



# Business Connectivity Market Review Model Audit

Final Report (NON CONFIDENTIAL)

Version 1.0

16 April 2015

Prepared for:



## Version History

Version	Date	Author	Changes	Distribution	Approval
1.0	16/4/2015	Cartesian	Final report for publication	Public	M Dargue

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## 1. Executive Summary

Ofcom is currently undertaking a Business Connectivity Market Review (BCMR) to examine retail and wholesale connectivity services.

There are two important analyses for the current BCMR (BCMR 2016) involving large datasets, which will inform the market definitions and Significant Market Power (SMP) determinations:

- The Network Reach analysis, which measures the extent to which BT's competitors have laid their own networks in different parts of the UK; and,
- The Service Share analysis, which measures the market share of the different types of leased lines that BT and its competitors supply.

The above two analyses are supported by the Postcode analysis, which ensures that postcode input data is verified and addresses are mapped to the latest valid postcode.

Ofcom engaged Cartesian to review the two analyses of 2016 BCMR consultation as well as the Postcode analysis to identify any issues that potentially threaten the robustness of the model.

We used a combination of methodologies to audit the functionality of the analysis.

*Black box testing:* We independently re-created Ofcom's analyses using our own tools. Results from our analyses were compared with those generated by Ofcom. This method provided an objective way to validate Ofcom's analysis.

*Manual inspection outputs and a code review:* A manual inspection of outputs generated by Ofcom and a review of the code was also carried out. This provided an opportunity to identify other potential errors in the analysis, had there been any.

In our review of the two analyses in the BCMR consultation we found both the Network Reach and Service Share analysis to be robust in functionality and accuracy. We did not identify any issues that would impact the results of either analysis.

From a black box testing perspective there were no material differences between the results generated by our independent analysis and those generated by Ofcom for both the Network Reach analysis and the Service Share analysis.

While we found no reason to change Ofcom's methodologies for this review period, our review of the analysis implementation enabled us to develop a set of recommendations that Ofcom may want to consider in future implementations of both the Network Reach and Service Share analyses. These considerations are listed at the end of this report.

## 2. Introduction

Ofcom is currently undertaking a Business Connectivity Market Review (BCMR) to examine retail and wholesale connectivity services.

Ofcom last reviewed the market for business connectivity services in 2013 in which it identified and defined a number of distinct markets on the basis of interface technology, bandwidth and geography.<sup>1</sup> In the BCMR 2013, Ofcom determined that BT and KCOM each held significant market power (SMP) in a subset of these markets.

For the current BCMR (BCMR 2016) there are two important analyses involving large datasets which will inform the market definitions and SMP determinations:

- The Network Reach analysis, which measures the extent to which BT's competitors have laid their own networks in different parts of the UK; and,
- The Service Share analysis, which measures the market share of the different types of leased lines that BT and its competitors supply.

The above two analyses are supported by the Postcode analysis, which ensures that postcode input data is verified and mapped to the latest valid postcode.

On 8 October 2014, Ofcom published a consultation on the data analysis.<sup>2</sup> The scope of the consultation included the data requested and the methodologies, assumptions and judgements that Ofcom has used to clean the data. As part of the consultation, Ofcom also sent each communications provider (CP) a cleaned version of the data that it had provided to review and comment on the outputs of the data processing.

Ofcom intends to publish the main BCMR consultation in the spring of 2015. Before publishing the BCMR consultation, Ofcom required an independent review of both the Network Reach and Service Share analysis.

## 3. Project Overview

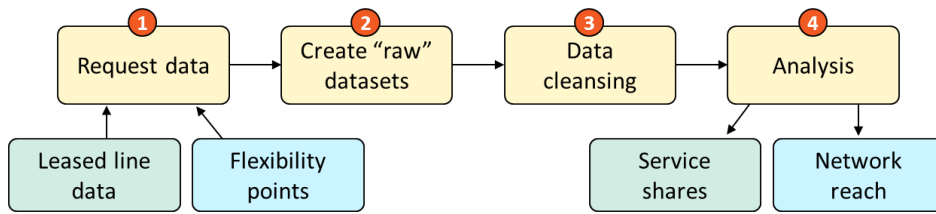
This project was focused on auditing the functionality of the Network Reach and Service Share analyses. To perform this audit effectively we relied heavily on Ofcom's documentation, in-house experts and the most recent available versions of the analysis implementation files. We acknowledge that in some cases we used data that may in the future be updated, however this would have no impact on the validity of the methodology audit.

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<sup>1</sup> Ofcom, *Business Connectivity Market Review*, 28 March 2013. <http://stakeholders.ofcom.org.uk/consultations/business-connectivity-mr/>

<sup>2</sup> Ofcom, *Business Connectivity Market Review: Consultation on Data Analysis*, 8 October 2014. <http://stakeholders.ofcom.org.uk/consultations/bcmr-data-analysis/>

Figure 1. Ofcom Key Steps in Data Analysis



Source: Ofcom

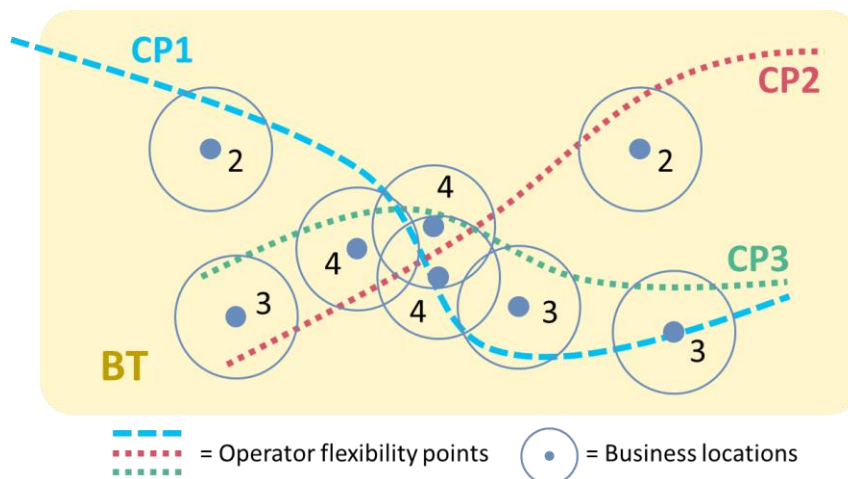
### 3.1. Network Reach Analysis

Ofcom purchased a list of all UK business locations from Market Location. All locations of businesses with 250 or more employees were filtered from this list and selected for further analysis. In parallel operators were asked to provide a list of locations of their network flexibility points.

For each business location in the list Ofcom calculated the shortest distance to each network flexibility point for every communications service provider (CP). Each CP network is represented by the flexibility points in the data.

For each postcode sector Ofcom calculates the number of network operators with at least one flexibility point within a 200m radius of every business. This sum is then divided by the sum of businesses in the post code sector. The result is the network reach score for the postcode sector.

Figure 2. Ofcom Network Reach Analysis Overview



Sum of networks = 4+4+4+3+3+3+2+2 = 25

Sum of businesses = 8

Network reach = 25/8 = 3.125

Wholesale Service Reach Analysis

Source: Ofcom

A small C++ program was used to calculate distances between business locations and network flexibility points. Additional analysis and outputs, including the network reach score are implemented in Excel.

### 3.2. Service Share Analysis

Ofcom requested all CPs to provide an inventory of leased line sales and purchases.

For each leased line, CPs were requested to supply data on the line’s interface (Ethernet, AI, etc.), bandwidth, postcodes for locations at each end of the leased line, and the CP footprint classification of the site at each end (e.g. on-net vs off-net).

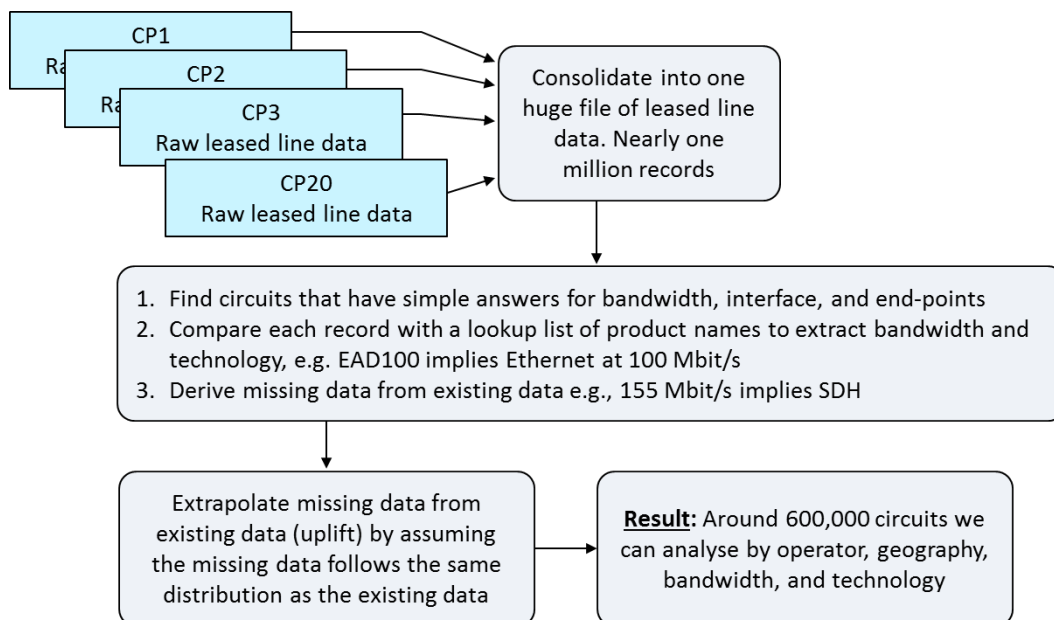
Ends that were considered non-UK/International, as determined by their address, were not considered in the analysis.

Ofcom requested additional data from CPs on their network sites as well as joint network/customer sites to classify each end of the circuit data as either a network or customer site.

In many instances data provided by CPs was incomplete and presented in non-standard formats. Ofcom processed the data to standardize formats and terminology as well as extrapolate missing data points.

The leased line records were then aggregated by different variations of interface, bandwidth and geographic area to estimate CP service share.

**Figure 3. Ofcom Service Share Analysis Overview**



Source: Ofcom

MS Access was used to implement all data extraction processes leading up to the data extrapolation/uplift process. Due to data size limitations of MS Access, MySQL was used to implement the data extrapolation/uplift process.

### 3.3. Postcode Analysis

Ofcom developed the Postcode analysis database to allow for streamlining and automating – to the extent that is practically feasible – the processing of postcode information.

The BCMR Postcodes analysis database produces a single table containing postcode definitions known to Ofcom, including the postcode itself, the geographic coordinates (Easting, Northing) of the postcode's centroid and, where a postcode has been invalidated, the corresponding (new) postcode.

The mapping of old (invalidated) postcodes to new postcodes is performed using MAPINFO. MS Access was used to develop the Postcode analysis database.

## 4. Our Approach

We used a combination of two distinct techniques to audit the Network Reach analysis, Service Share analysis and Postcode analysis. A description of these techniques can be found in section 4.1 of this report.

In order to ensure that we validated the most critical aspects of the analysis, we enumerated key steps in Ofcom's analytical process and addressed the audit of each process step with an appropriate combination of audit techniques. A mapping of these process steps and our audit methodology can be found in section 4.2 of this report.

### 4.1. Audit Methodologies Overview

#### Black Box Testing Overview

We sought to recreate Ofcom's analysis based on provided documentation and source files, comparing our outputs and results against those generated by Ofcom's analysis.

The primary tool used to black box test the Network Reach module was PostgreSQL, with the PostGIS extension installed. For authoring and execution of all queries was undertaken using pgAdmin III, an administrative tool for PostgreSQL which includes components supporting the development of SQL queries.

The primary tool used to black box test aspects of the Service Share analysis was Alteryx. We used Alteryx to independently re-create large blocks of Ofcom's analysis, sometimes using Excel in conjunction to test individual calculations.

#### Review of Code Logic and Manual Inspection Overview

We performed a close inspection of code logic to ensure that the analysis followed Ofcom's intent, based on a review of the documentation and several discussions with Ofcom. We also selectively reviewed outputs generated by Ofcom's analysis manually.

GeoServer was used for visual 'sense check' validation of components. To visualize the data stored in PostgreSQL as layers we used Ascertain, a Cartesian-developed software platform. Both Ascertain and GeoServer run in the same virtual machine as the database.

Operis Analysis Kit (OAK) was also used to validate calculations in Excel.



## 4.2. Mapping Analysis Processes for Audit

In order to effectively audit the Network Reach, Service Share analysis and Postcode we mapped out key steps within the analysis and used appropriate methodologies to validate individual stages in the analysis. We audited each process step leveraging the approach that was most appropriate to provide a high level of confidence in the findings/results.

**Figure 4. Key Process Steps Audited in the Network Reach Analysis**

Process	Process Elements	Audit Approach	Tools	Key Findings
Data Extraction and Preparation	For each CP coordinate transform raw data of network flex points provided by CPs into Eastings and Northings using MapInfo (where necessary), throw away any data that is obviously visually incorrect (e.g., points that map to the middle of the ocean)	Review of code logic, black box testing and manual output inspection	N/A	See EASTING & NORTHING DATA CONVERSION AND CONSOLIDATION REVIEW
	Merge flex point data from each CP into one file containing all network points for all CPs	Review of code logic, black box testing and manual output inspection		
Data Processing and Analysis	Network reach scores for a 200m, 500m and 1000m for each post code sector	Review of code logic, black box testing and manual output inspection	PostGRES/GIS	See NETWORK REACH SCORE CALCULATIONS REVIEW
			Alteryx	
Additional Analyses	Sum of flexibility points for each operator; Average distance to BT network and any OCP network; Sum of businesses with 0, 1, 2,...13 operators within 200m; Postcode sectors for specific cities; Postcode sectors forming the 2013 WECLA and 2008 CELA; Total and per MNO mobile sites; Additional summary of network reach calculations at city and regional levels	Review of code logic and manual inspection	OAK	See ADDITIONAL EXCEL CALCULATIONS REVIEW

**Figure 5. Key Process Steps Audited in the Service Share Analysis**

Process	Process Elements	Proposed Audit Approach	Tools	Key Findings
<b>Data Extraction and Preparation</b>	Extracting Raw Data: Performing a union on data from various providers	Review of code logic, selective black box testing and manual output inspection	N/A	See CP DATA TRANSLATION AND CONSOLIDATION REVIEW
	Data Translation: Mapping table field labels from various providers to a common set standardized by Ofcom and Identifying and drawing inferences on missing pieces of data based on existing information mapping	Review of code logic, selective black box testing and manual output inspection	N/A	
<b>Data Processing and Analysis</b>	Clean-up and estimation of network sites: Establishing Eastings and Northings for CP provided data	Review of code logic, selective black box testing and manual output inspection	Alteryx	See NETWORK SITES CLEAN-UP REVIEW
	Data Uplift Approach: Data for unknown values for postcode, sub-market and on-net/off-net are uplifted from existing data sets	Review of code logic, selective black box testing and manual output inspection	Alteryx	See UPLIFT ANALYSIS REVIEW
	Designating locations as Network or Customer Sites: 4 Scenarios developed by Ofcom to designate classification of circuit end-types as either Network or Customer based on site lists	Review of code logic, selective black box testing and manual output inspection	Alteryx	See JOINT CUSTOMER & NETWORK SITE SCENARIOS REVIEW
<b>Additional Analysis</b>	Output tables/files and additional cuts of data (e.g. testing logic for build-up service share to city level)	Review of code logic, selective black box testing and manual output inspection	Alteryx/OAK	See ADDITIONAL ANALYSES

**Figure 6. Key Process Steps Audited in Postcode Analysis**

Process	Process Elements	Proposed Audit Approach	Tools	Key Findings
<b>Data Processing and Analysis</b>	Postcode Analysis and Clean-up: Mapping old post codes to new post codes from various post code data sets and mapping Eastings and Northings for each postcode entry	Review of code logic, selective black box testing and manual output inspection	Alteryx	See POSTCODE MATCHING ANALYSIS REVIEW

## 5. Key Findings from Analysis

We focused our analysis on the key processes and their respective elements defined above for both the Network Reach and Service Share analyses. In the next two sections we highlight the findings from auditing each of the key process steps in the analysis. For each process step the objective of the audit was to validate that results generated by Ofcom's analysis were in line with our expectations.

### 5.1. Network Reach Analysis

#### 5.1.1. Data Extraction and Preparation

##### **EASTING & NORTHING DATA CONVERSION AND CONSOLIDATION REVIEW**

###### Ofcom Process Overview

The CP-provided data for flexibility points requires some conversions to consistent and usable formats (e.g., Lat/Long data to Eastings and Northings, up-to-date postcodes), as well as aggregation into single files prior implementation in the Ofcom analysis. Ofcom implemented a number of automated and manual processes and checks to execute this portion of the analysis.

###### Audit Approach

Data received from operators for network flexibility points required varying degrees of preparation, cleansing, and aggregation prior to use in the Network Reach analysis. Cartesian reviewed a selection of raw operator data to validate that the extraction and aggregation process was performed accurately. Cartesian decided to review the extraction process for one operator that required a particularly complex extraction process and for another that was considered representative example of a typical extraction. By auditing a more complex extraction and a typical extraction process Cartesian was able to gain comfort around outputs of all other extraction processes.

Cartesian successfully recreated the raw data used in the Network Reach analysis for specific spot-checks of the CPs that were selected for validation. While it was possible to recreate the aggregated data used in the analysis, we encountered a few challenges in clearly understanding the extraction process and locating the correct files to extract from.

###### Findings

Cartesian found no errors in the extraction process for the Network Reach analysis.

However, the methodology would benefit from more comprehensive documentation. As is often the case for analyses involving numerous disparate data sources, the varied nature of the operator inputs can lead to complicated data cleaning and aggregation exercises. While existing documentation is good overall, it could be slightly clearer on updates to the data or data-cleaning processes after the initial sets were provided by the operators.

Business location data was provided by a third-party and therefore was not audited as part of this exercise.

### 5.1.2. Data Processing and Analysis

#### NETWORK REACH SCORE CALCULATIONS REVIEW

##### Ofcom Process Overview

The primary outputs from the Network Reach analysis are the specific Network Reach scores for postcode sectors and other defined geographic areas. The Network Reach score is calculated as the average number of Network Operators within reach from each business, a network operator is considered within reach of a business when the distance between the business and the network flexpoint distance is less than or equal to a defined radial distance.

In this version of the model Ofcom calculated these scores for radial distances of 200, 500, and 1,000 metres. While the model calculated these distances at the time of the review, the logic would extend to any distances used in the future and work in exactly the same way; our audit of these distances gives us confidence that the model will function correctly and accurately for any other distances used in the model.

##### Audit Approach

Cartesian implemented “black box” testing of the Network Reach scores and distance calculations between businesses and flexibility points for comparison with the Ofcom outputs. The validation was performed at a postcode-sector level, with additional investigation of specific businesses and their respective distance calculations when appropriate.

##### Findings

Cartesian found no errors in the Network Reach score calculations.

Results for Network Reach scores at a postcode sector level from Cartesian’s analysis matched almost perfectly with Ofcom’s results. However, due to differences in floating point number precisions in the programs used (e.g., C++ vs. PostgreSQL), there were a few instances of small differences in the scores. It should be noted that these minor differences were not significant enough to push any of the postcode sectors into or out of the High Network Reach category

### 5.1.3. Additional Calculations

Along with Cartesian’s validation of the detailed analysis producing the Network Reach score outputs, we reviewed additional aggregated calculations performed by Ofcom.

#### ADDITIONAL EXCEL CALCULATIONS REVIEW

##### Ofcom Process Overview

Ofcom aggregated the detailed Network Reach analysis results into a selection of City and Regional outputs. These results were included in the latest version of the Network Reach analysis Excel file.

##### Audit Approach

The accompanying Excel workbook developed by Ofcom to analyse the network reach calculations was straightforward and only contained a few sheets with calculations relevant for the final results. The preliminary additional calculations were tied directly to the summary outputs at a postcode-sector level. Cartesian conducted a manual review of these calculations to ensure there were no conceptual or syntactic errors in the summary.

### Findings

No errors were found in the Excel workbook.

## 5.2. Service Share Analysis

### 5.2.1. Data Preparation

#### CP DATA TRANSLATION AND CONSOLIDATION REVIEW

Cartesian's validation of the Service Share analysis began with the data preparation steps Ofcom took to extract, aggregate, and clean up the various sets of data provided by CPs. This exercise was integral to the overall analysis audit, as any inaccuracies identified in data preparation could impact the accuracy of the overall service share findings.

#### Ofcom Process Overview

The Service Share analysis required multi-stage cleansing and aggregation for the more detailed circuit-level data received from CPs. Ofcom's initial task in the Service Share analysis attempted to fill in missing pieces of information in the received data, as well as merge the varying terminology and field names into a common set of data for use in the Access and SQL data processing steps.

While the majority of the operator-provided data contained sufficiently accurate information, there were a number of records for many operators with one or more missing or incomplete fields. When these fields were vital to the Service Share analysis (e.g., Market, Postcode, Submarket, On-Net/Off-Net), Ofcom attempted to fill or update in the missing or incomplete fields based on the circuit information of other circuits.

#### Audit Approach

The first step of validating the data preparation included spot-checking the processes performed on a selection of operator-provided circuit data and other inputs for the service share analysis. Most of the raw operator data was similarly formatted so we randomly selected operators determined to be representative of the data aggregation process, providing us with confidence that the remaining operator data was also correctly added into the analysis. For this section of the audit we recreated the joining process for aggregating multiple files into a single set of input data for the analysis.

The criteria for filling in incomplete or inaccurate information for these circuits was developed by Ofcom in the form of the translation tables and approved by respective operators as an accurate method of cleaning up their provided data.

#### Findings

We were able to reproduce with 100% accuracy the same results of the joining / cleaning process for all of the selected raw data spot-checks. Following these tests we are confident the operator data has been accurately joined for use as inputs in the analysis.

Cartesian's discrete spot-checks on a random selection of the translation tables also resulted in identical reproduction of the updated set of data. Both the development of the tables (from other operator data) and their application in completing the incomplete or missing fields were tested to ensure both processes were free of errors. Individual operators also had the opportunity to review and offer feedback on the translation tables and resulting "cleansed" outputs from this process, so along with Cartesian's spot-check of the analysis we have concluded there are no errors.

### 5.2.2. Data Analysis

Once the raw data extraction process and application of translation tables had been validated, Cartesian audited the Service Share analysis itself. One additional set of data involved in the analysis, the list of network sites provided by operators, was reviewed.

#### NETWORK SITES CLEAN-UP REVIEW

The Network sites list was used in the analysis to filter out circuits that served postcodes with network sites that should not necessarily be included in the Service Share analysis. Some postcodes contained both customer and network sites, and were flagged accordingly to allow for different assumptions with respect to which postcodes and circuits should be excluded in the analysis.

##### Ofcom Process Overview

Ofcom aggregated a number of data files pertaining to these sites based on a developed set of scenarios, depending on how the joint customer-network sites were to be treated for the purpose of filtering network ends. For example, a joint customer-network site listed by a specific CP could either be treated as a customer site for that CP, a customer site for all CPs, or left as a network site.

##### Audit Approach

A list of the network site postcodes was provided by each operator. Cartesian aggregated and matched the full list of D1 sites with the provided lists of postcodes that were both customer and network sites. Cartesian then recreated the specific Ofcom scenarios based on provided documentation, comparing results of the different criteria to the corresponding Ofcom outputs.

##### Findings

This matching resulted in some incorrect or invalid postcodes for the joint customer-network sites, which is in line with the results Ofcom experienced performing the same analysis.

Upon further discussion of these findings with Ofcom we identified that the majority of erroneous postcodes could be attributed to one particular CP with relatively low circuit volumes. Therefore there was no impact on the findings of the service share analysis as a result of these erroneous postcodes, particularly for scenarios where joint customer/network sites are applied at a per-CP level.

#### UPLIFT ANALYSIS REVIEW

##### Ofcom Process Overview

The key component of Cartesian's audit concerned the various "uplifts" performed at the final stage of the Service Share analysis. The primary objective of the uplift analysis was to proportionately allocate circuits with unknown information {for either Postcode, Bandwidth ranges (Submarket), or On-Net/Off-Net data} based on the share of circuits that matched the known variables of the circuits that are uplifted.

Ultimately 7 distinct uplifts are performed on the data: 3 uplifts where only one of the 3 key variables is unknown (e.g., postcode); 3 uplifts where two of the variables are unknown (e.g., postcode and submarket); and, 1 uplift where all three variables are unknown.

### Audit Approach

To validate this analysis Cartesian conducted both a detailed code review of each distinct type of uplift (1 Unknown, 2 Unknowns, 3 Unknowns), as well as a “black box” test to recreate the uplift values independent of the Ofcom analysis.

### Findings

Cartesian’s detailed code review did not find any errors in the Access or SQL queries. Overall code and queries are correct and free of any issues that could impact final results. The results of the “black box” test also aligned with Ofcom’s outputs, matching the majority of the circuit IDs to a very high degree of accuracy (6 decimal places).

## JOINT CUSTOMER AND NETWORK SITE SCENARIOS REVIEW

### Ofcom Process Overview

In order to test the impact of different approaches to designating specific circuits as either Customer or Network ends, Ofcom developed four distinct scenarios for circuit end classification. These scenarios are based on operator-provided data on existing network sites and joint customer/network sites, with the provided data referencing specific postcodes in which they have either a network site or a joint customer/network site. The treatment of the list of operator customer/network sites was the main source of the differences in the scenarios and determining whether the circuits in that postcode would be classified as a customer site or network site for each of the operators.

The scenarios are as follows:

- Scenario 1: All circuit ends in a network site are considered “network ends” for ALL operators; joint customer/network sites are NOT excluded from the network site list.
- Scenario 2: All circuit ends in a network site are considered “network ends” for ALL operators; ALL joint customer/network site postcodes are excluded from the network site postcode list for ALL operators (i.e., all circuit ends in a joint/customer network sites are considered “customer ends” irrespective of the listed operator).
- Scenario 3 (this scenario is used to generate Ofcom’s base case estimate): All circuit ends in a network site are considered “network ends” for ALL operators; joint customer/ network sites are excluded from the network site list on a PER OPERATOR basis (i.e., a listed joint customer-network site for Operator A would be a “customer end” for Operator A, but still a “network end” for Operator B if it is listed as a network site).
- Scenario 4: Network sites and joint/customer sites are applied on a PER OPERATOR basis (i.e., a circuit end in a network site is considered a “network end” ONLY for the operator that listed the postcode as a network site, and if the same site is NOT listed as a joint customer/network site for that specific operator).

### Audit Approach

Cartesian used a black box testing approach to validate the outputs of the different scenarios for creating a list of operator network sites to be applied to the Service Share analysis model. Cartesian used Alteryx software to combine, filter, and aggregate the data for each of the four scenarios to provide validation of the Access queries with a different software. Outputs of each scenario (provided by Ofcom) were

compared with Cartesian's results from taking all input files and applying the criteria specified by Ofcom for each of the scenarios.

The relevant output of each scenario analysis was only the resulting lists of operator network sites; the list of customer sites was not material to the analysis, as only the network sites are used to flag specific circuit ends that will ultimately be excluded from the analysis.

### Findings

The results of the black box testing performed by Cartesian matched the results provided by Ofcom for all 4 scenarios. As the remainder of the Service Share analysis that used the resulting data from the Scenarios had been previously validated and found to be both robust and accurate in its calculations, we are confident that the end-results of any calculations using the different scenarios are equally correct.

## ADDITIONAL ANALYSES

### Ofcom Process Overview

For an aggregated view of the data produced in the preceding Service Share analysis Ofcom produced service share statistics and network reach statistics presented in two separate spreadsheets. Both worksheets use outputs from a separate Access database that pulls in data from the final outputs of the Network Reach and Service Share models.

Once the Access data is pulled into the Excel files, a number of formulas and named ranges are used to aggregate the Network Reach and Service Share data at a city and regional level, with additional calculations, such as combined operator market shares, HHI, network reach scores by various segments, also included.

### Audit Approach

The provided Access database was reviewed to ensure the input tables (taken from the Network Reach and Service Share models) aligned with outputs, in addition to reviewing some of the key queries to input and output the relevant data. Selected Access queries were further validated using Alteryx to recreate the results of the output tables.

Cartesian primarily used OAK (Operis Analysis Kit) to help map out the structure and formulas used in Ofcom's Excel files containing the additional analysis of the Service Share and Network Reach data produced by previous models. Individual formulas were manually inspected for consistency and validity in calculating the different values.

### Findings

Ofcom's Additional Analysis contained no errors in formulas or cell references, and individual spot-checks of outputs yielded matching results to the calculations in the provided spreadsheets. The Access database was also free of errors and straightforward in its queries to aggregate / transform the data to be used in the Excel files.



### 5.3. Postcode Mapping Analysis

#### 5.3.1. Data Processing and Analysis

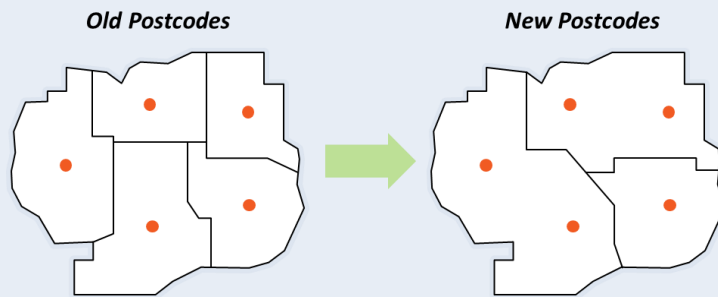
##### POSTCODE MATCHING ANALYSIS REVIEW

Data received from operators contained a wide range of now-defunct postcodes for the location of circuits, network sites and flexibility points. These older postcodes needed to be converted to the most recent list of postcodes for use in the Service Share analysis.

##### Ofcom Process Overview

To build the comprehensive list of postcodes for use in the Service Share analysis, Ofcom aggregated a number of older postcode lists (dating back to 2003) into a single database. The centroid of these older postcodes are then mapped to the polygons of the most recent list of postcodes to provide a conversion postcode for each of the older sets of postcodes. An illustration of this process is provided below.

**Figure 7. Old Postcode Centroid Mapping**



##### Audit Approach

Cartesian reviewed the Ofcom Access files related to this process, as well as conducting an independent analysis of the final list of postcode matching used in the later stages of Ofcom’s analysis.

##### Findings

Upon review Cartesian found varying degrees of accuracy in the underlying postcode data, whereby the “centre” of the same older postcodes had been mapped to a different new postcode, resulting in multiple possibilities for postcode conversions. In addition, it was discovered that a number of newer postcodes had a very high volume of older postcodes mapped to them.

Following discussions with Ofcom, these occurrences were determined to be the result of PO boxes included as the location for certain circuits, though the volume of circuits this impacted was low and steps have already been taken by Ofcom to remedy the situation.

We believe the observed variation in the accuracy of the postcode data will have no impact on the validity of the Service Share analysis. This is because the Service Share analysis is performed only at the Postcode Sector level or, more commonly, at a regional level.

## 6. Overall Conclusions and Considerations for Future Implementations

Overall we found both the Network Reach and Service Share analysis to be robust. We did not identify any issues that could impact the results of either analysis.

There was no material difference between the results generated by our independent analysis when compared with results generated by Ofcom for both the Network Reach analysis and the Service Share analysis, further re-enforcing the accuracy and robustness of the Ofcom models. A detailed review of the implementation enabled us to develop a set of recommendations that may simplify, improve the ease of audit and better safeguard business continuity for both sets of analyses in the future.

### 6.1. Future Implementation Considerations for Network Reach Analysis

- As previously discussed we needed significant additional guidance from Ofcom in order to fully re-create the data extraction process. Therefore we recommend that Ofcom consider documenting the data extraction process to a greater extent to assure business continuity and facilitate an easier model audit process in the future.
- Currently, Ofcom uses a combination of a small C++ program and Excel to implement the Network Reach Analysis. Cartesian re-created this analysis using PostgreSQL with Post GIS. Implementing this analysis on a single toolkit can lead to several benefits for Ofcom, such as a more straightforward audit process, a less time-consuming process to handle changes to the analysis and less reliance on in-house experts. Therefore Ofcom could consider using a tool capable of performing the end-to-end analysis for future implementations of the Network Reach analysis.

### 6.2. Future Implementation Considerations for Service Share Analysis

- The Service Share analysis is implemented partially on Access and partially on MySQL. MySQL was adopted to facilitate the uplift process as this process requires significant manipulation of large datasets. Going forward we recommend that Ofcom consider consolidating all analysis related to service share on MySQL as opposed to dividing portions of the analysis between Access and MySQL. Consolidating the analysis implementation on one tool may lead to several benefits (as discussed previously).
- Dealing with postcode location data can be problematic due to the evolving nature of postcode boundaries. The Service Share analysis in its current state mitigates this issue as the analysis is summarized at the postcode sector level. However a more granular approach to calculating service share (e.g., Postcode level) could expose the analysis to errors in the data. Ofcom may wish to consider asking CPs to provide data in Eastings and Northings to potentially avoid this issue. However, we concede it may not be a trivial process for CPs to comply with this request

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