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NEXT GENERATION NETWORKS

Network Assessment Tool: Interim Development Report

Electric Nation

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Glossary

Abbreviation	Term
BaU	Business as Usual
NOP	Normally Open Point
NCP	Normally Closed Point
EV	Electric Vehicle
WPD	Western Power Distribution
NAT	Network Assessment Tool
REC	Regional Electricity Board
UI	User Interface
SQL	Structured Query Language
SSIS	SQL Server Integration Services
WMS	Web Mapping Server
C#	.NET framework based object-oriented coding language
ERD	Entity Relationship Diagram
Feeder	A circuit which feeds electrical energy from a substation
MPAN	Meter Point Administration Number
Vector Data Model	Data stored as co-ordinates
Raster Data Model	Matrix of pixels (i.e. image based)
Adjacency Model	Pathfinding, redistricting, allocation
Coincidence Model	Topological overlay, intersection analysis
Geometric Model	Distances between points, buffers and perimeters
Convex Hull	Geometrical spatial analysis method

1 Executive Summary

The ongoing development of the prototype Network Assessment Tool (working title) described in this report is being developed by EA Technology as part of the Electric Nation project. This report describes the progress and developments to date from the previous report in late July 2017.

EA Technology has continued the development activities as previously described to implement the user interface and to improve the algorithmic spatial processing to reconstitute local distribution network data to a point where network load studies can be implemented. After this phase is complete further work will then progress to establish a method for EV scenario-based analysis across all identified local networks across all Western Power Distributions' four licence areas.

EA Technology have completed a manual review of the current iteration of the spatial processing results to develop a complete categorisation of the identified failure modes. Subsequently, these outputs have informed the design of a mechanism to automatically flag a successful interpretation versus a failed attempt. Following on from this, a further method has been designed and is currently under manual review to estimate a simplified line and load model as a fall-back position for any failed reconstitution of available data to produce a full network design and load analysis using the DEBUT engine.

In parallel with the algorithmic iterations and reviews, further efforts have concentrated on the user interface implementation. The initial user interface as detailed in the previous report has now been developed and is providing a stable and efficient platform which is further aiding in manual reviews and algorithmic refinements.

Next steps in development of the Network Assessment Tool have also been developed, which are primarily the implementations of the newly designed mechanisms. Once complete, focus will begin to be shifted over to the EV analysis phases and the user interface requirements to facilitate this functionality.

2 Introduction

This report details the ongoing development of the Network Assessment Tool (working title) since the last progress report (July 2017). The tool aims to provide LV network planners with a new platform to view and assess LV networks under future Electric Vehicle (EV) market scenarios and assess the potential benefit of using smart charging as a method to delay or avoid the need to reinforce networks overloaded by EV charging loads.

The tool is currently under development; development has been phased into three distinct workstreams; data transformation and pre-processing; the user interface and the calculation engine. A full development update on the progress to date is provided within this report alongside a status update for each development path.

2.1 The Electric Nation Project

Electric Nation is the customer-facing brand of CarConnect, a Western Power Distribution (WPD) and Network Innovation Allowance (NIA) funded project. WPD's collaboration partners in the project are EA Technology (the authors of this report), DriveElectric, Lucy Electric GridKey and TRL.

Electric Nation, the world's largest domestic electric vehicle (EV) trial, is revolutionising domestic plug-in vehicle charging. By engaging 500-700 plug-in vehicle drivers in trials, the project is answering the challenge that when local electricity networks have 40% - 70% of households with electric vehicles, it is estimated that at least 32% of these networks across Britain will require intervention.

A parallel activity as part of the project is the development of a Network Assessment Tool, this aims to enable a LV planner to assess smart charge solutions to support plug-in vehicle uptake on local electricity networks. A key outcome will be an analysis specifically tailored for highlighting plug-in vehicle related stress issues on networks and identifies the best economic solution where appropriate. This 'sliding scale' of interventions will range from doing nothing to smart demand control, from taking energy from vehicles and putting it back into the grid, to traditional reinforcement of the local electricity network where there is no viable smart solution.

The immediate challenge to such a tool is the prevalence of poor data quality historically present for LV networks in comparison to the vast and accessible datasets available at HV levels. As such, the tool under development will be of great interest country-wide as the next step to high visibility of LV network data at the planning stages. The outcomes of this project will be communicated to central government and the GB energy and utility communities.

This report focuses on the developments undertaken since the previous reporting cycle. Namely this is focussing on the new user interface which has been implemented and the developments and reviews which are guiding further refinements and completing the looped cycle of the data re-constitution activities within the processing stack.

3 Overview of the Latest Progress

The primary developmental focus on the Network Assessment Tool (the tool) through to the end of 2017 has been on realising the plans described in the previous report. The previous report covered the data validation and reviews from a small data sample concentrated in the Plymouth area. Following on from this spatial processing algorithms were employed to develop the data associations between the customer and asset data which were previously unrelated and didn't allow for individual networks to be defined to a point which network analysis could be undertaken without manual intervention on each network in isolation. The previous report also described a mock-up of a potential front-end environment in which the user could view and interact with the identified networks.

Since July 2017, development work has focussed on further development of the underpinning framework of databases and dataflows through to a new front-end. In parallel with these activities, further work has reviewed and refined the algorithmic spatial procedures for accuracy optimisation across the wide-ranging network topologies and various data issues which can occur due to missing or incorrect/outdated data (as supplied by Western Power Distribution).

3.1 Multi-tier Architecture Realised

To manage developments, the software architecture is partitioned into three distinct elements which make up the multi-tier architecture. That is, the data tier, the business logic tier and the presentation tier. Figure 1 below illustrates the completed data flow through the software architecture and the sub-elements which support each tier.

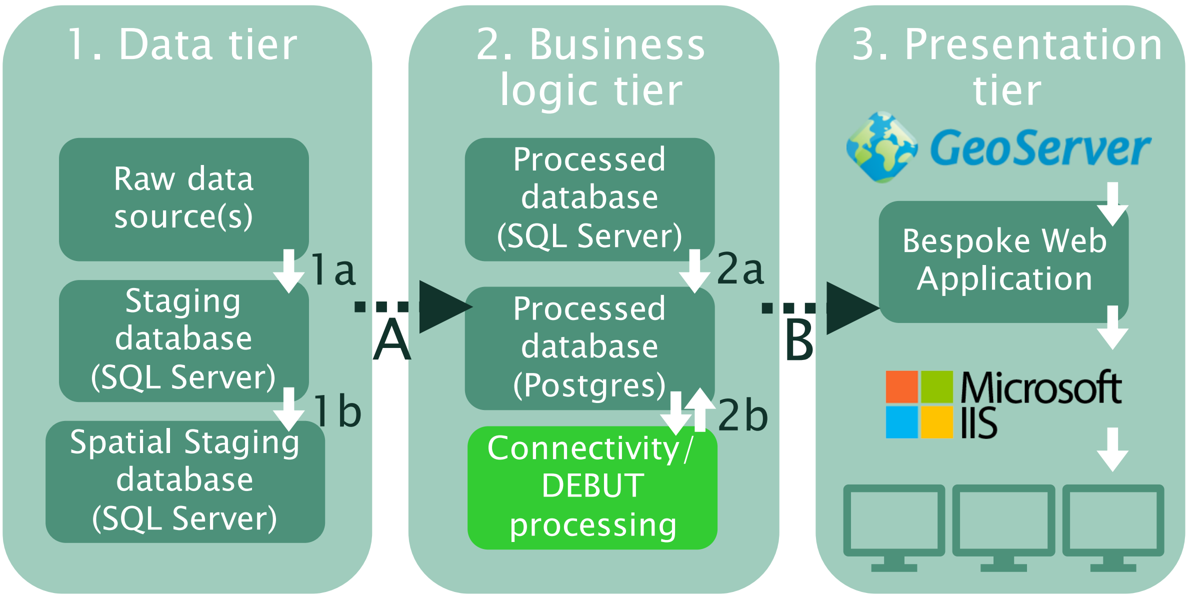

Figure 1: Further detail on the multi-tier architecture

To explain the above stages:

- 1a (Data tier): Raw data imports are stored in an initial database which are mirrored into a staging database. The initial import database stores all original data to allow for validation activities and thus improve data integrity overall.
- 1b (Data tier): Pre-process migrated raw-data, to validate and update missing data, where possible. For example, location data is checked and where possible a spatial location is created off the best available data which could be easting and northings, grid references or even postcodes.
- A (Data tier -> Business Logic): The spatially pre-processed and validated data is passed over to the business logic tier, where it will be re-associated and processed to identify and define each network.
- 2a (Business Logic tier): Consolidate and restructure data into the defined schema upon which the algorithms and spatial re-associations are based. This database is then mirrored to an object-relational database management system, which enables simpler front-end integration.
- 2b (Business Logic tier): Custom routines to carry out the algorithmic processes which spatially re-associate the datasets and define the available networks for DEBUT processing. Initial DEBUT processing will give initial outputs on the anticipated worse case voltage drop and cable/substation utilisations before any future (e.g. EV) loads are added. Further developments will enhance these routines to allow for iterative calculations for future EV load impacts.
- B (Presentation tier): A database format suited to the web-mapping services (Postgres) database has been used. This interrogated via Geoserver, which is used to share the spatial database data to the bespoke web application, then provides the front-end data interactions to be performed.

At time of writing, the multi-tier architecture is in place and developed to a point which is already being used to review and interrogate the processed results manually. Further refinements will be made as the project develops, to allow for future EV loads to also be injected, calculated and for the outputs of this to be viewed locally and across wider areas via a summary view.

3.2 Presentation Tier

The top level of the application is the User interface (UI); its function is to translate front end tasks to-and-from the business logic layer using a Web Mapping Service and Framework.

3.2.1 Implemented User Interface

A full functional front-end is now in place, as discussed in the previous project report, this is a fully-fledged web mapping environment akin to any major (web-based) mapping provider. This benefits the users' ability to pick up the new software and use it immediately with minimal training required. Another major benefit of the tool being supplied by a webserver is simplified deployment. Once the server is in place and configured, each user on the network can simply navigate to the relevant webpage without any specific software installations being required, or internet access as the server will be internally located.

Initial View

Upon loading the tool via a web browser, the user will be presented with a zoomed-out view of WPD's licence area boundaries, if the user zooms in a little, Energy Supply Area (ESA) boundaries will be displayed.

At this point the user can either click a defined boundary area and view the aggregated summary view of key results via an onscreen popup dialogue, or locate a specific local area using the substation search bar or by zooming in further manually.

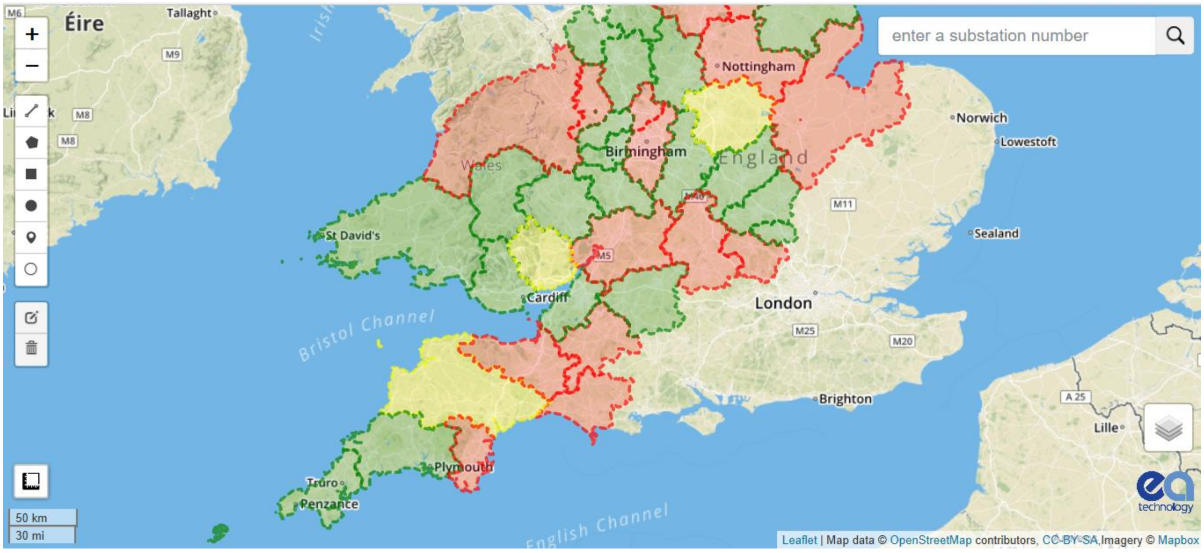

Figure 2: Initial view upon loading the tool (Note: current development build version is only showing postcode boundaries rather than licence areas or ESAs)

Zoomed-in View

For speed of response and keeping onscreen elements to a practical level, the next zoom levels will at first populate substations only. The substations are colour coded by the initial results before EVs impacts, after further development work this will either be selectable to illustrate various degrees of EV penetration, or a static metric which correlates to an EV tolerability.

At this point the user can either, click and drag around the map to view the health of the area in general terms, or click to select a substation to then bring the customers served and associated feeders into view.

Figure 3: Zoom-in in level with a population of substations and their current health from initial calculations (note. health metrics are still in development)

Substation View

Once the user has selected a local substation, the associated asset data and customers are populated on-screen. Depending on the contextual items selected through the layers options, additional information can also be displayed such voltage drop (V or %), demand (A or % utilisation).

At this point the user is still able to navigate around and zoom in and out to select other substations, if they wish.

Figure 4: Substation view of the local network and associated assets and customers – colours show feeder/customer associations produced by the tool, the circled numbers show voltage drop at each cable segment node (black are intermediary, red are maximums)

Dialogues & Ancillary Data/Results

In order to display specific object-based information, the user can simply click on any object (customer or asset) to bring up a pop-up dialogue window on-screen which presents a small tabular view of key data points. These can easily be dismissed by clicking on the map behind or by closing the pop-up using the close button. The data points are still under refinement however the current iteration is detailed in the below figure.

Substation

Name	Congreve Gardens
Number	330943
Install Date	Mon Jul 01 1968
Rating	Unknown
Type	GMT unknown struct.
Max Volt Drop (%)	4.1
Max Cable Utilisation (%)	48.2
Max Tx Utilisation (%)	56.29
Debut Result	Success
Debut Input File	330943.txt
Debut Output File	330943-out.txt

Static and dynamic data fields to give the following substation data; name, number, installation date, rating, type, maximum voltage drop, maximum cable utilisation, maximum transformer utilisation.

Also available are links to download the text files direct from DEBUT for the input file and the full output of results.

Customer

MPAN	2200010515047
Substation Number	330943
Feeder Number	20
Meter Class	Domestic Unrestricted Customers
Meter Timeswitch Class	835
Measurement Class	A
DEBUT Consumer Type	URMC (3550, 0)
Energisation Status	E
EV Charging Point?	No

Static data fields to give the following customer data; MPAN, associated substation number, associated feeder group, meter class, meter time- switch class, measurement class, associated DEBUT consumer type, Energisation status and a flag for a known EV charging point.

Segment

Length	15.17
Type	AL 0.3
Source	LvRoute
Computed Substation Number	331765
Computed Feeder Number	20
ID	2676664
DEBUT Cable Type	AL 0.3
Rating (A)	350
Max Current (A)	88.7
Max Utilisation (%)	25

Static and dynamic data fields to give the following segment data; length, cable/conductor material type and size, computer substation number, computer feeder number, asset ID reference, data source table name, associated DEBUT cable type, rating, maximum current and maximum utilisation.

Figure 5: Pop-up dialogue windows for key object data points

Contextual Layers and Ancillary Objects

A key advantage of web mapping services is the ability to easily implement additional contextual layers and enable/disable ancillary on-screen objects.

The list of available layers is to be decided, however, current available layers and objects to the local development activities are;

- satellite imagery
- dark mode map
- voltage drop (V)
- Voltage drop (%)
- spatially processed convex-hulls for debugging activities
- all segments
- all customers.

There are many potential development avenues that could be explored *outside of this project* using this mechanism, such as impedance contours, HV assets, soil resistivity, other buried utilities etc.

3.3 Business Logic Tier

This tier co-ordinates the application and performs the key logical steps as an intermediary between the UI and the core database. This central application engine will also ensure data integrity and security. Primarily this is in a C# codebase, however other intermediary code interfaces are present.

3.3.1 Algorithmic Process Flow

EA Technology has been evaluating the optimal process to utilise the available WPD data and reconstitute it to enable a level field upon which EV impacts can be understood at a local level. An obvious ideal would be to allow for a full network study on every LV network to evaluate these impacts to properly understand the network stresses that are likely to occur. This has been the development aim, to enable LV network studies en-masse using all available data points.

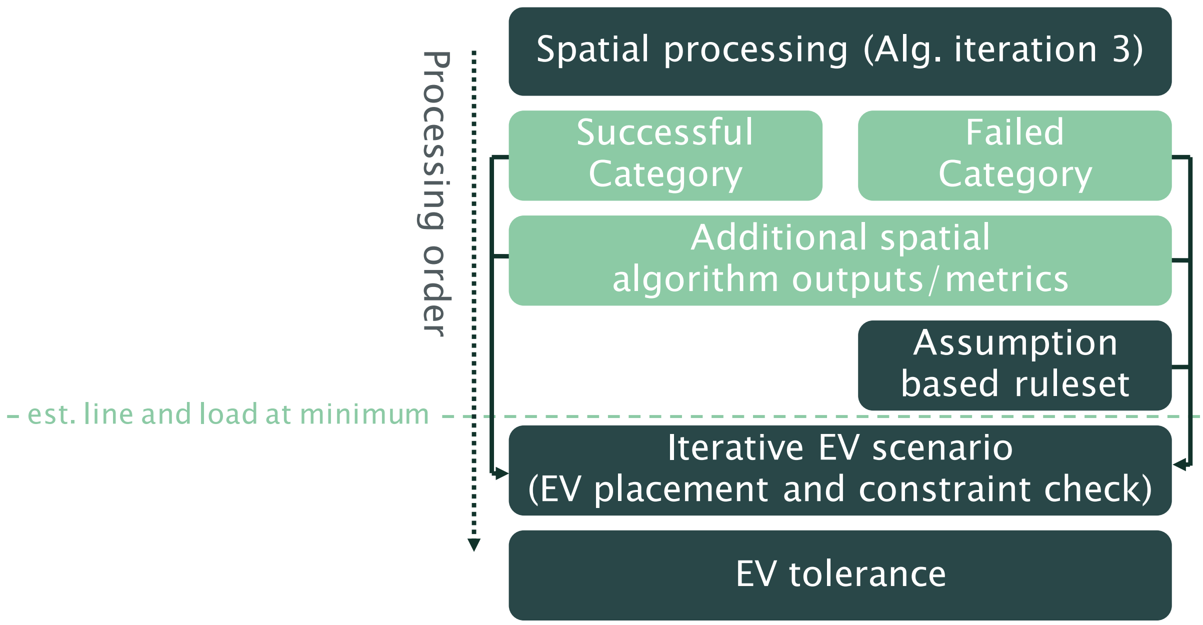

Figure 6: Algorithmic stack processing order

The above figure illustrates the algorithmic stack which functions in the following order;

- Spatial processing; this step first defines the LV networks, their customers at a feeder level and the point of connection for each and then goes on to evaluate them (one at a time) through the existing DEBUT engine.
- Scoring; the processing to determine whether the previous spatial processing is deemed successful or a failure based on several outcomes from the previous step.
- In parallel to the above, additional supplemental data points are output; for example, customer densities, furthest distance from substation to customer etc. These data points will assist in further algorithms such as the subsequent assumption-based ruleset.
- The assumption-based ruleset will process all failed spatial attempts to reconstitute the data, to produce an assumed line and load model primarily based upon the customer locations provided. Where these are unavailable a further backup process will be developed which will infer template networks. After this step is completed all networks identified from the available data will have a network model which can be assessed for EV impacts.
- The routines to assess EV impacts on each LV feeder/substation are to be developed with iterative DEBUT calculations. Outcomes from this will produce an EV tolerance rating which can be cross-compared against anticipated EV penetrations and more importantly the likelihoods of local level clustering.

The above described set of algorithms and processing order allow for the optimum level of detail to be sought for local LV network studies to be carried out. However, it is not realistic to expect historic data to always be accurate and complete enough for this to be relied on for each and every network. It is for this reason that the alternative assumption-based routines are available to complete the holistic picture for any networks where the data and developed algorithms cannot determine a suitable result alone.

Since the initial conception of the spatial re-associations further refinements have been developed to improve results. In parallel with these refinements, manual reviews have been undertaken to categorise each failure with the aim to develop a targeted approach for the next algorithm iteration. The outputs from this failure mode analysis have also fed into the development of the success/failure metric which is to be automated.

3.3.2 Failure Mode Effects Analysis

Due to the interrelations between networks it is paramount that each developmental iteration to the algorithms are positive steps forwards. Simply identifying an issue and trying to fix it in isolation could lead to negatively affect the results for surrounding networks, or networks in other regions. Due to this, a systematic approach to categorise and thus measure the volume of failures due to spatial processing is crucial to attain an optimal output across the four licence areas of WPD.

Upon categorisation and then measurement of the impact of each failure mode further developments can then target resolutions to the most beneficial areas in the set of algorithms. Upon each subsequent algorithm iteration, the summary of failed attempts versus successful attempts can quickly be regained for direct cross-comparison against the previous. Thereby gaining a stable development path and the optimal results.

Verify the success of the iteration by direct cross comparison against the initial review. Iterate back through to stage 1 for further refinements.

Design and develop the chosen path from the previous stage.

Analyse the results and devise potential approaches to address each failure mode. Targeted development can then commence on the optimal blend of effort/reward.

Measure the volumes and impact of each defined failure mode category.

Define the failure modes so they can be categorised and assessed independently of one another.

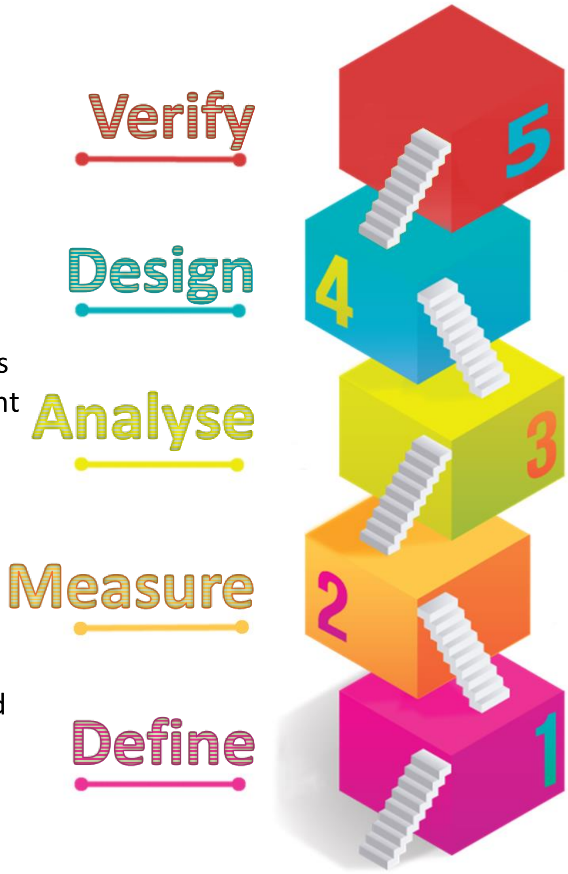

Figure 7: Failure Mode Effects Analysis process

3.3.3 Manual Sample Based Review of Failure Modes and Effects

Taking a small subset of the algorithmically processed data from the initial Plymouth sample, a manual review has been carried out to implicitly detail each full substation's processed networks. First to categorise whether the processing is deemed correct, if not how it has failed. Once completed across just over 220 substations, the failures were then categorised into typical failure modes.

For the most part the spatial connectivity algorithms were deemed quite successful. The initial review scored a 39% success rate across the sample. Of this, 43% of all PL20 (mostly rural) sites were successful, whereas 25% of all PL5 (mostly urban) circuits could be processed correctly. For the majority of the remaining 57% of the networks in the reviewed sample, it is one or two small errors that prevent the network model from working properly, some of these negatively affecting otherwise successful neighbours.

The following table details the categories that these problems were sorted into, and their prevalence in the sampled PL5 and PL20 areas.

CAT	PROBLEM CAUSE	%PL5	%PL20
NOP	Incorrect NOP assignment	7.8%	1.1%
INT	Interconnection	5.5%	0.0%
INT-COL	Interconnection caused by miss-assignment	10.2%	2.2%
INT-NFEEDS	Interconnection caused by something unexplained with multiple start points	0.8%	0.0%
NFEEDS	Problem due to Number of Feeder Start connections (duplicate, too few or too many)	10.9%	3.3%
OUTS	Problem caused by outliers	1.6%	2.2%
BAD	Other cause-unidentifiable problems	1.6%	1.1%
BAD-DISJOINT	Disjointed feeders, no route to sub	8.6%	2.2%
BAD-ISLAND	Islanded cables created	5.5%	0.0%
BAD-COLOUR	Other miss-assignments	0.8%	0.0%
BAD-ZERO	No cables assigned to colour group	2.3%	0.0%
NOCUS	No connected customers to sub	10.9%	13.2%
SUSP	DEBUT result incorrect (data mapping)	3.1%	0.0%
FILE	Problems with file generation	1.6%	26.4%
GOOD	No problem	24.2%	42.9%
NXTDR	An otherwise ok network disrupted by a failed assignment in an adjacent network	4.7%	5.5%

Table 1: Failure Mode Effect Analysis categorisation and veracity

NOP

Normally open point assignment problems can be in two forms, but usually the latter; sub-par assignment of a NOP between two feeder groups belonging to the same feeder around a loop line, or sub-par designation of a NOP between two neighbouring networks, taking either a connecting cable or the line closest to different customers. In the example below in figure 8, the cables in the area around node 70 should belong to the network above. Their assignment adds nothing to the lower network but causes a break in the above network. This problem is quite common, suspected to be often caused by “over-enthusiastic” allocation of cables to a network during initial processing.

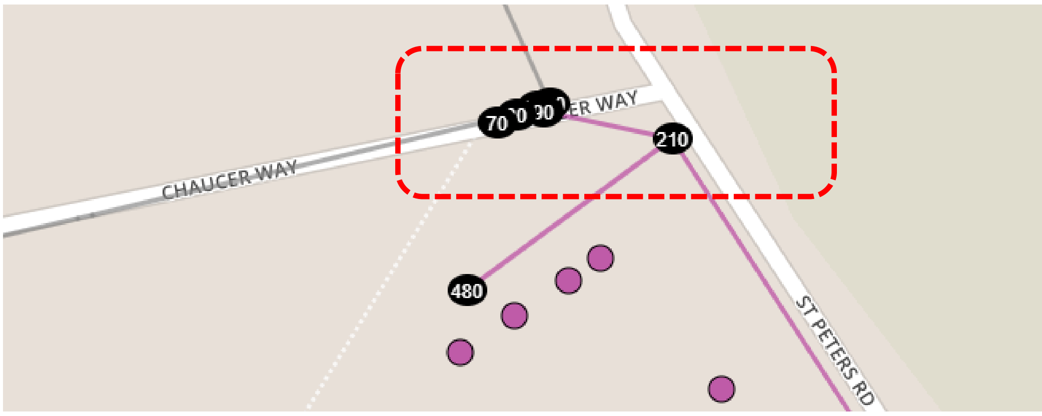

Figure 8: NOP assignment failure (coloured lines indicate different feeders)

INT

Interconnected errors are simple interconnection problems - there is a loop in the WPD cable data. INT-COL problems are where a loop in one feeder has been caused by cables being assigned the wrong feeder group. In the example in figure 9 below, a section of cable is green when it should be pink, causing a loop in the green. Often, these problems are similar (but not always) to DISJOINT problems. Others are a by-product by NOP or ISLAND errors in neighbouring networks.

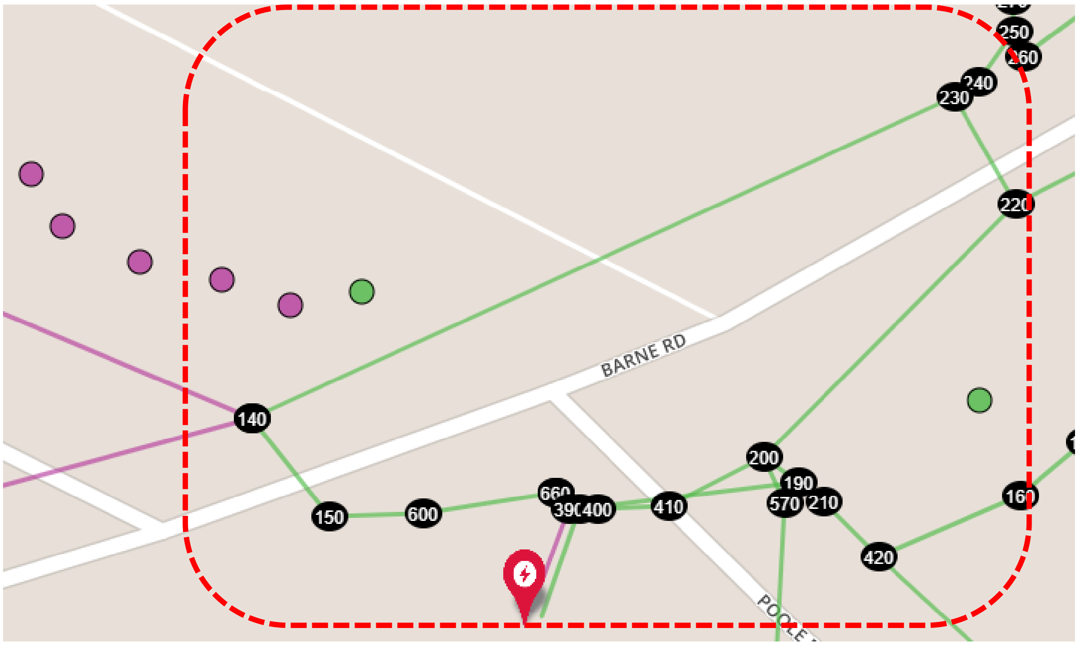

Figure 9: INT failure due to an apparent loop in the cable segments

NFEEDS

These problems are defined by the number of potential starting points in a network. While some protection for this is built in to the algorithm, it is not absolute, and due to its brute-force approach is not used entirely for some of the more complex networks. Some networks have the problem of not having enough potential starting points within the defined radius. This is usually because the other points are meant to be a NOP at the join of two cables, but the algorithm cannot detect this. Often, this results in open-ended cables from distances

50m or more away being designated feeder start points and can be detrimental to correct Feeder (colour) assignments.

OUTS

Outlier problems are where designations have been negatively affected by the presence of outliers. These problems are unlikely to be easily solved as there is already internal processes in place to attempt to avoid these specific issues. This is a similar case to the problems labelled BAD and BAD-COLOUR, where a direct cause of the problem has yet to be diagnosed.

BAD-DISJOINT

These problems are where a cable's assigned group has no direct route back to the substation; typically, where feeder branches are in close proximity to an adjacent feeder group. Disjoints of any kind prevent a cable's return to the substation, which causes Debut to return errors. The example below in figure 10 shows the purple group has pink start cable.

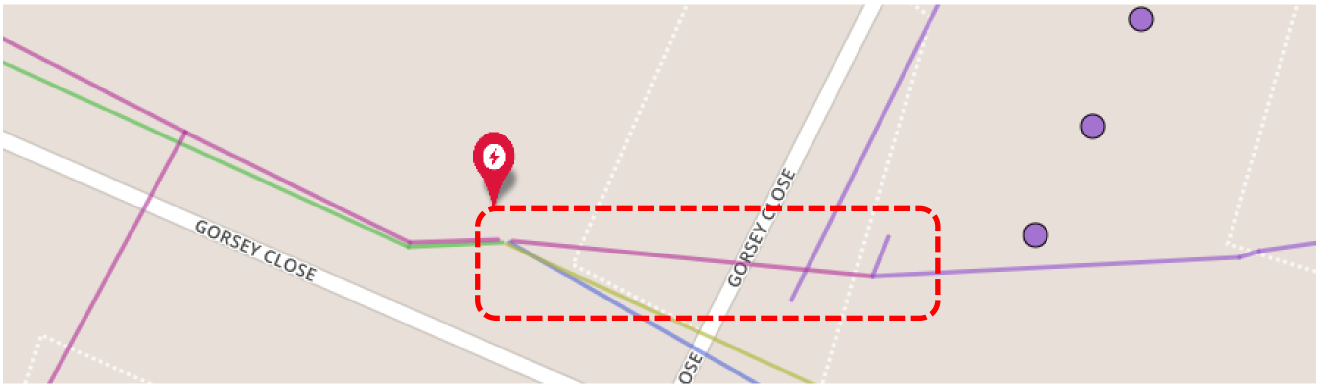

Figure 10: BAD-DISJOINT failure whereby a cable segment is disjointed from the main

BAD-ISLAND

Bad-island problems are caused by a cable or cables being assigned to a substation, but they are not connected to the main network, and in some cases, have no way of connecting to the main network. In most cases, the island cable created belongs to a separate network and causes a break in that network. The example presented in figure 11 shows the island in pink has been taken from neighbouring network and will prevent both from calculating successfully.

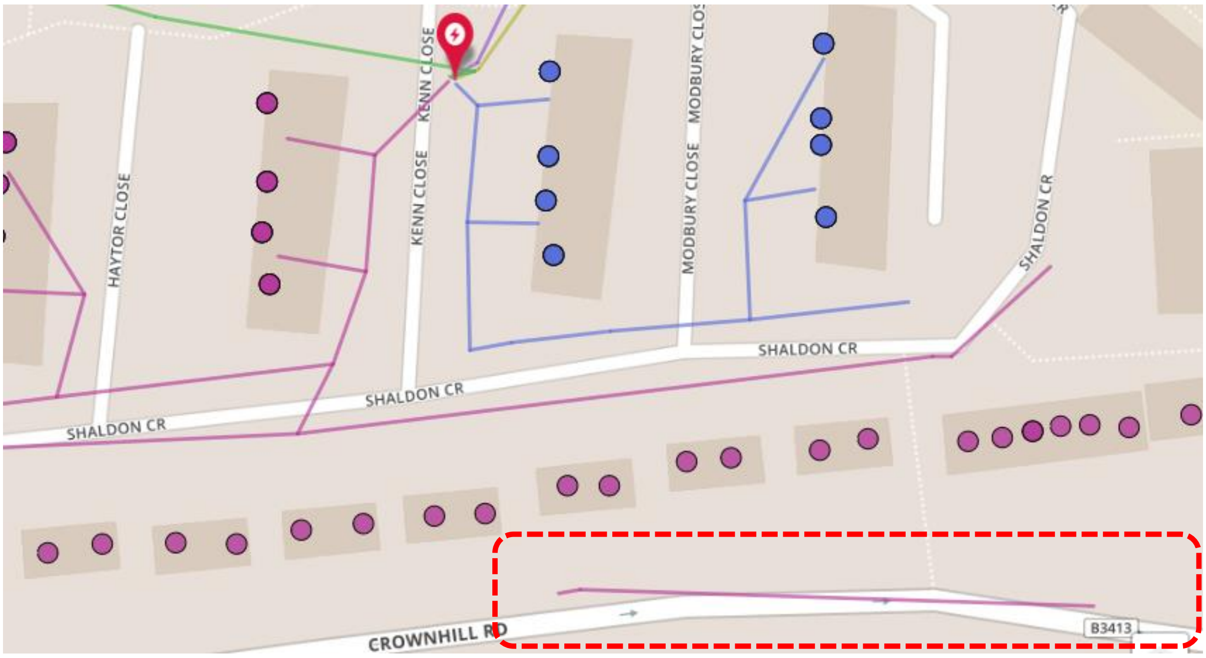

Figure 11: BAD-ISLAND failure whereby a cable segment is islanded from the main

BAD-ZERO

Bad zero problems are when a customer group exists, but for one reason or another no cables have been assigned to it, as shown below in figure 12, where there are no cables for the green customer group.

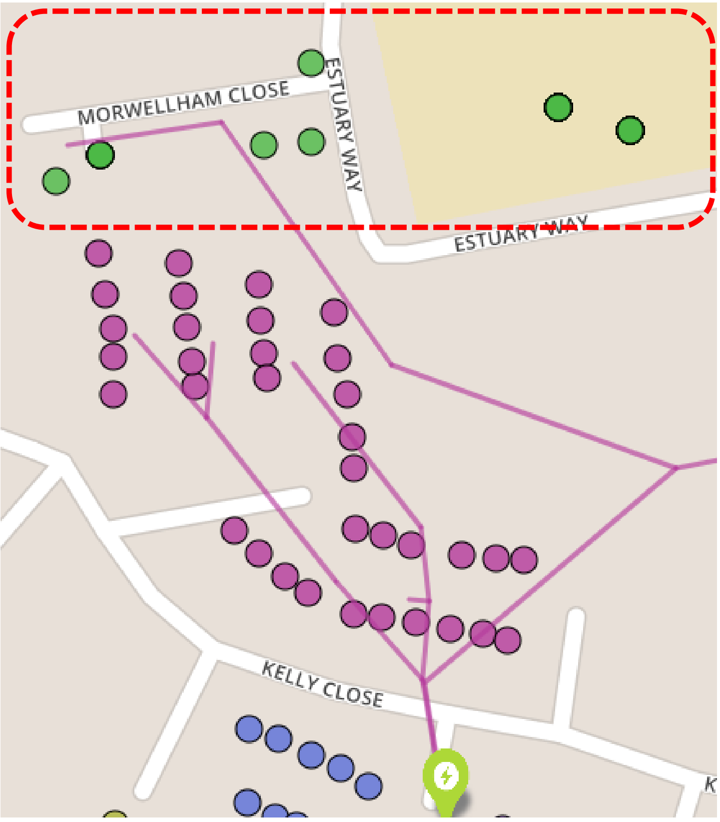

Figure 12: BAD-ZERO failure whereby a customer group has zero cables assigned

NOCUS
There are many cases of NOCUS, where there are no customers assigned to a substation. These data gaps will be investigated further but are thought to either be due to private networks or we are missing full volumes of profile classes 5-8. This is pending further review at present. These situations are always fatal in terms of the calculation results as Debut rejects them for having no load. These networks will be disregarded unless further data can be made available to process them.

FILE
File errors are when Debut has problems generating the input files. Almost exclusively caused by a lack of cables within the vicinity, so loads cannot be connected to substations.

GOOD
Good networks are self-explanatory - these are the ones which successfully process a calculation within the DEBUT engine and subject to a by-eye examination, have been suitably processed.

NXTDR
Next-door errors are from networks which would, left to their own devices, be fine. However, something is altered by a neighbouring network, such as an island created or the NOP is ended too far down the feeder, which results in a connector cable being disconnected or a feeder start line occupied elsewhere. In figure 13 below, the section between 270 and 1060 has been assigned to a neighbouring network as an island, preventing a section of this network from being connected.

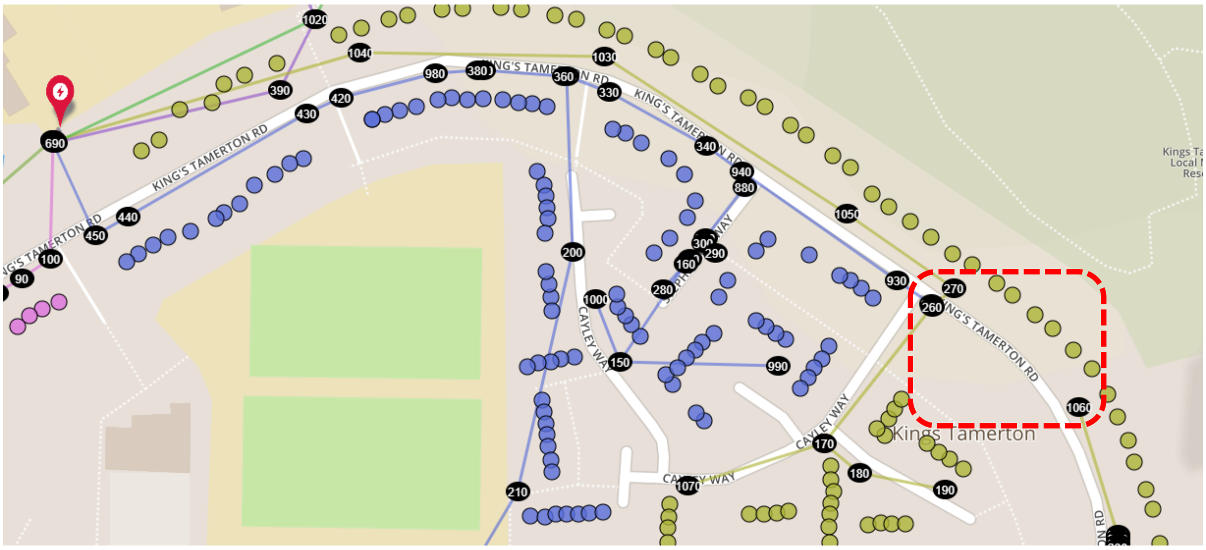

Figure 13: NXTDR failure whereby an issue in an adjacent network left another incomplete

3.3.4 Automated Failure Mode Identification

Two methods have been so far developed as an automatable form of Failure Mode Effect Analysis. While not as comprehensive as the above manual categorisation, these allow an approximation of where the errors are potentially located, without slow manual analysis. The following details two methods that errors can be detected and categorised. FMEA during spatial processing is the more complex method developmentally, but it is more accurate and meaningful. The post-DEBUT method is the converse and serves as a backstop for counting failures, if DEBUT cannot process the defined network there is an inherent issue and thus associated failure mode.

Simplified Failure Mode Assessment Categorisation for Automation (8 categories)

- DATA: 0 customers assigned to network, or 0 cables starting within 100m.
- ISLAND: Traverse post-processed feeder groups continuously from the first leg, any segments that are remaining will be islands
- DISJOINT: Fails disjoint test, is not STARTS.
- STARTS: Fails disjoint test and one of n potential starts > N customer groups OR n < N OR duplicate colours within the designated start cables
- INT: Cable(s) traversed twice (i.e. used in two distinct, neighbouring, networks) and passes disjoint test.
- NOP: For cables with one open end, any customers within Xm assigned elsewhere?
- OTHER: 0 cables assigned to customer group, repeated cables, catch all.
- GOOD: None of the above (preferably paired with a successful Debut result).

The revised categories have been sorted and a process and been devised for this to be automated. The flow chart in figure 13 below illustrates this process and subsequently the steps have been further detailed.

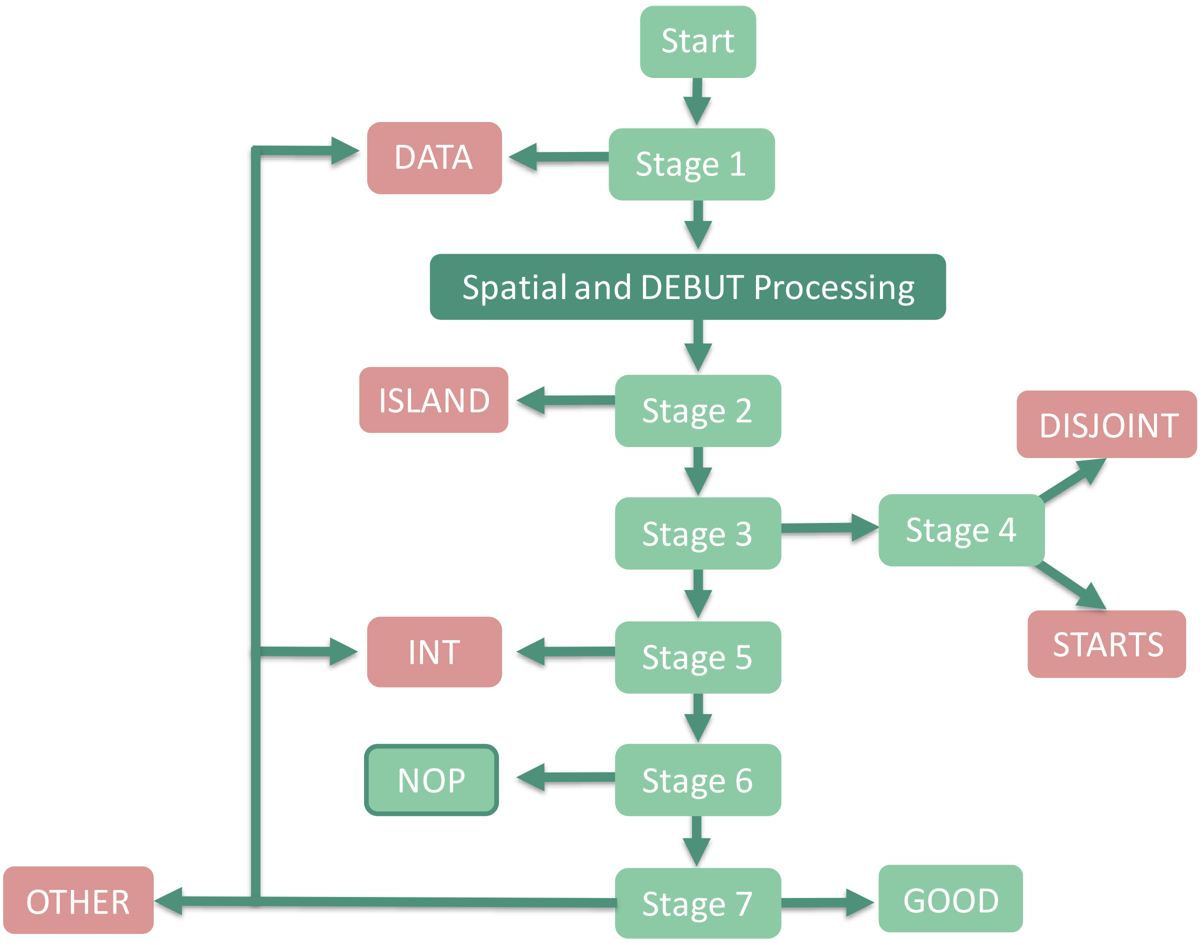

Figure 14: Automated failure mode process flow (during spatial processing)

1. **Stage 1 (DATA Review)**
   a. Verify that there is suitable data to analyse.
   b. Network fails if either;
      i. 0 customers are assigned to the substation.
      ii. 0 cables staring within Xm (calibration required initially $100m$).
   c. Failing networks are assigned a DATA failure mode categorisation and abort the processing.
   d. Successful networks will proceed onto Spatial Processing.
2. **Stage 2 (ISLAND Review)**
   a. Pick a feeder start cable.
   b. Traverse outwards (ignoring feeder group designations from the spatial processing) and continue until all other connected start and end cables are reached.
   c. Compare list of cables traversed in this way to the list of cables assigned to the network.
   d. If any cables are in the latter list but not the former, there is a disconnected section of the network, an ISLAND failure model type will be assigned.
   e. Successful networks will proceed onto stage 3.
3. **Stage 3 (DISJOINT/STARTS Indicative Review)**
   a. Indicative test which is a separate routine, loops through all assigned cables and routes from the substation to assess whether any are disjointed and have no direct route back to the substation.
   b. If no issues are found here Stage 4 is skipped and the network can pass through to Stage 5.
4. **Stage 4 (DISJOINT/START Review)**
   a. For a network with n cables starting within $25m$ (potential start points), and N customer groups, the network is assigned a STARTS failure mode if any of the following conditions are true;
      i. $N < n$
      ii. $N > n$
      iii. $N = n$ AND if any assigned start cables have a duplicate assignment
   b. Else, a general DISJOINT failure mode is assigned
5. **Stage 5 (INT Review)**
   a. Networks with a and interconnection (loop) cannot be processed by the DEBUT engine. As such for each feeder group the cables will be traversed outwards, flagging each cable which has been passed.
   b. If a cable is traversed twice the network is assigned an INT failure mode.
6. **Stage 6 (NOP Review)**
   a. If an NOP has been misplaced beyond allocated customers a cable will be designated to a feeder group with no load attached. The knock-on effects are the adjacent networks to which one of them the cable segment should be associated with will be incomplete and likely error.
   b. For each end-branch cable, check if all the customers within Xm (calibration required initially $30m$) are assigned to other cable segments. If there are none, the NOP failure more classification is applied, and the segments are flagged.

7. **Stage 7 (OTHER Review)**
    a. A catch all remaining failures category which assesses whether any of the following points are true;
        i. If a feeder group has no cables assigned.
        ii. If cables are repeated.
        iii. A DEBUT calculation fails, and the failure mode wasn't captured using the spatial review. Specific failure modes for DATA, INT can be determined based on the following DEBUT output error sorting.

Note: An NOP designation will contain some successfully processed and valid network results

Failure Mode Categorisation from DEBUT results (6 categories)

- DATA: Cannot generate Input File or Not Assessed Debut errors.
- INT: Detect by Debut's Interconnected Network error.
- NOP: Detect by identifying any $0A$ loading on any modelled cable segments.
- OTHER: Branch Is Repeated or other Debut errors not specified above.
- ISLAND/DISJOINT: Branch Not Connected errors. This will be a mix of islanding, disjoint, NFEEDS and NXTDR errors, and will be by far the largest category.
- Due to the unknown failure mode assignment this will either fall into both categories or a parent category to capture this specifically.
- GOOD: No error upon calculation and no other issues detected.

3.3.5 Assumption Based Spatial Processing for Failures

Before development moves through too many iterations of targeted refinements, a catch all approach will be developed to serve as a backstop. This will be able to estimate a simplified line and load network to enable EV studies to be commenced with the data that is available such as the customer types and known locations from the substation for example.

An initial developmental approach has been devised which is under manual assessment. A manual assessment is undertaken by taking a successfully processed network which has already been reviewed, ignoring the available cables and applying a simplified approach to estimate the line and load model. This is then drawn up and calculated in WinDEBUT for direct cross comparison against the original network with the complete data. Repeat this for a few examples and assess the outcomes to determine if the approach is suitable.

Centroid-based Network Estimation

The devised method will assess the customer groups locations and determine a suitable estimation of the network mainline and branch points by following a sequence of steps. For example, taking a network with no issue for direct comparison as illustrated in figure 15 below. If we then strip away the cable segments to demonstrate (figure 16) a lack of this data being available and follow the steps to estimate an approximate network topology for the given geospatial objects

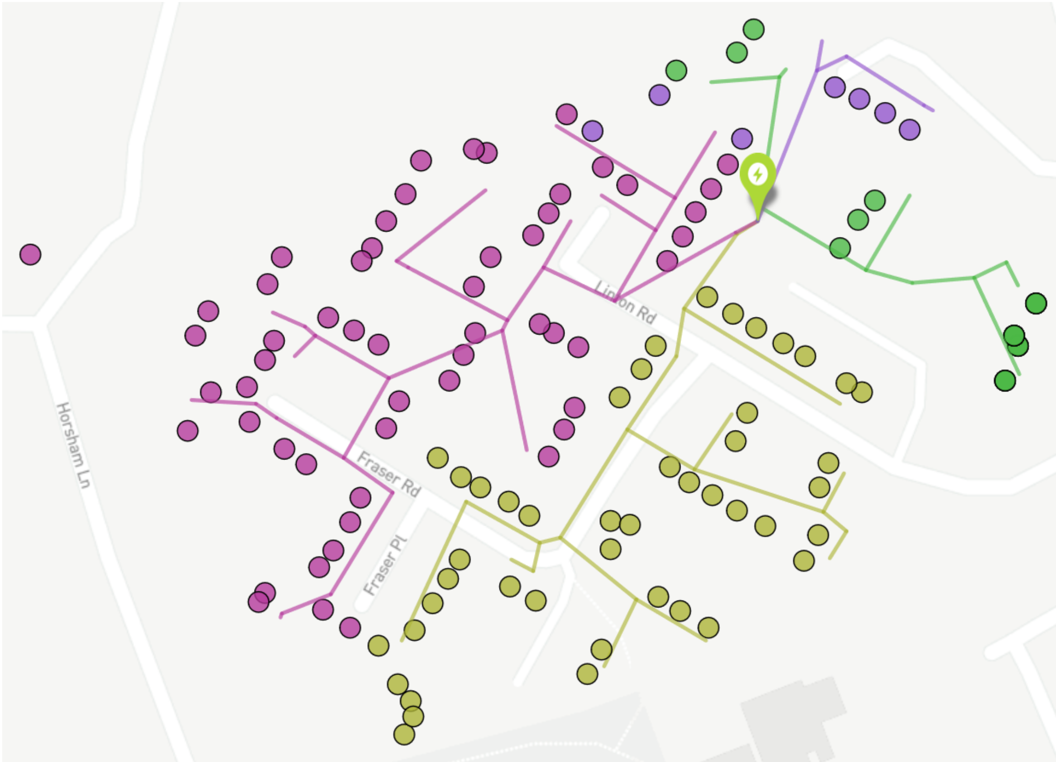

Figure 15: An example network with the actual cable data in place

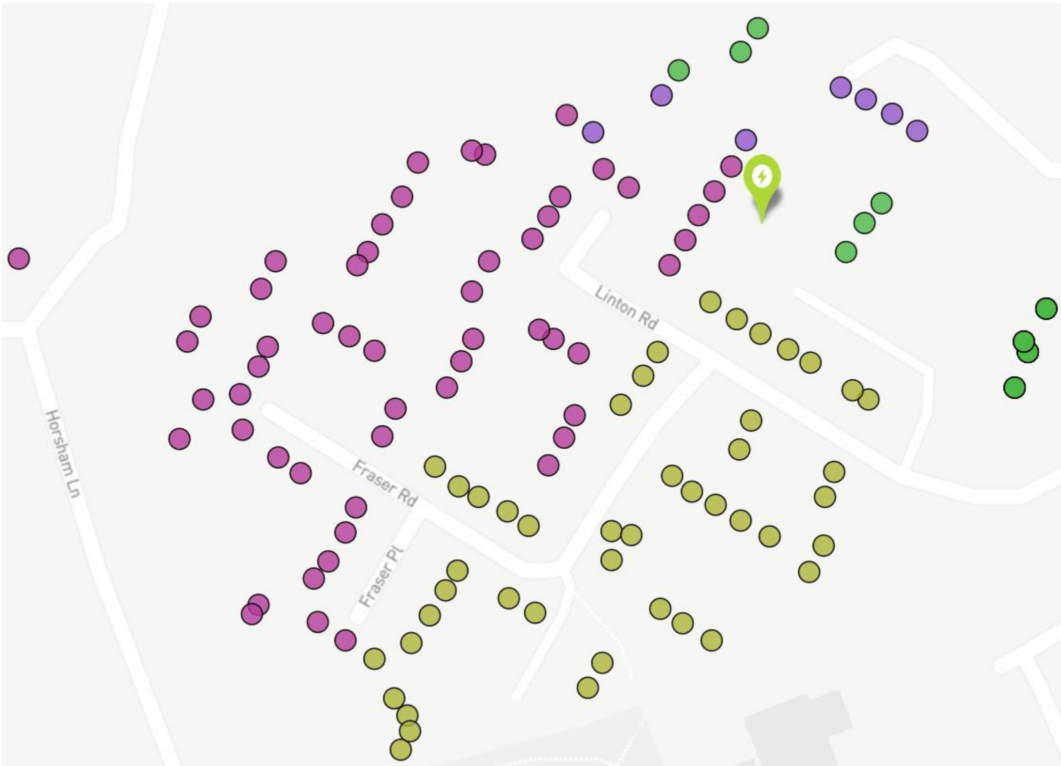

Figure 16: An example network with the cable data removed to demonstrate the centroid based estimations outcomes

1. Apply a convex-hull to a customer group (processing for one feeder group at a time)

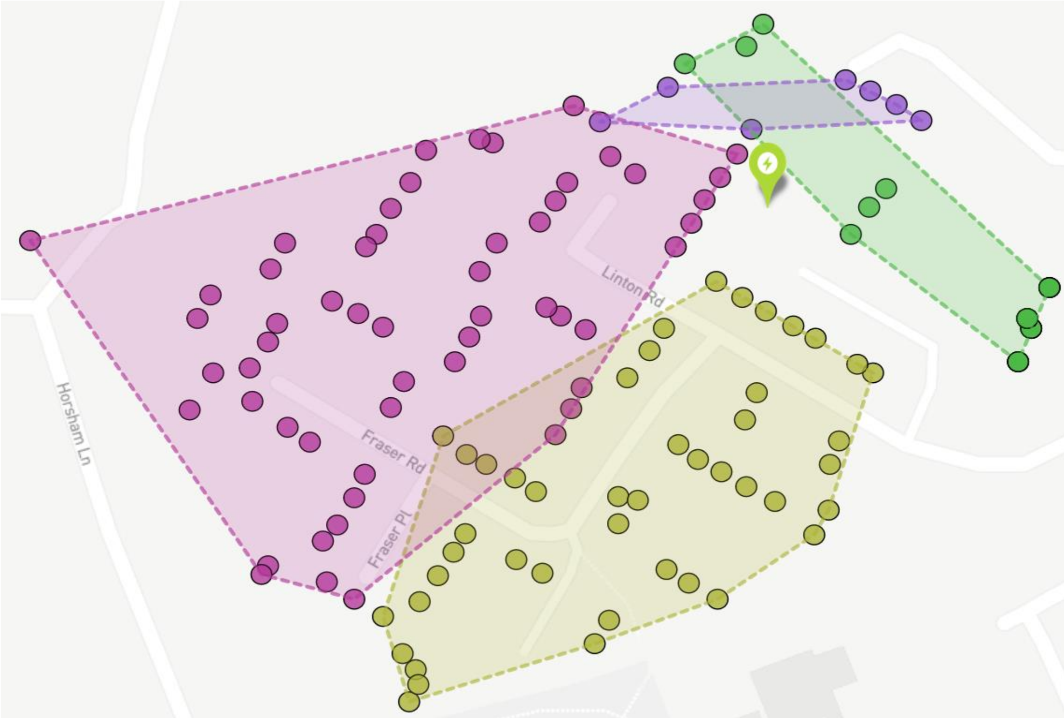

Figure 17: Centroid based estimation, stage 1 applied convex hulls

2. The median centroid of the convex-hull will present the first nodal point to designate a cable end position from the substation (additional length will be added on a $X\%$ basis to account for the lay paths never being a straight line).

Figure 18: Centroid based estimation, stage 2 median centroid designated main

3. Assign customers within Xm (calibration required, initially $30m$) of the node.

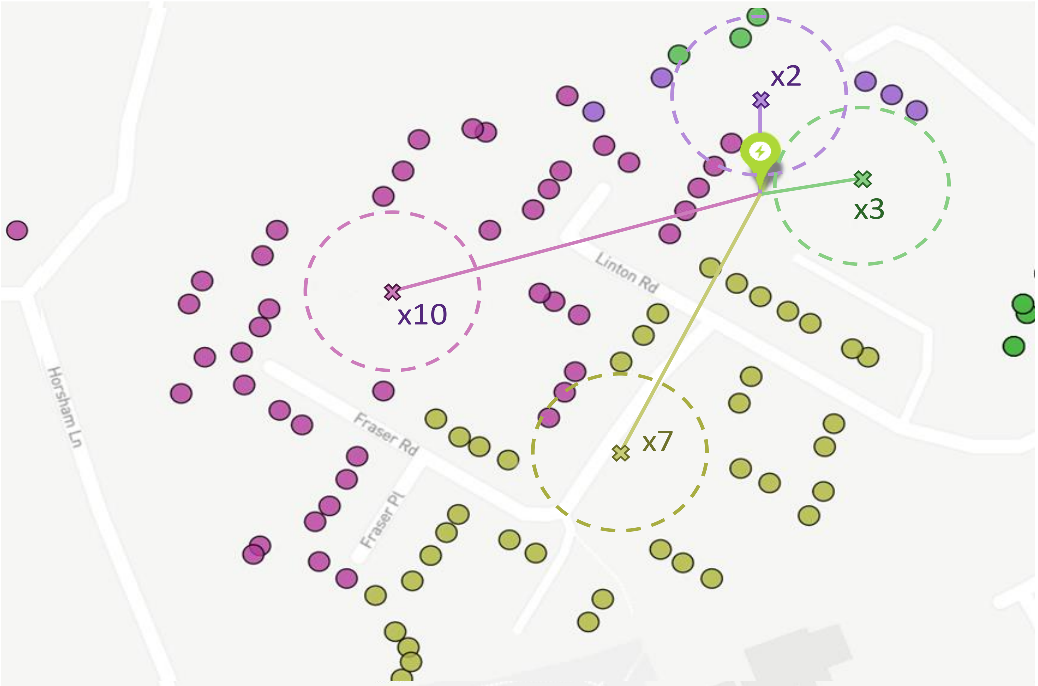

Figure 19: Centroid based estimation, stage 3 nearby customers served by the placed node

4. Divide the remaining customers into two separated convex hulls (either by assessing to a higher density or by extending querying against the placed node).

Figure 20: Centroid based estimation, stage 4 new convex hulls for split groups based on placed main from the previous step 3

5. Create new node points for the new median centroids and repeat the above until no customers are left unassigned.

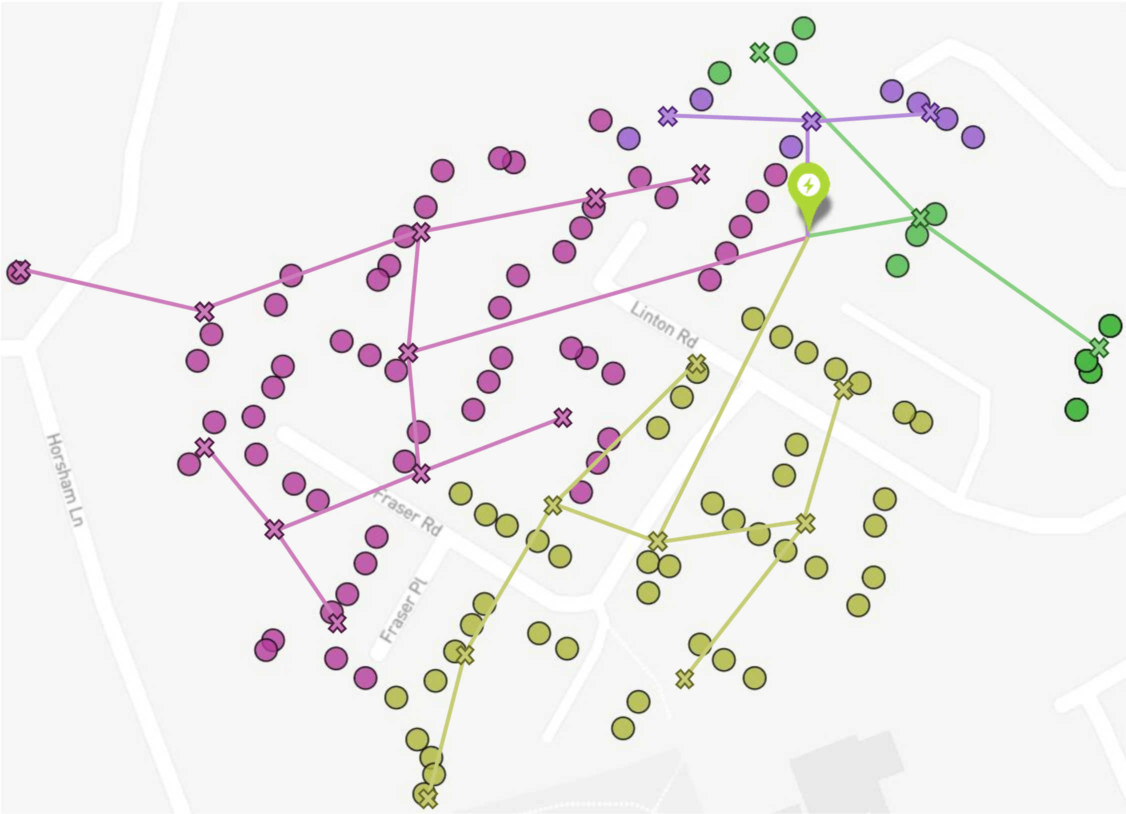

Figure 21: Centroid based estimation, stage 5 looped result once all customers have been assigned

From this manual illustrative example presented in figure 21 above, it can be seen that the approximation is simplistic as there is less inherent branches when directly compared to the real network presented in figure 15. However, with further calibration to the Xm that is used for the radius to capture customers, also to the lengths of the laid paths to allow for curvature the branching will be increased. This method is currently undergoing further manual cross comparisons with actual DEBUT studies being carried out to assess the delta against the real networks.

3.4 Data Tier

The bottom-most level of the application, this is the data store where the raw and pre-processed data version is stored and accessed. Spatial SQL functions are at the core of processing the available data to locate and validate each data entry in a unified manner across all available data.

3.4.1 Expanded Bulk Data Importing Routines to Accommodate Expanded Dataset

Previously only a small area concentrated in the Plymouth region was provided for the customer base. This enabled early developments and manual review to progress. However, EA Technology now have obtained almost the entire customer base from WPD for processing and further reviews and refinements.

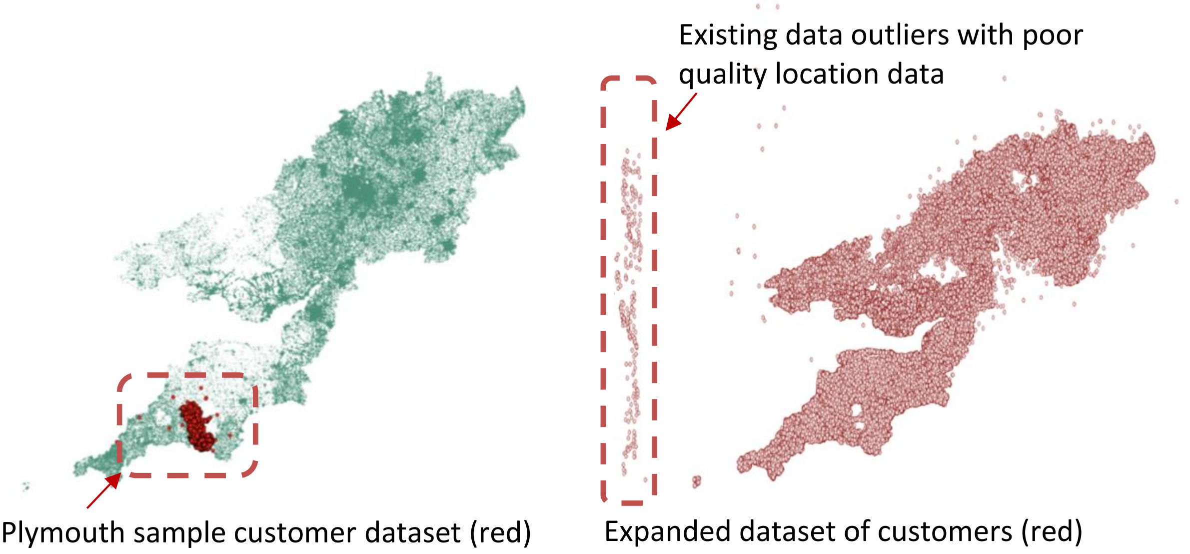

Figure 22: Expanded dataset from the original Plymouth data sample

The above illustration clearly shows the upscaled data recently made available to EA technology to migrate into the software development, allowing for a full system test to commence as soon as the final algorithm refinements are in place. In the short term, further manual samples will be collected and reviewed in other licence areas to ensure that the algorithms will continue to work as expected with data collected further afield.

There are still a few customer outliers with poor location data. A substantial portion of these will be remedied with a refined location correlation process which uses the assigned substation to place them geospatially in an approximate location to the serving substations vicinity, at a minimum. It has also been noted that this isn't quite a complete dataset as there are still small areas with data gaps which are visible in the above figure. It is estimated that there are 600,000 MPANs absent.

The data flow procedures were upscaled to allow for data migration through to the user interface. Spatial processing will be carried out on the entire dataset upon the completion of the final algorithm iteration review discussed in sections 3.3.2 through to 3.3.4.

3.4.2 Energy Supply Areas (ESAs)

The idea to be able to display and aggregate results to Energy Supply Areas (ESAs) came out of discussions with WPD in relation to potential end use cases. EA Technology have since obtained the relevant borders as data points which are being interlaced into the software to allow for grouped aggregate results and visual boundaries.

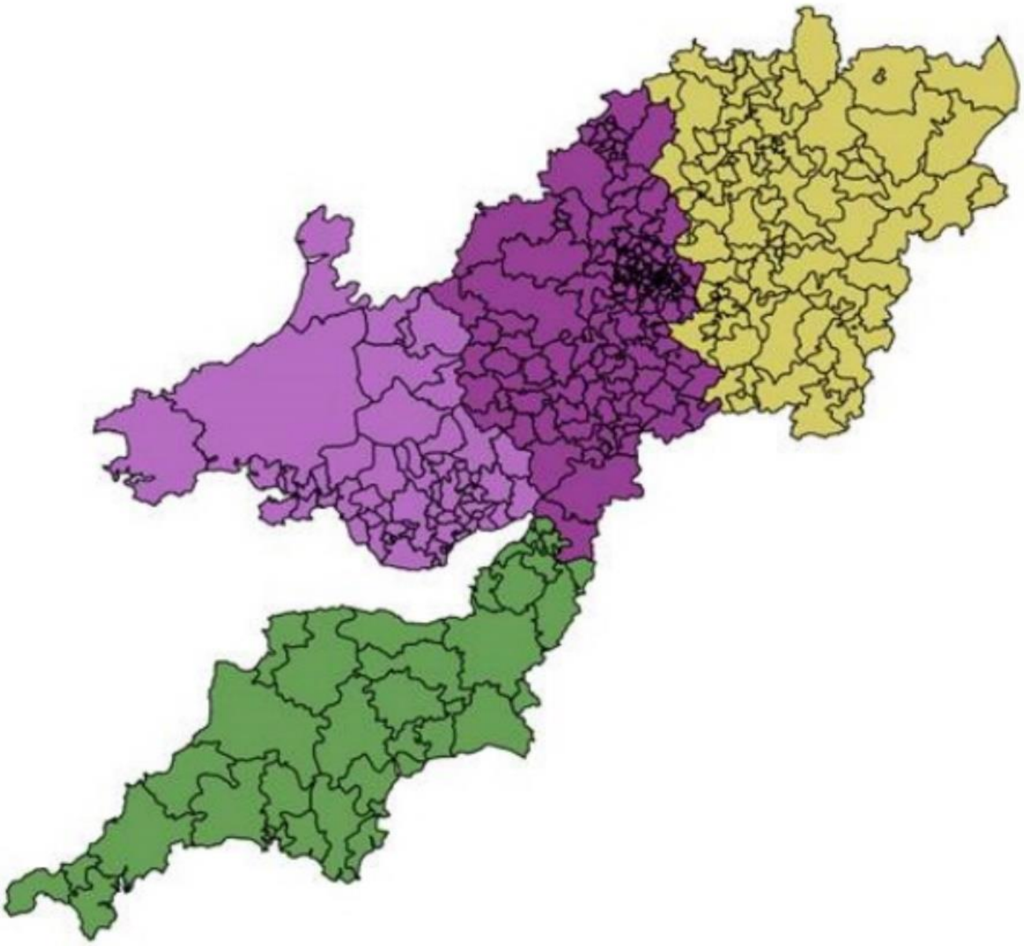

Figure 23: Energy Supply Area boundaries for easy visual separation of aggregated results

4 Ongoing Development Path

The foundations of the tool are now in place, the core data is structured and expanded to all regions (bar, as already mentioned, some apparently missing data), data is spatially processed and all key relationships between the varied data sources have been identified and re-established. Further efforts have structured development iterations to get the optimal algorithm stacks to process, sort and categorise the processing. A backstop procedure has been defined and the method to interlace this into the overall architecture has been scoped. Furthermore, the user interface is now in place and is providing a fast, stable platform that is aiding in further algorithmic refinements and manual reviews.

This section discusses the substantial development which is required to provide a functional network assessment tool.

4.1 Remaining Development Paths

The following development paths are still either in progress or awaiting a pre-requisite task;

- Success/Failure automation and algorithmic refinement
- Assumption based estimation of line and load network studies
- EV scenario assessment mechanism and output metric
- User interface addition for wide-area results summaries
- Options assessment module – which will enable assessment of smart charging as a mitigation method (vs reinforcement) for networks overloaded by forecast EV loads.

4.1.1 Success/Failure automation and algorithmic refinement

As detailed in section 3.3.4, a method to measure the volumes and thus the total impact of each failure mode has been devised. This is to be implemented and further tested to ensure it functions as expected. Once in place development can be progressed to push any failed processing attempts over to the assumption-based estimation of line and load to produce a simplified network model.

4.1.2 Assumption based estimation of line and load network studies

As detailed in section 3.3.5, a method to produce a more simplistic representation of the local network with a limited dataset available has been conceived. At present this is undergoing further manual reviews to assess its suitability before commencing further development. Once complete all identified local distribution networks will have a network model to undergo EV impact assessment.

4.1.3 EV scenario assessment mechanism and output metric

Focus will begin to shift onto the area of EV analysis once the data re-constitution activities are completed. There are opportunities to explore different development directions for this phase, as such this phase is under discussion at present to understand the best approach that reflects the available and attainable data.

4.1.4 User interface addition for wide-area results summaries

Mock-ups of potential summary views are in progress. However, a finalised design will not be commenced until the EV mechanism is better understood as the outputs will ultimately drive what the summary view needs to accommodate. This will likely be via a new page overlay which will allow for tabular and graphed outputs which would be interactive to enable varied data aggregations for selectable areas.

4.2 Next Steps

The next steps in relation to the Network Assessment Tool development are as follows;

- Implement full FMEA approaches and automate the success/failure metric as discussed earlier in this report.
- Assess the manual review of the assumption-based estimation of line and load and implement this is satisfactory, else further methods will be investigated before implementation proceeds.
- Design the EV assessment mechanism to place EVs on each network for a scenario-based assessment of EV tolerance for each local distribution network.
- Design the user interface modifications required to allow for a wide-area summary view of the EV analysis, interaction would be desired to change scenarios and investigate resulting outputs at different points in time and for different data aggregations etc.