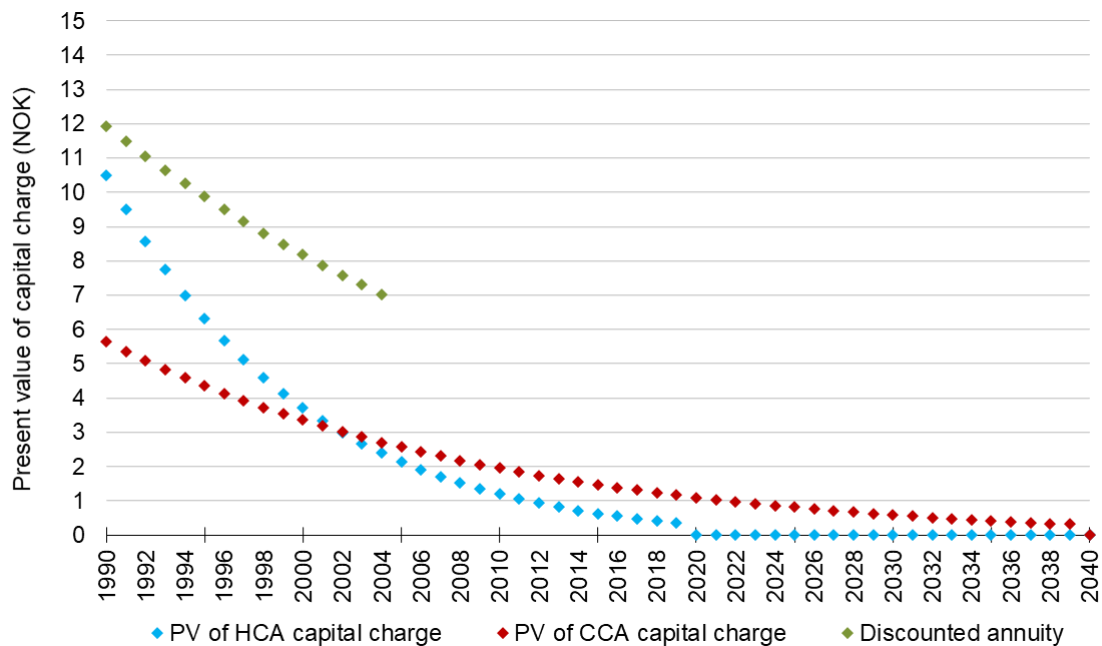
Figure E.2: Reproduction of Telenor's calculation, but using the asset age distribution provided by Telenor instead of assuming a one-off purchase in 1990 [Source: Analysys Mason, 2018]



Moreover, we understand the assumed lifetimes in the ‘replacement cost’ standard annuity regime were at most 15 years for the network assets in the period 2000–2006. 15 years is far shorter than the lifetimes assumed in either the HCA regulatory accounts or our proposed modelled economic lifetimes. Using Telenor’s “example asset purchased in 1990” calculation but assuming a 15-year lifetime would lead to the annuity charges (15-year) exceeding both HCA (30-year) and CCA (50-year) before the 15-year lifetime expired in 2005 (assuming no asset replacement). In other words, the recovery was not lower than HCA in this period. This is shown in Figure E.3 below.

³⁷ It could be argued that a 50-year economic lifetime be considered rather than the 30-year accounting lifetime in order to determine the fully depreciated assets. This would mean only excluding all assets before 1968. In this case, the PV of the CCA capital charges would overtake those for HCA in 1996. However, we do not consider this to be a realistic consideration, since we do not believe that a lifetime of over 30 years has ever been considered for these network assets, at least until Nkom’s cost model of fixed access networks was first developed in 2009.

Figure E.3: Reproduction of Telenor's calculation using a hypothetical asset bought in 1990, with the additional case of a 15-year lifetime replacement cost flat annuity [Source: Analysys Mason, 2018]



► *Paragraph 11*

Da HCA-orienterte priser ble innført i 2006 og i senere år har dette gitt mindre kompensasjon enn CCA. I denne situasjonen, som er typisk for komponentene i Telenors infrastruktur, gir det ikke mening om å snakke om en overkompensasjon ved overgang til CCA fra HCA.

We understand that Telenor believes it experienced a windfall loss from moving back to HCA in 2006. In reality, it would require additional modelling to estimate the different windfall gains and losses as this depends on how heavily depreciated the assets were when the transitions from HCA to CCA and from CCA to HCA happened in 2000 and 2006, respectively.

However, as described above, we observe that the replacement cost flat annuity regime in place during 2000–2006 used far shorter lifetimes than the HCA regime that superseded it. As illustrated in Figure E.3, the annuity regime would most likely have led to much higher compensation in those years, before reverting back to the HCA regime in 2006. Therefore, it is entirely possible that Telenor experienced higher than HCA compensation for the 2000–2006 period, which would more than compensate (because it would be better off than if it had remained on HCA for the entire period).

► *Paragraphs 12, 13 and 14*

At Telenors infrastruktur befinner seg og har befunnet seg i slutten av livssyklusen lar seg vise i aldersinformasjon for Telenors infrastrukturaktiva tilsendt Nkom i forbindelse med utvikling av LRIC-modellen i 2015.

Dette demonstreres ytterligere gjennom kostnadsresultatene fra Nkoms LRIC-modeller i de årene disse har vært tilgjengelige (fra 2010), som uten unntak har gitt høyere resultater enn det HCA orienterte kostnadsregnskapet og de regulerte LLU-prisene.

Dette gjelder også i perioden 2006-2009, siden LRIC modellene gir resultater også for tidligere år.

Telenor's asset age distribution indicates that the copper network is, on average, quite old (with an average age of approximately 38 years), although this value is still lower than the assumed economic lifetime of 50 years.

Telenor's statement that Nkom's previous LRIC model in historical years (we assume this is the v1.7 model that Telenor is referring to)³⁸ invariably has given higher results than the HCA-oriented cost accounts is not quite true, in that it is not inevitable that the results will be higher than the HCA-oriented cost accounts. This model uses a multi-year economic depreciation of the copper network costs over time, and there are more complicated multi-year dynamics arising that limit the comparability of that model to previous LLU pricing.

► *Paragraph 16*

Det stemmer fortsatt at en overgang mellom HCA og CCA medfører et brudd, og at nåverdien kostnadsinndekningen sett fra anskaffelsesåret vil øke ved overgang til CCA. Dette representerer imidlertid ikke en overkompensasjon/windfall. Tvert imot representerer det en delvis reversering av underkompensasjonen som fulgte det forrige metode-skiftet - nemlig overgangen til HCA-orientert prisregulering fra 2006 og utover.

Telenor states that the valuation increases at the point that CCA is used, but then that it partly compensates a previous windfall from moving from CCA to HCA in 2006.

The translation may be slightly unclear – Telenor appears to argue that this is not a windfall (which is false), or perhaps that it is not an “*excessive windfall*”. As noted above, it is hard to be sure of the relative size of the potential windfall gains or losses arising from the transition into and out of the regime used in the period 2000–2006. However, if the prices in that period were above the HCA costs, then in aggregate Telenor would thus far have received more compensation than if HCA had been used throughout the asset lifetimes (i.e. Telenor does not need to be allowed a windfall gain today to compensate for past under-recovery).

► *Paragraph 17*

Ettersom verdsettelsesmetode som underbygger prisingen allerede har blitt endret flere ganger i løpet av LLU-produktets eksistens, vil ikke bruk av HCA i fremtidig regulering medføre noen bedret konsistens.

³⁸ See <https://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-aksess>, under the heading “LRIC-modell fastnett aksess (marked 4)”

Telenor further argues that its proposal will have improved consistency.

However, in our view, an argument of consistency is limited in that the method has been changed multiple times already. Telenor's proposal (not using HCA regulation) is no better than ours (moving to tilted annuity but avoiding a potential windfall) on that basis; our argument is better on other grounds (including the avoidance of inefficient overcompensation).

E.2 Behaviour of results from the copper network calculation

Four operators provided comments related to this topic:

- Broadnet (Section 5.1.2 of its response)
- NextGenTel (Section 2.1 of its response)
- Telenor (first page of its comments on the consultation responses)
- Get TDC (first page of its comments on the consultation responses).

We set out the relevant text from their responses below, before providing our response.

E.2.1 Feedback from Broadnet

LRIC-modellen (Long Run Incremental Cost) er en metode for kostnadsberegning basert på fullfordelte historiske kostnader brukt i forbindelse med prisregulering. Nkom utviklet en LRIC-modell i perioden 2009-2011. Modellen ble ikke brukt direkte i forbindelse med gjeldende vedtak i tidligere marked 4 i 2014, men inngikk som en del av helhetsvurderingen. Nkom har siden vedtaket fra 2014 videreutviklet modellen, og ønsker nå å benytte en videreutviklet modell som skal være mer i samsvar med Kommisjonens anbefaling som utgangspunkt for prisreguleringen.

Modellen fremstår etter Broadnets mening som uegnet for å beregne nivået på pristaket for lokal, fysisk tilgang til kobberbaserte aksessnett i Marked 3a, særlig i form av at den legger opp til et for høyt pristak i form av jevnlig prisøkninger. Broadnet vil under punkt 5.1.3 nedenfor redegjøre nærmere for hvorfor det ikke er grunnlag for de varslede prisøkningene.

På overordnet niva er det flere viktige forhold som tilsier at en LRIC-modell med fullfordelt historiske kostnader ikke er egnet verktøy for prissetting i kobberaksessmarkedet. Dette er knyttet til;

- i. en fullfordelt historisk kost som grunnlag gir ikke noen mening for en døende aksessteknologi som ikke under noen omstendighet vil bli erstattet. Hvis det skal bygges nytt aksessnett i gitte områder fordi kobber ikke lenger holder nødvendig kvalitet, vil hverken Telenor eller andre aktører erstatte kobber med ny kobber. Gjenanskaffelse er med andre ord uaktuelt for alle markedsaktører. Et kostnadsgrunnlag fra 2006 gir for øvrig ingen mening som fremtidig kostgrunnlag.

ii. at størrelsen på kobbernettet blir systematisk mindre for hvert år. Flere og flere aksesser erstattes med fiber eller LTE og kobberet legges ned. Videre erstattes alle de store kobberkablene mellom sentraler og underfordelere med fiber. Det vil si at all transport fra aksessniva erstattes med transport over fiber. Dette får to vesentlige konsekvenser for LRIC-modellen; a) det er et mindre og mindre kobbernett som teoretisk skal gjenskaffes og b) det er et mindre og mindre kobbernett som skal vedlikeholdes. Med andre ord burde vedlikeholdskostnadene for dette nettet synke over tid. Kostgrunnlaget fra 2006 er 12 år gammelt og gjenspeiler en helt annen økonomisk virkelighet.

iii. at Telenor har varslet at de ikke vil gjennomføre noen modernisering av kobbernettet i form av implementering av ny teknologi (G.fast eller vektorisering). Senest 12. februar 2018 fastslo moderniseringsdirektør Arne Q. Christensen i Inside Telecom at det er uaktuelt for Telenor å investere mer i kobbernettet – “Kobberbredband er dødt for Telenor”⁸. Det innebærer at det da ikke tilføres nye investeringer (CAPEX) i dette nettet som skal ayskrives fremover i tid og som ville kunne medført en økt gjenanskaffelseskost/økt kostgrunnlag. I sum tilsier disse forholdene at det er et mindre og mindre kobbernett hvor det ikke foretas nyinvesteringer. Det betyr et lavere og lavere kostgrunnlag og en lavere gjenanskaffelsesverdi og som da skal ha en synkende vedlikeholdskostnad (mindre nett å vedlikeholde). Et kostnadsgrunnlag fra 2006 blir en helt gal referanseramme for å beregne den virkelige kostnad for å opprettholde et minskende kobbernett fremover.

Som Broadnet har påpekt i tidligere klager og i dialog med Nkom sa er også kostnadsnivaet man skal foreta reguleringen fra ikke rettvise;

- Modellen gir ikke nødvendigvis et korrekt bilde av den faktiske kostnadssituasjonen (dvs. for høye modellerte kostnader) og dermed en for høy prisregulering, jf. også punkt 5.1.3 under om nivået på de varslede pristakene.
- Modellen åpner for fortolkning av hvilke kostnader som skal inkluderes. Telenor vil gis rom for å innta en rekke kostnader som kan medføre at prisen settes for høyt. Problemet har blant annet realisert seg i England, der Ofcom har vist til at det har vært ytret bekymring fra en markedsaktør om dataen den dominerende operatoren (BT) hadde avgitt (“BT’s reported data (...) is of questionable accuracy”). Ved bruk av LRIC-modellen vil det være helt nødvendig at Nkom har inngående kjennskap til kostnadskalkylene for å kunne utelukke overflødige kostnader, hvilket Broadnet anser at blir vanskelig i praksis.
- Ofcom anvender videre ikke Kommissjonens anbefalte “bottom up long run incremental costs-plus (BU LRIC+) costing methodology” på markedet for wholesale broadband access, blant annet fordi de mangler data å basere “a Modern Equivalent Asset cost model” på. Det britiske tilsynet har i denne forbindelse uttalt at: “Ofcom considered that LRIC+EPMU has the disadvantage of involving a time consuming process which BT carries out on an irregular basis and, moreover, that Ofcom has little visibility as to how BT generates costs from its LRIC model, and this extra iteration by BT of its financial data is not subject to external audit scrutiny.”⁹ () I relasjon til markedet for wholesale

local access har Ofcom uttalt at: “if we wished to use estimates, we have previously been largely reliant on BT's estimates of LRIC produced by its own LRIC model. We have been cautious when using output from this model because it is unaudited and not well understood by our stakeholders.”

- Både Storbritannia og Frankrike har gått bort fra LRIC-modellen basert på konkrete vurderinger av de nasjonale markedene.”
- Telenor har historisk sett operert med et høyere prisnivå/kostnadsnivå enn tilsvarende aktører i sammenlignbare land. Det finnes ingen rasjonelle grunner til at den samme LRIC-modellen skal kunne gi et utfall som tilsier at det koster veldig mye mer å drive et kobbernett i Norge enn andre europeiske land. Nkom bør således sikre en kostmodell som ivaretar behovet for et mer harmonisert prisnivå innad i EØS.

Både kommersielle og tekniske forhold tilsier at pris på kobberaksesser bør synke, ikke stige, i tiden fremover.

E.2.2 Feedback from NextGenTel

For det første fremstår det som uklart, og under enhver omstendighet er det vanskelig å få oversikt over, hvorvidt modellen faktisk tar hensyn til ulike kostnadseffektiviserende forandringer som har blitt gjennomført i det kobberbaserte aksessnettet de siste årene. Eksempelvis er kobberandelen i aksessnettet sterkt synkende. Eldre og fordyrende kobberbasert infrastruktur skiftes i stort tempo ut med ny og mer effektiv fiberbasert infrastruktur, og avstanden fra sluttkunde til ny fiberbasert infrastruktur blir stadig kortere. på denne bakgrunn er det vanskelig å ha tillit til et modellresultat som viser at prisen skal økes, og ikke reduseres, i årene som kommer.

Videre, og under henvisning til at Telenor tilsynelatende kan hente ut superprofitt fra kobbernettet selv med dagens grossistpris på NOK 85,- per måned, har NextGenTel vanskelig for å forstå hvordan Nkom kan ha tillit et LRIC-resultat som viser at prisen skal økes i årene som kommer. Det vises i denne sammenheng til vedlagte artikkel fra Telecom Revy 5. februar d.a. med overskriften «Fortsatt milliardoverskudd i kobbernettet».

Vedlegg 1: Artikkel 5. februar 2017 Telecom Revy med overskrift «Fortsatt milliardoverskudd i kobbernettet».

I forlengelsen av ovennevnte, og tatt i betraktning det Nkom selv skriver i varselet om at tilgangsprisen til det kobberbaserte aksessnettet verken har hatt negative effekter på fiberutbyggingen eller utviklingen av antall fiberkunder det siste tiåret, er det slik NextGenTel ser det mye som taler til fordel for gjeldende pristak i hvert fall ikke har vært for lavt. NextGenTel mener det derfor kan stilles spørsmål ved hvor robust et LRIC-resultat som viser at prisen skal økes i årene som kommer, faktisk er.

For det tredje mener NextGenTel at det er grunnlag for å sette spørsmålsteget ved et modellresultat som ikke bidrar til at prisene her til lands for tilgang til det kobberbaserte aksessnett har harmoniseres med tilsvarende priser i EU-landene for øvrig. Selv om gjeldende grossistpris i Norge ligger innenfor EUs mål om LLUB-priser mellom 8 og 10 €, viser oversikten fra Cullen, inntatt på s. 105 i varselet, at prisen i Norge ligger godt over gjennomsnittet i EU. Foreslått årlige prisstigning frem til og med 2020 vil bidra til at LLUB-prisen her til lands beveger seg i feil retning. Hensynet til harmonisering med tilsvarende priser i EU for øvrig, tilsier at prisene her til lands bør reduseres snarere enn å økes.

E.2.3 Feedback from Telenor

NextGenTel og Broadnet har i sine høringsvar gitt noenlunde overlappende argumentasjon mot anvendelse av en LRIC modell (alene) for fastsettelse av kobberpriser og mot en økning av pristaket for kobberbaserte aksesser (dvs SLU, LLU og Bredbåndsaksess). Telenor har enkelte bemerkninger til dette:

- Broadnet mener LRIC-modellen er uegnet fordi den benytter gjenanskaffelseskost på en døende aksess teknologi. Vi viser her til at EU-kommisjonens anbefaling (2013), og Nkoms implementering av modellen foretar en betydelig nedskrivning av gjenbrukbar infrastruktur. Gjenanskaffelseskost benyttes dermed ikke på denne delen av kostnadsbasen. Nkom går betraktelig lengre enn Kommisjonens anbefaling på dette punktet og inkluderer også all kobberkabel i en tilsvarende nedskrivning.
- Både Broadnet og NextGenTel mener kobbernettets kostnader burde reduseres i takt med at kobbermettet minsker og delvis skiftes ut med fiber. Denne antagelsen er kun riktig når man ser på absolutte størrelser for denne kostnadsbasen til kobbermettet. Når man imidlertid ser på enhetskostnader, fører den nedadgående kundemassen til at det blir stadig økende kobberlengde/trasselengde per kobberkunde, og kostnadene per kunde stiger.
- Utskiftning av kobber med fiber fører heller ikke til nedgang i enhetskostnader for gjenværende kobberkunder. Fiber som anlegges som en del av et kobberaksessnett er også en del av kostnadsbasen for kobberaksess på lik linje med faktisk kobber. Og ny fiber i aksessnett erstatter kobber og infrastruktur som i høy grad er nedskrevet, og vil dermed øke kostnadene i aksessnett dersom man bruker et modelleringsprinsipp om å skrive ned eldre infrastruktur, et prinsipp vi vil tro Broadnet og NextGenTel støtter.
- Broadnet mener Telenors intensjon om å ikke gjøre større investeringer i kobber fremover tilsier at kostnadsresultatene må bli lavere. Dette poenget er irrelevant da Nkoms modell anvender annuiteter for å beregne capex-kostnader. Dette betyr at anskaffelseskostnader og tilhørende kapitalkostnader fordeles jevnt ut over et aktivums levetid som årlige annuiteter. Kostnadene man ser i et år reflekterer kun allerede utførte investeringer, ikke

fremtidige. Reduserte investeringer i fremtiden vil således kun få betydning for senere kostnadsbilde.

E.2.4 Feedback from TDC

Vi kan ikke se at det skal være grunnlag for å øke prisen på leie av tilgang til fysisk kobber. Telenor har selv varslet at de ikke ønsker å gjøre investeringer i modernisering av kobbernett. Selskapet er tvert imot i gang med å legge ned denne typen linjer der det bygges overlappende fibernett. Infrastrukturen er videre avskrevet. Vår erfaring tilsier dessuten at vedlikeholdskostnadene er stabile.

For det tilfelle at Nkom fastholder at det er grunnlag for å øke pristaket, mener Get TDC at den varslede oppjusteringen gjennomgående er for høy. Vi slutter oss på dette punktet til Broadnets og NextGenTels merknader.³⁹ Videre anses det som uheldig å benytte marginskivestesten som utgangspunkt for prisregulering av fiber.⁴⁰

Både Broadnet og NextGenTel viser til at det er uheldig at det varslede prisnåvet i Norge ligger over nivået i EU. Den varslede reguleringen tyder på at Nkom ikke harmoniserer virkemiddelbruken. Dette til tross for at Telenor har hatt og fortsatt har svært høye marginer på de aktuelle tjenestene. Vi kan ikke se at det er grunnlag for å øke denne superprofitten i tiden fremover.

E.2.5 Response by Analysys Mason

First, we note that the comments relating to the increase in copper unbundling prices compared to existing prices are now largely redundant, following the revisions made to the vAcc2.2 model regarding the demand forecasts and the asset age distribution.

We also note that there are several misconceptions in the comments above. In our response we:

- correct these misconceptions
- describe the behaviour of the model over time.

Correction of misconceptions

The model has never been intended to consider the cost base of a mix of access technologies: it calculates the costs of an access technology on a standalone basis.

³⁹ Hearing response from Broadnet, page 10.

⁴⁰ Get TDC slutter seg til kommentarer fra NextGenTel slik det fremgår av høringsvaret, page 14, and Broadnet hearing response, page 15.

In the case of the copper calculation, the costs of a national copper network are determined. The network is assumed to carry the demand of Telenor's access connections (copper and fibre), as well as those fibre connections served by fibre providers where Telenor will not build a competing next-generation access (NGA) infrastructure. This was described under Principle A18 of the final model specification.⁴¹

We have summarised the other incorrect comments and provide corrective statements in Figure E.4.

Figure E.4: Correction of misconceptions [Source: Analysys Mason, 2018]

Operator	Statement	Correction
Broadnet	The LRIC model is a cost calculation method based on fully allocated historical costs used in price control	The model uses fully allocated costing but uses different cost bases for the different technologies: <ul style="list-style-type: none"> The copper network capex is depreciated using HCA principles and then enters a RAB which is indexed and depreciated using a tilted annuity The fibre network is calculated at replacement cost, except for assets reused from the copper network, which are treated in the same way as in the copper network approach. Tilted annuity is used to annualise the capex costs
Broadnet	A 2006 cost base does not make sense as a forward-looking cost base	The costs are based on 2009, not 2006. However, the cost base for the selected year is modified using long-term cost trends
Broadnet, NextGenTel and Telenor	All these respondents refer to the size of the copper network changing over time as fibre overbuild occurs	The modelled copper network is intended to be a hypothetical national network that is standalone copper in all years. We do not model a migration to a national fibre network or a hybrid network of fibre and copper
Broadnet	This means a lower and lower cost base and a lower replacement value	The cost model does not use replacement costs for the copper network (as noted by Telenor)
Broadnet	Both the UK and France have abandoned the LRIC model based on concrete assessments of the national markets	This statement about Ofcom's model is factually incorrect. In its statement of March 2018, Ofcom sets a copper unbundling price based on a top-down LRIC+ model. ⁴² The comments quoted by Broadnet, which are taken from the Canadian regulator's website, refer to Ofcom's statements from 2005/2006 and are therefore out of date (and we believe relate to BT's calculations of LRIC, which are not based on a bottom-up approach). Ofcom uses a bottom-up model to inform its calculations regarding FTTC products In the case of France, Broadnet's statement is partially correct: the French regulator currently uses a top-down analysis of the incumbent operator's regulatory accounts to set the copper unbundling

⁴¹ Available from https://www.nkom.no/marked/markedregulering-smp/kostnadsmodeller/lric-fastnett-aksess/_attachment/20026?_download=true&_ts=150237e5c85

⁴² See https://www.ofcom.org.uk/__data/assets/pdf_file/0023/112478/ec-letter-draft-statements.pdf, page 9

Operator	Statement	Correction
		price; however, it does cross-reference these prices with a bottom-up model ⁴³

Behaviour of the model over time

Several comments also point to the year-on-year increase in costs per line. There are three main contributors to the costs per line over the period 2018–2020: annualised capex, modelled opex and active lines. The projected evolution of each of these items over the period 2018–2023 is shown in Figure E.5 below.

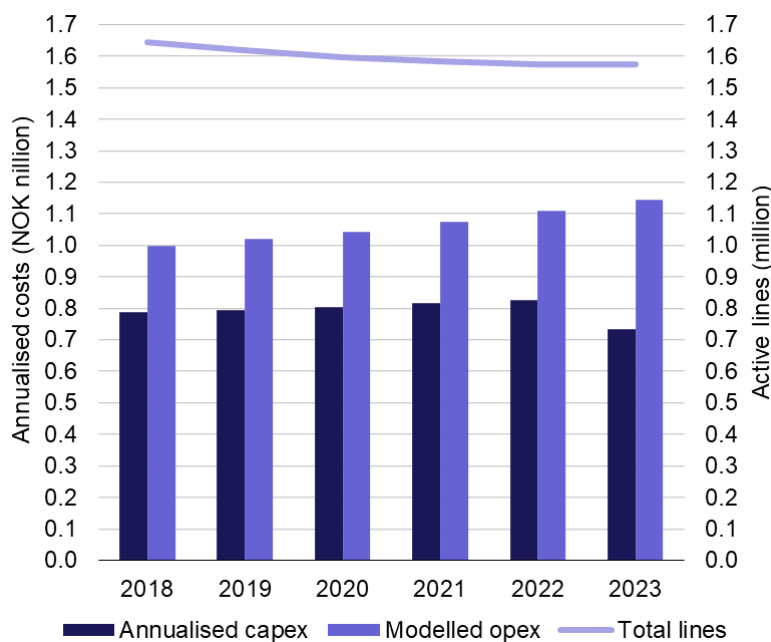


Figure E.5: Modelled costs for the copper model [Source: Nkom vAcc2.2 model, 2018]

► Annualised capex

After the RAB is begun at the start of 2018, the depreciation charge is relatively stable over the forecast period. This is because the cost trend for the dominant asset in the RAB (trench) is almost 0%. The modelled overhead capex also increases with inflation over time.

► Modelled opex

Modelled opex comprises fault-related opex (related to trenches, ducts, cables, joints and manholes), opex for network nodes (distribution points, cabinets and the MDF location) and business overheads:

- fault-related opex is assumed to grow with a real-term growth in earnings plus inflation⁴⁴
- network node opex is assumed to be flat in real terms (increasing with inflation)

⁴³ See https://circabc.europa.eu/webdav/CircaBC/CONNECT/e-ctcf/Library/01%20-%20Commission%20Decisions/Commission_Decisions_2017/FR-2017-2046%20ADOPTED_EN.pdf, page 4

⁴⁴ This real-term growth is derived from Statistisk Sentralbyrå (SSB) data on average earnings.

- business overhead opex is assumed to remain flat in nominal terms.

Overall, the modelled opex increases by approximately 2% per year over the forecast period.

► *Active demand*

The number of active lines is assumed to fall over the period 2018–2020. Even when demand is considered as determined by Principle A18 of the model specification, total modelled lines fall by approximately 1% each year. This causes the unit costs to increase.

Conclusions

Broadnet indicates in its response that maintenance costs should fall for the copper network over time, but this is for the real copper network that is shrinking over time as it is overbuilt with fibre. This is not what the cost model is considering, which is a national copper network.

TDC indicates in its response that maintenance costs are stable, which we would interpret as flat in nominal terms over time. However, TDC provides no quantitative evidence to back up its claim. The model already assumes that overhead opex is stable over time.

We believe that the assumption of fault-related opex increasing with earnings is reasonable since this opex is largely related to staff wages (which should increase in line with earnings rather than inflation). Further, node-related opex will relate to power and rentals, which can also be reasonably assumed to increase with inflation.

The trend in annualised capex is largely being driven by the trend in trench costs, which has been derived using long-term data from SSB.

We therefore consider that the LRIC model is behaving in a reasonable fashion.

E.3 Outputs of the bitstream modelling

Two operators provided comments related to this topic:

- Broadnet (Section 5.2 of its response)
- NextGenTel (Section 4.1 of its response).

We set out the relevant text from their responses below, before providing our response.

E.3.1 Feedback from Broadnet

For Bredbandsaksess (ADSL Basis og VDSL Basis) varsler Nkom en vesentlig økning av tilgangsprisene sammenlignet med dagens nivå. Det varsles videre at prisen skal være økende de neste tre årene.

Som redegjort for over under punkt 5.1.2 burde ikke LRIC-modellen brukes for å heve et pristak alene, da modellen ikke sikrer et riktig kostnadsnivå og medfører at nivået vil kunne settes for høyt.

Nkom fremlegger ingen nærmere forklaring på hvorfor prisene skal øke de neste årene, og den varslede økningen fremstår derfor som ugrunnet. Økningen, som innebærer en fordel for Telenor på bekostning av tilgangskjøperne, bør ikke finne sted uten at det foreligger konkrete bevis som tilsier at en slik økning er nødvendig. Broadnet etterspør på denne bakgrunn en forklaring på den varslede økningen, og ber om at reguleringen endres dersom slik dokumentasjon ikke skulle foreligge. For Broadband Access (ADSL Basis and VDSL Basis).

E.3.2 Feedback from NextGenTel

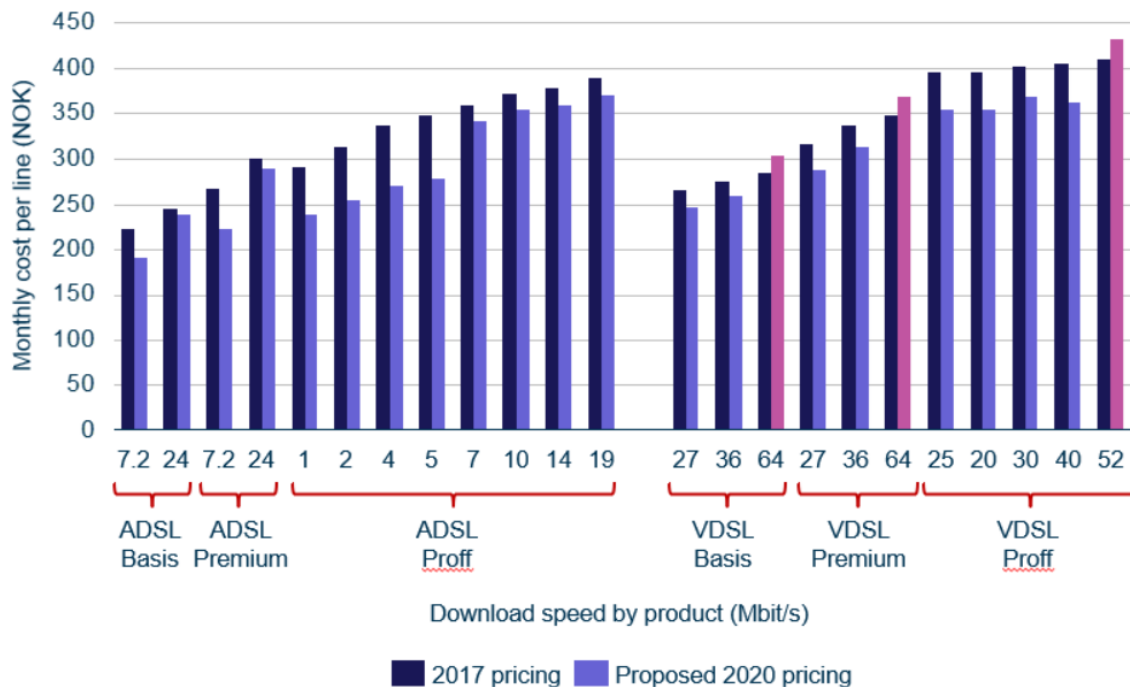
Når det gjelder varslede tilgangs- og prisregulering for sentral tilgang til det kobberbaserte aksessnett, ønsker NextGenTel først og fremst å knytte kommentarer til den varslede prisreguleringen. For Bredbandsaksess (ADSL Basis og VDSL Basis) varsles det en signifikant økning av tilgangsprisene sammenlignet med dagens prisnivå, herunder at prisen fremover skal økes år for år som følge av at de "modellerte kostnadene" er økende de neste tre årene.

Det gis i varselet ingen nærmere forklaring på hvorfor tilgangsprisene for ADSL/VDSL Basis plutselig skal øke signifikant. Det gis heller ingen forklaring på hvorfor de modellerte kostnadene skal være økende fremover. NextGenTel mener således at LRIC-resultat ikke kan danne grunnlag for fastsettelsen av pristak alene, men at dette må skje med basis i en helhetsvurdering der modellresultat inngår som en av flere faktorer. Videre finner NextGenTel at den foreslåtte metoden for fastsettelse av pristaket for Premium- og Proff-variantene der dagens relative prisforskjell mot Basis-variantene opprettholdes, for noe tilfeldig og lite egnet som grunnlag.

E.3.3 Response by Analysys Mason

The increase in prices over time is solely due to the increase in the cost per copper access line, which is explained in Section E.2.5. For the avoidance of doubt, for any given product, the contribution of costs from the core network per subscriber is assumed to be flat over the period 2018–2020.

Figure E.6: Comparison of output costs per subscriber of bitstream (BSA) services in 2020 with current pricing [Source: Analysys Mason, 2018]



Moreover, we do not understand the comments about a significant increase in prices. If we compare the prices proposed for 2020 with the current prices, then only three products have an increase in price. These are the fastest VDSL products, shown by the pink bars in Figure E.6 above.

The revisions to the model described in the consultation held in June 2018 mean that the proposed prices will now be lower than before, and will increase slightly over time.

We therefore consider that Broadnet and NextGenTel have likely misinterpreted the pricing results.

E.4 Outputs of the SLU modelling

Telenor provided feedback on this issue from Section 4.2 of its response. We set out the relevant text from its response below, before providing our response.

E.4.1 Feedback from Telenor

Dersom maksimalprisene for SLU Kobber som foreslått av Nkom blir implementert, vil Telenor dessuten få enda flere ulønnsomme områder (SLU omsetning dekker ikke faktiske driftskostnader med linjene under punktet).

E.4.2 Response by Analysys Mason

The SLU price proposed by Nkom is a national-average price which has been derived using the LRIC model, and would be relevant for the network modernisation programme.

In Nkom's prior regulation of SLU, the price was the same as the price set for LLU. This may have allowed Telenor the opportunity for over-recovery, since LLU (a copper line to an exchange) as a service will use more assets than SLU (a copper line to a street cabinet), with the additional assets being the additional network between the street cabinets and the exchange. The proposed LLU and SLU prices derived from the LRIC model reflect this difference.

Nkom could assume a sub-national SLU price (e.g. only including those geotypes where SLU might be sold as a product). However, this would not be compatible with national-average prices for LLU and wholesale line rental (WLR) that are already in place, particularly if the de-averaged SLU price exceeded the LLU/WLR prices.

In such an instance, Telenor could migrate LLU/WLR subscribers to the SLU service and charge the higher price, thereby increasing its revenue. To avoid such issues, it is most reasonable to take Nkom's approach and retain national-average prices for these existing SLU/LLU products.

E.5 Other comments related to the modelling

Telenor provided some further feedback related to the modelling from Section 4.4.1.3 of its response. We set out the relevant text from its response below, before providing our response.

E.5.1 Feedback from Telenor

Gjennom prosessen for utvikling av Nkoms LRIC-modell for aksess har Telenor med bekymring observert en tendens der Nkom, tilsynelatende systematisk, har gjort metodevalg som reduserer dagens kostnadsresultater fra modellen. Dette inkluderer eksempler på valg som er internt inkonsistente og valg som bryter med EUs rekommendasjon, hvis tilpasning var hovedmotivasjon for å utvikle en ny aksess-modell.

Eksempler på slike valg er:

- Inkludering av kobberkabel i RAB, til tross for at Rekommendasjonen ikke foreslår dette. (Gir lavere verdi og kompensasjon av kobberkabel)
- Bruk av HCA for å beregne verdi av infrastrukturnettverket i RAB til tross for at Rekommendasjonen eksplisitt sier CCA skal brukes. (Gir lavere verdi og fremtidig kompensasjon av infrastruktur)
- Bruk av CCA for å beregne kompensasjon i fremtidige år for infrastruktur i RAB, til tross for at dette valget er inkonsistent med valget av HCA for å fastsette startverdien for RAB. (Gir lavere kompensasjon på kort sikt for infrastruktur.)

E.5.2 Response by Analysys Mason

Telenor states in its response that the model uses CCA to calculate cost recovery in future years within the RAB. We should clarify that the RAB specifically uses the tilted annuity depreciation method, not CCA per se (which would imply CCA FCM or CCA OCM).⁴⁵

⁴⁵ This is stated in Section 6.4 of the model documentation and Section 5 of our December 2017 report on copper modelling.

Annex F Revisions to the vAcc2.2 model

In January 2018, Nkom released the vAcc2.2 model for consultation in relation to its draft decisions for Markets 3a and 3b.⁴⁶ The consultation ended in March 2018.

During the process of reviewing the consultation responses and finalising the model, two significant revisions have been made to the model, related to updates of the assumed demand and the asset age distribution. We describe both of these changes in Sections F.1 and F.2, respectively.

F.1 Demand updates

As part of preparing the vAcc2.2 model, the Market module was updated to include the latest market information up to 2016. This update is described in the model documentation published with the vAcc2.2 model.⁴⁷

For the copper-related calculations, a national copper network is modelled. The demand assumed to be carried on this modelled network is a combination of Telenor's copper and fibre active lines, as well as fibre lines defined as 'other relevant NGA' connections.⁴⁸ Subscriptions on cable networks are not carried by the modelled national copper network. This has been the approach implemented since the vAcc2.0D model, which was first released for consultation in October 2015. This approach was defined in order to reflect the 2013 EC Recommendation and has not been changed since.⁴⁹

F.1.1 Context for the change

In May 2018, full-year statistics were released for 2017 on Nkom's Ekomstatistikken website. It has been agreed with Nkom that the vAcc2.2 model should be updated with these values. The Market module has therefore been updated and the forecasts then reviewed in light of the additional year of actuals. The sources used are set out in Figure F.1 below.

⁴⁶ See <https://www.nkom.no/marked/markedsregulering-smp/anbefaling-2016/marked-3a>

⁴⁷ Vedlegg 2b, vAcc2.2 documentation; see https://www.nkom.no/marked/markedsregulering-smp/anbefaling-2016/marked-3a/_attachment/31875?_download=true&_ts=160f92eda3c. See Section 4.

⁴⁸ This is described in Section 4.4 of the vAcc2.2 documentation. This includes NGA networks not owned by Telenor or Get TDC (for example, including Altibox partners).

⁴⁹ Recommendation C(2013) 5761 of 11 September 2013, see <http://ec.europa.eu/digital-agenda/en/news/commission-recommendation-consistent-non-discrimination-obligations-and-costing-methodologies>

Figure F.1: Sources used to update the Market module [Source: Analysys Mason, 2018]

Source	Input updated
Nkom Ekomstatistikken database (http://www.nkom.no/files/ekomportal/alle.csv) for the years 2009 onwards	<ul style="list-style-type: none"> Total market subscriptions for fixed telephony and fixed broadband Total market fixed-originated voice minutes Total market mobile-originated voice minutes Telenor subscriptions for fixed telephony and fixed broadband Telenor fixed-originated voice minutes Fibre broadband subscriptions by service provider
Statistisk sentralbyrå (http://www.ssb.no)	<ul style="list-style-type: none"> Population (Tabell: 01222) Households (Tabell 10986) Establishments (Tabell 09029)
Pengepolitisk report 1/18	<ul style="list-style-type: none"> Inflation for 2017 onwards

Certain forecasts have then been reviewed and (on occasion) revised in order to smooth them out where appropriate. Most of our amendments relate to the evolution of the voice and broadband subscriber bases and their split between technologies.

The rationale for these revisions is based on the actual 2017 volumes compared to the forecast 2017 active lines in the vAcc2.2 model. This is illustrated in Figure F.2 below.

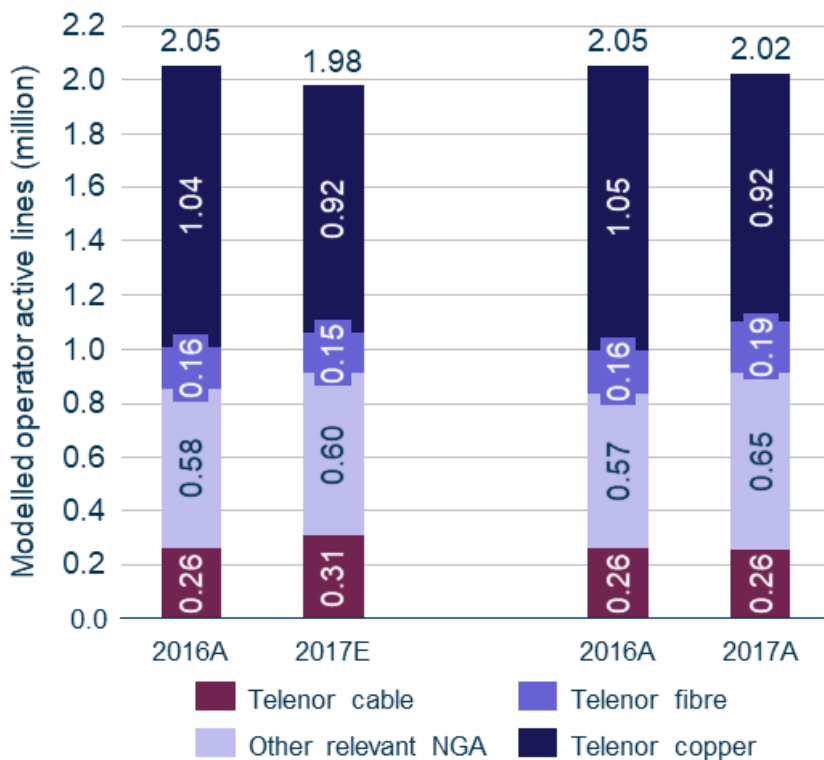


Figure F.2: Comparison of active lines for 2016-2017 in the vAcc2.2 model (left) and following the update (right) [Source: Analysys Mason, 2018]

The main observations are that:

- 2016 volumes are almost unchanged from the vAcc2.2 model (although some of Nkom's statistics on its Ekomstatistikken website have been corrected, which has then been reflected in the Market module)
- the total volumes shown above decreased by less than was forecast in the vAcc2.2 model
- fibre growth in 2017 exceeded the forecast, for both Telenor and 'other relevant NGA' connections
- Telenor's cable subscriptions have contracted slightly, rather than grown as was forecast.

As a result, we consider appropriate to make the following revisions:

- modify the forecasts of Telenor's cable subscribers so that they are largely stable, rather than experiencing growth
- increase the forecast growth in fibre connections (for both Telenor and 'other relevant NGA')
- reduce the copper line forecasts slightly to give a similar overall decline.

The original active line forecasts, and the impact of these revisions for the period 2017–2021, are shown below in Figure F.3 and Figure F.4, respectively.

Figure F.3: Relevant active line forecasts before the update [Source: Analysys Mason, 2018]

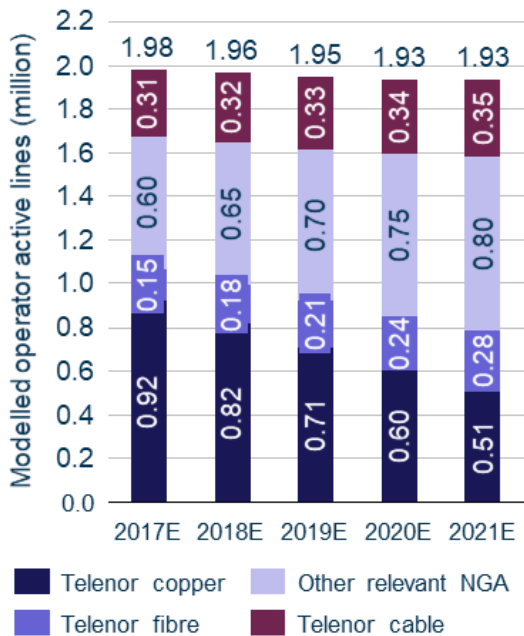
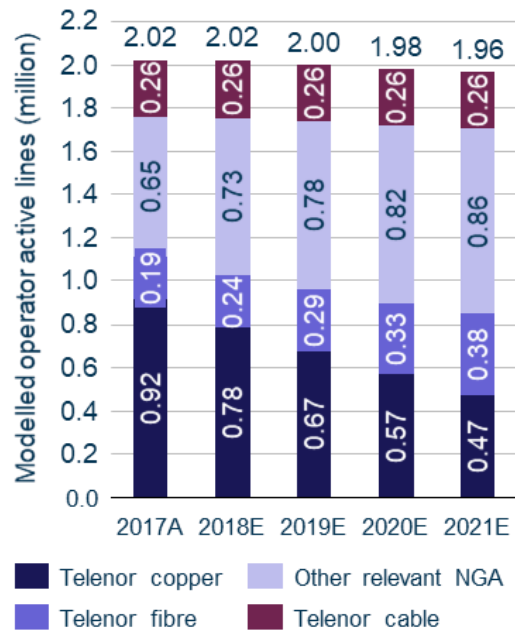


Figure F.4: Relevant active line forecasts after the update [Source: Analysys Mason, 2018]



The specific revisions are set out in more detail in Figure F.5 below.

Figure F.5: Forecasts revised in the Market module [Source: Analysys Mason, 2018]

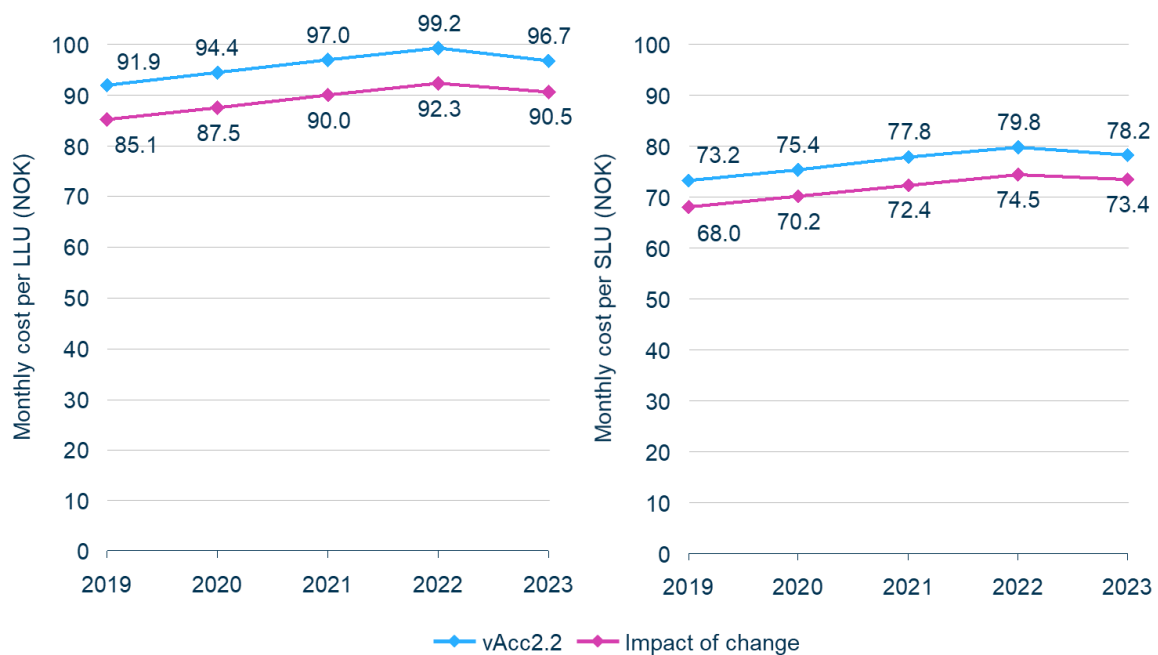
Worksheet	Forecast	Change in forecast curve
Market demand	Fixed residential voice penetration	Faster decline
Market demand	Fixed residential broadband penetration	Slower growth
Market demand	Proportion of residential broadband that is cable	Proportion reduced
Market demand	Proportion of residential broadband that is fibre	Proportion increased

Worksheet	Forecast	Change in forecast curve
Market demand	Increase in business broadband connections	Set to 0% annual growth
Market demand	Increase in analogue leased lines	Set to 10% annual reduction
Market demand	Pay-TV penetration	Saturation revised (100%→90%)
PUBLIC_TN	Retail xDSL as a proportion of all xDSL connections	Saturation revised (50%→60%)
PUBLIC_TN	Retail market share of PSTN/ISDN2 connections	Saturation revised (80%→90%)
PUBLIC_TN	Retail market share of cable broadband	Saturation revised (50%→40%)
PUBLIC_TN	Retail market share of fibre broadband	Saturation revised (25%→30%)
PUBLIC_TN	'Other relevant NGA' as a proportion of total	Saturation revised (60%→50%)
PUBLIC_TN	Wholesale xDSL-only lines as a proportion of all wholesale xDSL connections	Saturation revised (80%→95%)
PUBLIC_TN	Market share for IP-VPN	Saturation revised (20%→10%)

F.1.2 Impact of change

Figure F.6 shows a comparison of the costs per line for copper LLU (left) and SLU (right) over the period 2019–2023 from the model, *before* and *after* these updates were implemented.

Figure F.6: Costs per line for copper LLU (left) and SLU (right) [Source: Analysys Mason, 2018]



F.2 Asset age distribution

This set of inputs can be found in the Network Service Costing – Access module.

F.2.1 Context for the change

In Nkom's cost model of access networks, copper network assets are purchased in the past using an 'asset age distribution'.⁵⁰ The model uses different asset age distribution assumptions for assets with different assumed economic lifetimes. In the vAcc2.2 model (published in January 2018):

- assets with an economic lifetime of 40 or 50 years were assumed to be purchased according to a time series informed by Telenor's response to Q09 of the data request from 2015, which asked for statistics on the distribution of the age of the assets in its copper access network⁵¹
- assets with shorter economic lifetimes were assumed to be purchased according to alternative (linear) time series.

These assumptions were set in cells *A7ResidualValueCopper!U1220:U1225* of the vAcc2.2 model.⁵²

In the original submission from Telenor,⁵³ we note that the purchase schedule information is explicitly stated to be related to all copper access assets.

We consider that, in order for Nkom's model to be consistent with Telenor's data submission, all the copper network assets entering the modelled RAB should be purchased according to this asset age distribution, rather than just the longest-lived assets as is currently the case. This assumption can be made in the vAcc2.2 model by revising cells *A7ResidualValueCopper!U1222:U1223* to have the same value as cells *A7ResidualValueCopper!U1224:U1225*.⁵⁴

F.2.2 Impact of change

A comparison of the costs per line for copper LLU and SLU over the period 2019–2023 from the two versions of the model is shown below.

⁵⁰ Vedlegg 2b, vAcc2.2 documentation; see https://www.nkom.no/marked/markedsregulering-smp/anbefaling-2016/marked-3a/_attachment/31875?_download=true&_ts=160f92eda3c. See Figure 5.25 of this document for the reference.

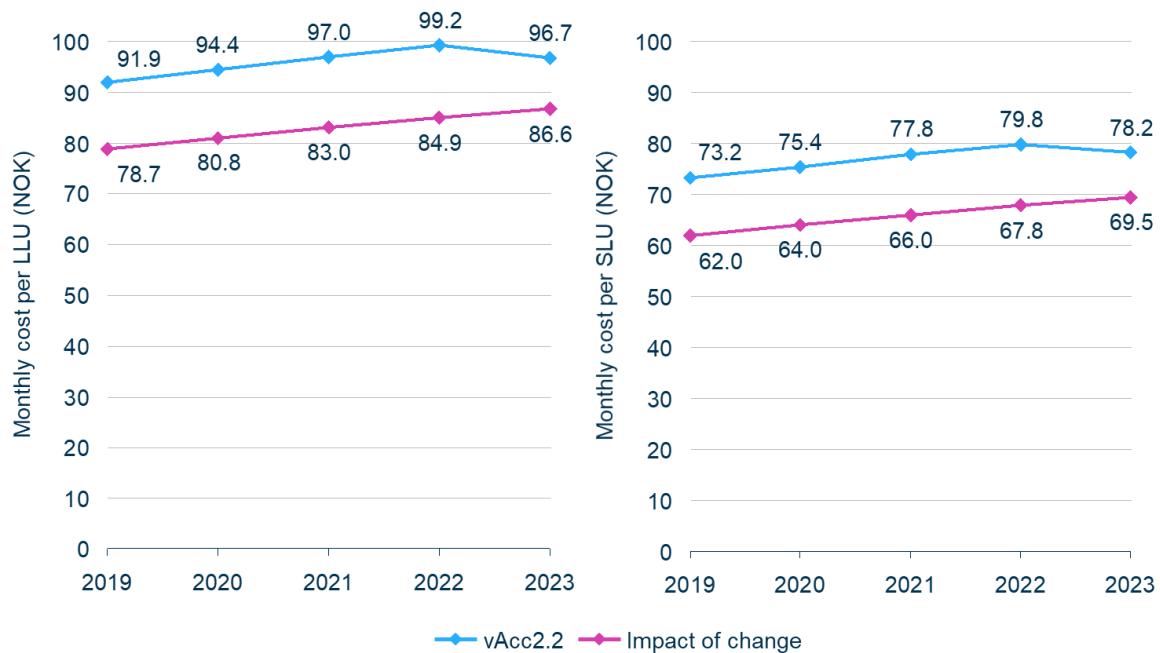
⁵¹ Spørreskjema for Telenor; see https://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-aksess/_attachment/17908?_download=true&_ts=14d0a3b5904, page 7

⁵² Vedlegg 2d, Network Service Costing - Access; see https://www.nkom.no/marked/markedsregulering-smp/anbefaling-2016/marked-3a/_attachment/31884?_download=true&_ts=1610eb538b7

⁵³ Excel file received from Telenor on 5 June 2015.

⁵⁴ The only assets that enter the modelled RAB have economic lifetimes of at least 20 years. Therefore, we only change the inputs for lifetimes greater than or equal to this value.

Figure F.7: Costs per line for copper LLU (left) and SLU (right) [Source: Analysys Mason, 2018]



F.3 Feedback from industry following the consultation

The changes described in Annex F.1 and Annex F.2 were consulted with industry in May 2018.⁵⁵ Responses were received from Telenor and Broadnet and published on Nkom's website.⁵⁶ Within these responses, some of the material was in relation to the cost model, which we summarise below by topic.

F.3.1 Feedback from Telenor

Telenor ser det som naturlig å oppdatere modellen med de siste tilgjengelige tall, og støtter dermed bruk av tall og fremskrivninger basert ekom-statistikken fra 2017.

Når det gjelder justering av kjøpshistorikken for aktiva i Telenors kobbernettverk, finner Telenor saksgangen underlig. Modellarbeidet ble etter omfattende konsultasjon ferdigstilt i 2016, og det er ikke fremkommet ny informasjon siden da. Endringen som nå foreslås burde vært vurdert som en del av konsultasjonen i 2015-16, slik at modellrammeverket kunne vurderes mer helhetlig av konsultasjonenes deltagere (LRIC vAcc2.2 og varsler om vedtak).

Når dette er sagt, så vurderer Telenor at Nkoms bruk av aldersprofilen innsendt av Telenor i 2015 også på kobber-aktiva med levetider på 20-25 år er korrekt. Det var ikke mulig å skille mellom ulike typer aktiva i kobbernettverket i det historiske materialet, og aldersprofilen som ble innsendt dekker aktiva med både kort og lang levetid.

⁵⁵ See https://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-aksess/_attachment/34900?_download=true&_ts=164178f3543

⁵⁶ See <https://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-aksess>

Telenor vil imidlertid påpeke at fremgangsmåten for å implementere denne endringen, beskrevet i Analysys Masons notat, medfører at alle aktiva med 20 eller 25 års levetid tilegnes aldersprofilen for Telenors kobberaktiva. Dette inkluderer fiber-aktiva. Dette ser imidlertid ikke ut til å ha betydning for kostnadsberegning av GPON-produkter.

F.3.2 Response by Analysys Mason

Regarding Telenor's comment on the process and how the correction was identified, the model has been internally reviewed on several occasions since the vAcc2.0D model was published.

The results of these internal reviews can be seen in the documentation published to accompany the vAcc2.2 model.⁵⁷ In particular, Annex E describes all the changes made between the publication of the vAcc2.0D model (in October 2015) and the vAcc2.2 model (in January 2018). Most of the changes were in fact triggered by internal reviews rather than by feedback from stakeholders through the consultation.

Regarding the implementation of the change, the cells changed (*A7ResidualValueCopper!U1222:U1223*) are only used to set the asset age profile for copper network assets for the copper modelling (within the *A7ResidualValueCopper* worksheet). The modelling of assets in the FTTH networks is unaffected by this revision.

F.3.3 Feedback from Broadnet

2.1 Broadnet er enig i at pristaket for tilgang i marked 3a og 3b må senkes

Som redegjort for i Broadnet sitt hørings svar datert 12. mars 2018 punkt 5 er Broadnet er enig med Nkom i at den tidligere varslede prisreguleringen av fysisk tilgang til kobber var for høy. Selskapet er derfor positivt til at tilsynet reduserer pristaket basert på en ny gjennomgang av datagrunnlaget til LRIC modellen. En oppdatert og korrekt prisregulering av tilgang til kobber er avgjørende for å fremme bærekraftig konkurranse i de markedene det her er snakk om.

I brevet viser Nkom til at tilsynet har justert etterspørselsdata og kjøpshistorikk basert på faktiske tall. De nye framskrivningene innebærer modererte framskrivninger i antall HFC-abonnement, økt vekst i antall fiber-abonnement og en reduksjon i framskrivningene for antall kobber-abonnement. Dette er i tråd med Broadnets kommentarer til den varslede reguleringen.

⁵⁷ See https://www.nkom.no/marked/markedregulering-smp/anbefaling-2016/marked-3a/_attachment/31875?_download=true&_ts=160f92eda3c

2.2 Prisreguleringen må hensynta Telenors faktiske kostnader, samt gjeldende forhold ved kobbernettet

De varslede justeringene reflekterer i større grad at kobbernettet i dag minker for hvert år, og at nettet ikke vil bli erstattet med ny kobber. Dette er også i tråd med våre kommentarer til varsel om vedtak.

Som vi redegjorde for i vårt høringssvar vil en fullfordelt historisk kost som grunnlag ikke gi mening for en døende aksessteknologi som ikke under noen omstendighet vil bli erstattet. Hvis det skal bygges nytt aksessnett i gitte områder fordi kobberen ikke lenger holder nødvendig kvalitet, vil hverken Telenor eller andre aktører erstatte kobberen med ny kobber. Kobbernettet er avskrevet, og alle driftsmessige og operasjonelle forhold tilsier at kostnadene skal gå ned da kobbernettet blir mindre og mindre over tid.

Størrelsen på kobbernettet blir som kjent systematisk mindre for hvert år. Flere og flere aksesser erstattes med fiber eller LTE og kobberet legges ned. Videre erstattes alle de store kobberkablene mellom sentraler og underfordelere med fiber. Det vil si at all transport fra aksessnivå erstattes med transport over fiber. Dette får to vesentlige konsekvenser for LRIC modellen; a) det er et mindre og mindre kobbernett som teoretisk skal gjenskaffes og b) det er et mindre og mindre kobbernett som skal vedlikeholdes. Dette tilsier at også vedlikeholdskostnadene for nettet synker. Broadnet mener det er avgjørende at dette tas hensyn til ved beregningen av pristaket.

2.3 Korrekt tilnærming å justere kjøpshistorikk

Nkom varsler også at det er grunnlag for å justere profilen for kjøpshistorikken av aktiva med 20/25 års levetid. Broadnet støtter justeringen, da den vil gi et riktigere bilde av alderssammensetningen av aktiva knyttet til Telenors kobbernett.

Det fremgår av vedlegget til Nkoms brev datert 8. juni 2018 at endringen er foretatt på bakgrunn av faktisk informasjon mottatt fra Telenor, som viser at en vurdering i tråd med "Asset age distribution" prinsippet vil gi et mer korrekt utfall basert på de faktiske kostnader. Broadnet er enig i at dette er mer treffsikkert. Den nedjusteringen i pris som følger fra endringen samsvarer også bedre med Broadnets oppfatninger av hvor pristaket for tilgang til fysisk kobber bør ligge.

F.3.4 Response by Analysys Mason

We note that Broadnet continues to misinterpret the design of the copper model. The model has never been intended to consider the cost base of a mix of access technologies: it calculates the costs of an access technology on a standalone basis.

In the case of the copper calculation, the costs of a national copper network are determined. The network is assumed to carry the demand of Telenor's access connections (copper and fibre), as well

as those fibre connections served by fibre providers where Telenor will not build a competing NGA infrastructure. This misconception is explained more fully in Annex E.2.

Annex G Implementation of bitstream costing using Nkom's cost models of fixed networks

In this section, we outline the approach taken to model a bitstream service using Nkom's existing cost models. This section covers the following aspects:

- Annex G.1 sets out the objectives of modelling bitstream core costs
- Annex G.2 details the adjustments made to Nkom's v2.0F core model in order to facilitate the modelling of bitstream
- Annex G.3 outlines the approach to calculating the costs of specific ADSL/VDSL bitstream products.

G.1 Objective

A bitstream access (BSA) service was already modelled within the vAcc2.0F/vAcc2.1 model. However, this only captured the access network-related costs. A bitstream service also requires a contribution from the core network, and it is this cost that we aim to calculate by revising Nkom's final LRIC model of the core network (v2.0F) as released in 2014.⁵⁸ The path of bitstream traffic through an IP core network, such as that in Nkom's v2.0F model, is shown below in Figure G.8.

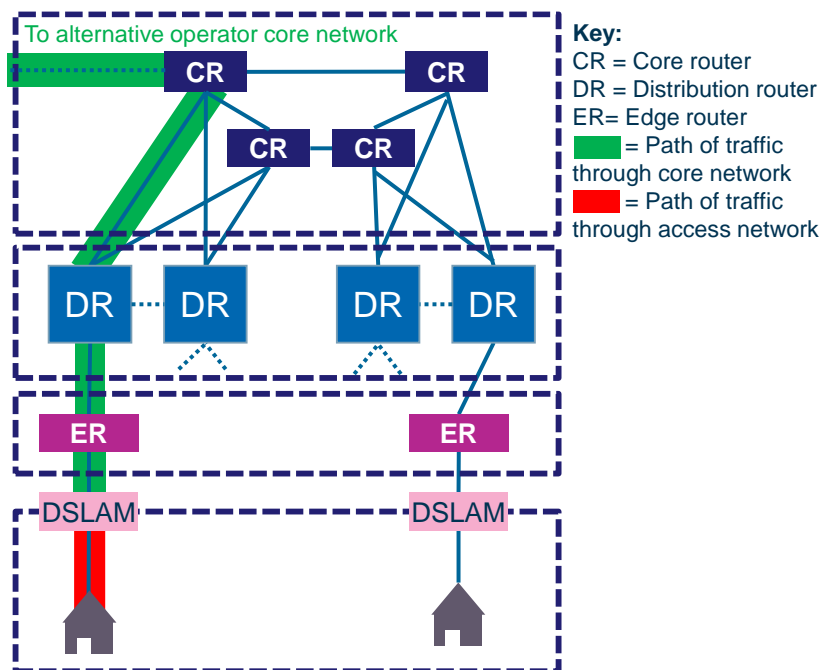


Figure G.8: Illustration of one form of bitstream traffic through an IP core network [Source: Analysys Mason, 2018]

⁵⁸ See: <http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-kjerne>

Our modelling implementation allows for the costs to be calculated where the bitstream operator:

- has a point of presence at a parent location for bitstream traffic, meaning that transit across the core network is not required ('direct bitstream')
- does not have a point of presence at a parent location for bitstream traffic, meaning that transit across the core network location is required ('indirect bitstream').

We assume that the traffic can be handed over at one of 7 CRs, 80 DRs or 558 ERs.

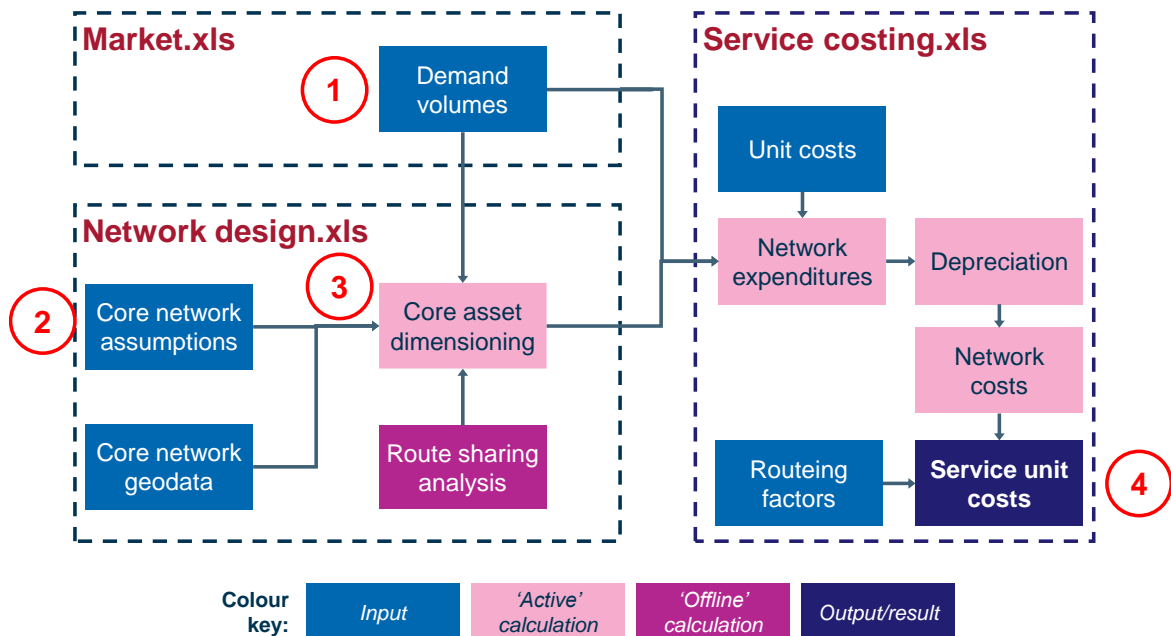
To illustrate, Figure G.8 above shows *direct bitstream* for a point of presence at a CR.

The objective is therefore to calculate the cost associated with the green section of the path. Adding this to the cost calculated for the access network (red section of the path) gives the full cost for a bitstream service.

G.2 Overview of implementation

We have modified the modules of the core model as required to calculate the core network cost contribution of bitstream and made appropriate updates to the Market module that is now used by both the core modules and the access module. The core model structure, and the location of the modifications, is outlined in Figure G.9 below, with additional detail given for the changes made to the three modules. All of the changes have been linked through to the CL worksheet in the Service costing module.

Figure G.9: Location of modifications in the core model modules [Source: Analysys Mason, 2018]



[1] Changes to the demand volumes in the Market module

- A bitstream service “BSA traffic” has been added to the *A0_Lists* worksheet
- A single subscriber is assumed from 2018 onwards on the *A3_Selected Operator Data* worksheet. A single subscriber has been chosen so that the final outputs reflect the costs attributable to a single, theoretical bitstream subscriber. Introducing only a low level of bitstream traffic has a negligible effect on the allocation of common costs to other services and therefore has little effect on the current v2.0F model base case. In any case, were a larger bitstream forecast used, this would most likely require a corresponding reduction in the forecasts of the other modelled broadband services. Therefore, by assuming one bitstream subscriber in the future, we are not significantly changing any economies of scale from the broadband traffic.
- Switches have been added to the *A1_Control* worksheet to specify:
 - the modelled bitstream demand assumed in busy-hour kbit/s per subscriber
 - the service to be either a direct or indirect path to the point of presence
 - the point of presence to be at either an ER, DR or CR
- The backhaul data provisioned per subscriber has been added on the *A3_Selected Operator Data* worksheet and takes the assumed value from the *A1_Control* worksheet
- The total bitstream traffic has been calculated on the *A3_Selected Operator Data* worksheet (which in this case represents the traffic for the single subscriber assumed from 2018 onwards).

[2] Changes to the core network assumptions in the Network Design module

- A new bitstream service has been added to the *Network_service_list* named range on the *A0_Lists* worksheet and was assumed to be routed from the DSLAM to the core router (CR)
- Routing factors for the bitstream service are added to both routing factor tables on the *A3_DmdSubCalc* worksheet. The routing factors vary based on the location of the point of presence and whether the bitstream service is direct or indirect, as shown below in Figure G.10.

Figure G.10: Routing factors for bitstream (*A3_DmdSubCalc* worksheet) [Source: Analysys Mason, 2018]

Path	Point of presence	Route	IP transmission			IP routing equipment		
			Access	Dist.	Core	Access	Dist.	Core
Direct	ER	DSLAM-L2S-ER	1			1		
Direct	DR	DSLAM-L2S-ER-DR	1			1	1	
Direct	CR	DSLAM-L2S-ER-DR-CR	1	1		1	1	1
Indirect	CR	DSLAM-L2S-ER-DR-CR-CR	1	1	1	1	1	2
Indirect	DR	DSLAM-L2S-ER-DR-CR-CR-DR	1	2	1	1	2	2
Indirect	ER	DSLAM-L2S-ER-DR-CR-CR-DR-ER	1	2	1	2	2	2

- Routing factors for the bitstream service are added to both service routing factor tables on the *B4_RF* worksheet for certain assets requiring specific allocation keys. The appropriate values for direct (respectively indirect) bitstream are assumed to be the same as those used for the direct (respectively indirect) xDSL services.

By comparing the modelled product to Telenor's BSA product specification, we believe that the appropriate configuration is direct BSA to an edge router (ER), or the first line shown above. Using other configurations (e.g. direct bitstream to a DR or CR) would lead to higher costs of service as more assets are used within the network to provide the service.

[3] Changes to the core asset dimensioning in the Network Design module

- Service volumes are calculated for the bitstream service on the *A3_DmdSubCalc* worksheet
- The network service volumes are converted to equivalent minutes on the *A3_DmdSubCalc* worksheet, to be used for cost recovery.

[4] Additions to the service unit cost calculation in the Service Costing module

- The final costs of the service are set out in the Service Costing module on the *A7_Results* worksheet.

G.3 Calculating costs of busy-hour throughput

We run the core model assuming 1kbit/s per subscriber of busy-hour throughput. Since, in the core model, the cost of the service is proportional to the assumed busy-hour throughput, the cost result for 1kbit/s busy-hour throughput can then be multiplied by the assumed throughput for a product (in kbit/s) to derive a cost for the service. The assumed busy-hour throughput is therefore a key assumption, which we consider below.⁵⁹

Telenor has provided month-by-month data in 2016 and 2017 on their broadband subscribers. Busy-hour traffic throughput has been provided for xDSL, cable and fibre separately. Subscribers have been provided for xDSL, cable and fibre as well, split into retail and wholesale. xDSL subscribers have been further reported by ADSL, VDSL and SHDSL. This data shows that SHDSL take-up is small and declining. ADSL take-up is also falling, but VDSL take-up is a significant proportion of the total and is growing.

The core model includes forecasts of busy-hour throughput per subscriber for each of xDSL, fibre and cable broadband subscribers. These forecasts are defined using s-curves. We have updated these forecasts in the model to better reflect the new information provided by Telenor for 2016–2017. Our updated forecasts are shown below. We have assumed some growth in xDSL due to growth in VDSL traffic.

⁵⁹ It should be noted that there is no committed capacity for an ADSL Basis subscriber or VDSL Basis subscriber in Telenor's bitstream product specification.

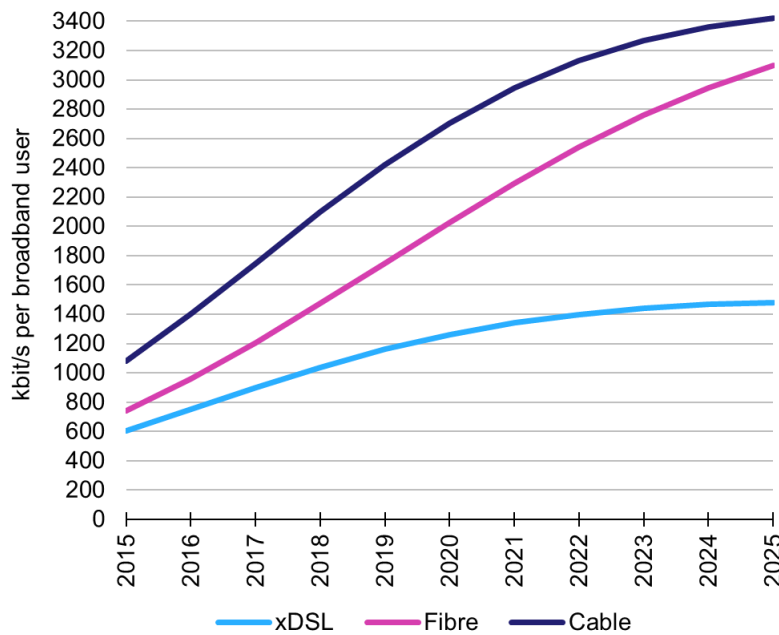


Figure G.11: Forecasts of busy-hour throughput by technology [Source: Analysys Mason, 2018]

In order to derive a reasonable busy-hour throughput, we have used the data provided by Telenor. Since this data was for xDSL in total, rather than the different types of xDSL, we have had to de-average values for each type (ADSL, VDSL) and then further for each wholesale product for each type. We describe these stages of de-averaging in turn below.

G.4 De-averaging busy-hour throughput corresponding to ADSL/VDSL BSA products

To first de-average between ADSL and VDSL, we assume that VDSL throughput per subscriber is 90% of that of a fibre subscriber (the throughput per fibre subscriber can be calculated directly from Telenor's traffic data for 2016–2017).⁶⁰ This then allows the de-averaging of xDSL into “VDSL” and “other”. We assume that the “other” category is representative of ADSL, although it does include some SHDSL traffic as well.

There are two products in the current wholesale offer for ADSL Basis and three products for VDSL Basis.⁶¹ We assume the busy-hour throughputs for these products as shown below.

Figure G.12: Assumed busy-hour throughput by wholesale product [Source: Analysys Mason, 2018]

Wholesale product	Assumed busy-hour throughput (kbit/s)
ADSL Basis: 160–7200kbit/s	$850 \div 1.50 = 567$
ADSL Basis: 7200–24000kbit/s	$850 \times 1.00 = 850$
VDSL Basis: 12960–27008kbit/s	$850 \times 1.05 = 893$
VDSL Basis: 22016–36000kbit/s	$850 \times 1.15 = 978$
VDSL Basis: 32000–63500kbit/s	$850 \times 1.45 = 1233$

⁶⁰ We are of the view that assuming VDSL throughput per subscriber is the same as that for fibre is not reasonable. Equally, if we assume that VDSL throughput per subscriber is 80% that of fibre, then in some months, the resulting de-averaged ADSL throughput is almost higher than that for VDSL. Therefore, we believe that assuming the midpoint (90%) is a reasonable assumption.

⁶¹ Other products listed in the published offers are no longer available for new subscriptions.

We describe our reasoning for these assumptions for ADSL and VDSL in turn below.

► *ADSL*

SSB publishes high-level data on broadband subscribers by speed. This indicates that, in Q4 2016, of the connections with speeds of 8Mbit/s or less, only 20% have speeds of 4Mbit/s or less. Further, the retail product with the lowest speed currently available from Telenor is 5Mbit/s. Therefore, we would propose to use this 5Mbit/s value as representative for the 160-7200kbit/s downstream wholesale product.

Ofcom have published their own statistics in their Connected Nations report,⁶² indicating how average headline download speed is related to average monthly data usage per premise in the UK. We have considered the information shown in the context of Norway's 7.2Mbit/s–24Mbit/s product range compared to the 5Mbit/s speed. Based on the chart published by Ofcom, it can be seen that in the UK (i) the average usage in the 7.2Mbit/s–24Mbit/s range is broadly flat and (ii) that this level of usage is approximately 1.5 times that for 5Mbit/s.

Assuming that the same relationship holds in Norway and that average busy-hour throughput per subscriber is proportional to average usage per subscriber per month⁶³, we conclude that the busy-hour throughput for the 160–7200kbit/s product should be set as the busy-hour throughput for the 7200–24000kbit/s product divided by 1.5.

We have received a breakdown of wholesale ADSL/SHDSL subscribers by individual product from Telenor. When we apply the assumptions in Figure G.12, the subscriber weighted-average busy-hour throughput per ADSL subscriber corresponds closely to that indicated by Telenor's data for mid-2017.⁶⁴ The assumed busy hour traffic per subscriber figures are therefore consistent with the available data.

► *VDSL*

We have also received a breakdown of wholesale VDSL subscribers by individual product from Telenor. When we apply the assumptions in Figure G.12, the subscriber weighted-average busy-hour throughput per VDSL subscriber corresponds closely to that indicated by Telenor's data for mid-2017. The assumed busy hour traffic per subscriber figures are thus consistent with available data.

All of these assumptions taken together allow Nkom to consider costs of ADSL Basis and VDSL Basis services using this revised version of the core model.

⁶² See https://www.ofcom.org.uk/__data/assets/pdf_file/0028/95581/final-report.pdf, Figure 3.1.

⁶³ This assumption is used frequently: for example, in the LRAIC model published by the Danish regulator.

⁶⁴ We assume that SHDSL subscribers achieve 10% more than their specified minimum committed rate.

Annex H Expansion of acronyms

Acronym	Definition of acronym
ADSL	Asymmetric digital subscriber line
BL	Original building coordinates
BSA	Bitstream access
BU	Bottom-up
CCA	Current cost accounting
CPS	Carrier pre-select
CTTH	Copper to the home
DF	Distribution frame
EC	European Commission
EFTA	European Free Trade Association Surveillance Authority
EPMU	Equi-proportionate mark-up
ESA	EFTA Surveillance Authority
FCC	Federal Communications Commission
FCM	Financial capital maintenance
FDP	Final distribution point
FTTC	Fibre to the cabinet
FTTH	Fibre to the home
FTTN	Fibre to the node
HCPM	Hybrid Proxy Cost Model
IN	Intelligent network
IP	Internet protocol
IPTV	Internet protocol television
ISDN	Integrated services digital network
LLU	Local loop unbundling
LRAIC	Long-run average incremental cost
LRIC	Long-run incremental cost
MDF	Main distribution frame
MEA	Modern equivalent asset
NGA	Next-generation access
Nkom	Norwegian Communication Authority
NGN	Next-generation network
NPT	The Norwegian Post and Telecommunications Authority
NRC	Net replacement cost
OCM	Operating capital maintenance
PBP	Property boundary point
PC	Personal computer
PDP	Primary distribution point
PGS	Pair-gain systems

Acronym	Definition of acronym
PON	Passive optical network
PSTN	Public switched telephone network
PTP	Point to point
RAB	Regulatory asset base
RCEA	Reusable civil engineering assets
RCP	Road centre point
RSX	Remote switching stage or remote switching unit
SDP	Secondary distribution point
SLU	Sub-loop unbundling
SMP	Significant market power
SSB	Statistisk Sentralbyrå
TDM	Time-division multiplex
TN	Telenor
TSP	Travelling Salesman Problem
VB	Visual Basic
VDSL	Very-high-bitrate digital subscriber line
VPN	Virtual private network
WLR	Wholesale line rental