Date of Submission

July 2017

Network Innovation Allowance Project Close Down Report

Notes on Completion: Please refer to the relevant NIA Governance Document to assist in the completion of this form. Please use the default font (Calibri font size 10) in any electronic submission. Please ensure all content is contained within the boundaries of the text areas.

Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

Project Progress

Project Title

Network Optimisation Project (NOP)

Project Reference

NIA_SSEPD_0024

Funding Licensee(s)

Southern Electric Power Distribution (SEPD), Scottish Hydro Electric Power Distribution (SHEPD)

Project Start Date

January 2016

Project Duration

9 Months

Nominated Project Contact(s)

David MacLeman, Innovation Strategy Manager

Scope

The project aims to utilise an optimisation tool in order to address the undergrounding of overhead lines within the test site. The anticipated benefit includes the reduction of the cost for the undergrounding of overhead lines through the design of optimal routes. The scope of the project is outlined below:

- Definition of Input: Scottish & Southern Electricity Networks (SSEN) along with the selected supplier will define the requirements and inputs of the optimisation tool that will be used for the project.
- Data Collection & Analysis: SSEN will undertake the required data analysis in order to provide to the selected supplier the data required for the optimisation exercise. The selected supplier will also prepare the data in a format that will be used by their optimisation algorithm.
- SSEN will select an external network planner in order to undertake the traditional network planning approach, define the design criterions of the optimisation assessment and support the project in reaching its goal.
- Design, Mapping and Testing: The selected supplier will undertake the mapping of SSEN input in their existing optimisation tool, run the optimisation process and test the outcome. SSEN will be involved in the stage by providing continuous support and steering the process.
- Results Evaluation: SSEN will undertake the network planning process and determine the route for the proposed underground work using traditional processes. The outcome of the traditional process will be used as the baseline for the comparison with the outcome of the optimisation tool undertaken by the selected supplier. Within this stage, and if the method is successful, SSEN will scope the following on steps.
- Project Close Out: SSEN will develop and produce a project close out report.

Objective(s)

The project will determine whether the optimisation tool offered by the selected supplier can result in more cost effective options for the undergrounding of overhead lines, in comparison to traditional network planning approaches.

Success Criteria

The project will be considered a success if it can determine whether the optimisation tool offered by the selected supplier can result in more cost effective options for the undergrounding of overhead lines, in comparison to traditional network planning approaches.

Performance Compared to the Original Project Aims, Objectives and Success Criteria

High level summary:

The project has completed all activities included within the project scope and achieved its objective. The project determined whether the innovative method investigated was more cost effective in comparison to the traditional approach and as such the project met its success criteria.

The data analytics and optimisation tool developed and tested within the project has resulted in more cost effective routes for undergrounding 11kV overhead lines. A range of additional benefits have also been identified and reported within the following sections.

Finally, the trial site and analysis undertaken were of sufficient scale and rigor in order for the project team to be able to generate outcomes on the applicability and potential uses of the data analytics and optimization concept and tool.

Background:

SSEN has committed in undergrounding 11kV overhead lines and lay 500km of 11kV underground cable. Under the traditional network planning and design practices, a network planner would select the circuits to underground based on historic fault performance and manually select a route to be followed by the underground cables. Although the traditional approach is well understood and is focused on compliance with relevant standards, it is believed that data analytics and optimisation tools would be able to assess a wider range of data, incorporate them in the decision making and offer benefits to the network operators and the customers. As a result, the method utilised within the current project was the utilization of a data analytics and optimisation tool, able to handle multiple data simultaneously and produce more cost effective routes for underground cables.

Performance against scope (100% Completed):

The project aimed to trial an innovative method for designing 11kV underground cable routes in response to the SSEN program for undergrounding 11kV overhead lines. An identified vendor provided the data analytics and optimisation tool able to incorporate a range of data into the decision making of the route design which resulted in more cost effective options for underground routes. The established project plan was followed and the implemented project management approach ensured consistent and rigorous delivery. The project was delivered in time, within budget and met the quality parameters outlined in the project scope.

- **Task 1: Definition of input to the optimisation algorithm (100% Completed)**:
  A range of workshops between SSEN stakeholders and the selected vendor of the optimisation tool were held and all input to the optimisation tool provided. The inputs required were grouped into 3 deliverables that capture all essential information needed in order for the application of the optimisation tool to be successful. It is recommended that all these deliverables be produced by network operators wishing to pursue a similar optimisation tool for undergrounding 11kV overhead lines. The deliverables include:

  ✓ **Network Design Criteria (civil engineering)**: This deliverable described the reasoning that would guide the algorithm in designing an optimal underground route from the civil engineering perspective. This deliverable is primarily concerned with the treatment of topological features (i.e. water crossings) and potential technologies that could be applied (e.g. horizontal directional drilling). It aimed to capture all possible scenarios that could be encountered when designing and constructing a route for 11kV underground cable and provide the reasoning that would guide the algorithm in regard to civil engineering decision making. In a commercial application, this deliverable would be owned by the team that deals with network design and route feasibility and could create a feedback loop that would result in continuous improvement of the

document and refinement of its impact to the optimisation tool.

- ✓ **Network Planning Criterions (electrical engineering)**: This deliverable is related to compliance with P2/6 Engineering Recommendation and internal SSEN network planning standards, as well as the network re-design decision making from the electrical engineering perspective. It aimed to provide a clear view of electrical engineering and network planning concepts that could be utilised by the optimisation tool in order to undertake an accurate estimation of electrical parameters (i.e. demand) that will guide the design and costing of the optimised underground route. In a commercial application, this deliverable would be owned by the team that deals with network planning and electrical design of the network, which would be responsible for maintaining a feedback loop as described above.

- ✓ **Cost Information and Cost Benefit Analyses input (financial analysis)**: This deliverable was concerned with the costing related to design decisions and technology (i.e. fixed and variable cost for horizontal directional drilling applied in watercourses). It also addressed the cost comparison between the option of maintaining a network overhead or undergrounding it and set the basis for the cost benefit analyses that was undertaken by the optimisation algorithm. In a commercial application, this deliverable would be owned by the team that has access to business frameworks and could advise on appropriate rates to be used (i.e. procurement and/ or quantity survey department).

  The above deliverables (excluding sensitive commercial information) can be provided to interested Network Licensees upon direct communication with the SSEN team.

- **Task 2: Data Collection and Analysis (100% Completed):**
  One of the tangible benefits of utilizing a data analytics & optimisation tool in designing a route for an underground cable in comparison to a design by a human, is the fact that the automated process can analyse multiple data simultaneously and therefore result in better informed decisions. Once the responsible teams define what the data mean, how they can be treated and the data are provided to the tool provider, the optimisation tool can then be used to analyse multiple and different data simultaneously. In the current project, data were collected from multiple data sources, either directly by SSEN, or through contracted providers. The data provided and utilised are shown in the sections below. The provided data were used in conjunction with the 3 deliverables described in task 1 which guided the algorithm in the interpretation and reasoning in order to utilise the data effectively.

- **Task 3: Outsource network planning and network design services (100% Completed):**
  An external company offering network planning and network design expertise was selected via a competitive tender that ran in the first quarter of 2016. The main activities undertaken by the external planner are listed below.

  The selected company:

  - ✓ Developed the network planning criteria reflecting the P2/6 Engineering Recommendation and SSEN internal network planning standards and contributed to the development of the network design rules of the project.
  - ✓ Continuously supported SSEN and the optimisation vendor in reaching the project goals.
  - ✓ Undertook the user acceptance testing of the optimisation algorithm which validated the inputs used, outputs produced and whether the rules of SSEN have been incorporated appropriately.
  - ✓ Produced the baseline route reflecting current best practice in network planning and design. The produced route assumed no changes in the electrical design of the network which was the first use case that the innovative optimisation method addressed.
  - ✓ Undertook the comparison of the baseline (traditional) and innovative route under the use case which assumed fixed connectivity between network components and no changes in the network topology.

- **Task 4: Design, mapping and testing of the algorithm (100% Completed):**
  - ✓ The optimisation supplier has designed the algorithm in order to interpret and use effectively the data provided along with the network planning criterions, network design rules and cost information that would need to be taken into account in order to provide meaningful outcomes.

- ✓ The optimisation supplier mapped all provided data into the algorithm utilizing internal algorithm capabilities and appropriate interpretation and reasoning as provided by the deliverables under task 1.
- ✓ In order for the optimisation supplier to ensure the integrity of the developed product, they undertook unit testing every time a work pack was completed and such activity ensured a consistent and 'surprise-free' product delivery. The agile project management approach implemented by SSEN prompted regular review points by SSEN which kept the effort focused on the key deliverables.
- ✓ The data analytics and optimisation vendor developed routes in order to reflect a range of use cases as described in later sections. The use cases used to drive the results had the objective to underground the entire section of overhead lines provided.
- ✓ The first variation of the entire undergrounding was to maintain the existing connectivity of network components and do not alter the network topology. Within this use case, the results of the innovative approach were compared with the results from the traditional (baseline) approach which was undertaken by the selected external network planner. The results were quite positive, but it was believed that further benefits would be realized if the data analytics and optimisation vendor altered the network topology as well while designing the underground route.
- ✓ The second variation of the entire undergrounding use case reflected the previous rationale and the optimisation vendor electrically re-designed the network (altered the network topology) while designing the route of the underground cable. The outcomes of such exercise were compared with the outcomes of network planning and network design under the same criteria as applied by internal SSEN network planning team and such comparison was used in order to drive the project conclusions.

- **Task 5: Results Evaluation (100% Completed)**:
  - ✓ The external company selected to offer network planning and network design expertise undertook the validation of the rules, processes and outputs.
  - ✓ The quality control processes implemented ensured that the developed product incorporated all required rules, processes and information. It was identified that the majority of the requirements have been implemented within the algorithm. It was also identified that some specifications (i.e. buffers around Listed buildings) were not incorporated. In these circumstances a full impact assessment took place, which resulted in corrective actions (i.e. re-work, do not re-work but manually incorporate outcome in cost calculations, accept). In summary, all essential requirements have been modelled by the optimisation algorithm and the generated results are considered reliable for the production of key outcomes. Any further updates to the rules should be included in future product releases.
  - ✓ As explained in Task 4, SSEN internal network planning team undertook the development of a route for 11kV underground cables at the target trial site which included overhead lines of 33.7km. This route reflected current practice in network planning and network design and served as the baseline against which the performance of the route produced by the innovative optimisation tool was measured.
  - ✓ The optimisation supplier undertook a similar assessment for developing a route for underground cables in order to compare with the route provided by the internal SSEN network planning team.
  - ✓ Quality control processes have been implemented in order to ensure that both traditional and innovative methods have utilised exactly the same information and data in order to derive to their routes.
  - ✓ Subsequent to the quality control processes which ensured that a direct comparison of the traditional method and innovative tool can take place, the project moved to business analysis and direct comparison of the routes.
  - ✓ During the project and after the results of the comparison, internal SSEN teams were consulted in order to review the work completed and offer perspective on uses of the optimisation tool.
  - ✓ SSEN has scoped the next steps and considering that the data analytics and optimisation tool has been proven successful, they are moving forward to get a better understanding of the current market offering and progress to implementation.

- **Task 6: Project Close Down Report (100% Completed):**
  During the course of the project, a number of deliverables and reports were produced. These deliverables have been combined within the current close down report which aims to provide an efficient platform to disseminate the work undertaken. The results produced, provided a clear view to interested parties on the use and benefits of a data analytics and optimisation software.

Performance against the project plan (100% Satisfied):

The end date of the project was estimated to be in October 2016 and the project has successfully been delivered as of the end of October 2016. In order to ensure delivery on time an agile project management approach was implemented in order to allow for regular reviews of early versions of the data analytics & optimisation tool and maintaining the focus on key aspects.

Performance against the project budget (100% Satisfied):

The allowed budget of the project was £185,000. The actual cost incurred within the project was **£181,000.04. The project has therefore been delivered within budget**.

Performance against the project objective (100% Satisfied):

Objective 1: The project will determine whether the optimisation tool offered by the selected supplier can result in more cost effective options for the undergrounding of overhead lines, in comparison to traditional network planning approaches.

The project has undertaken the comparison between the traditional route (served as baseline) and the route which has been produced by the innovative optimisation tool. The project has concluded that the use of the data analytics & optimisation tool will result in more cost effective routes for undergrounding of 11kV overhead lines. The saving is estimated at **11.33% reduction in capital expenditure (CAPEX) or £14.73 per meter of underground cable laid**. Considering that the project was able to quantify the anticipated saving from the use of such a data analytics and optimisation tool, it has **successfully achieved its objective**.

Performance against the success criteria (100% Satisfied):

Success Criteria: The project will be considered a success if it can determine whether the optimisation tool offered by the selected supplier can result in more cost effective options for the undergrounding of overhead lines, in comparison to traditional network planning approaches.

As described earlier, the project has undertaken the comparison between the traditional method and an innovative tool for designing routes for 11kV underground cable and has demonstrated the potential of the innovative tool to provide savings to the network operator and the customers. The savings are estimated at £**14.73 per meter of underground cable laid** or **11.33% reduction in capital expenditure**. Considering the fact that the project quantified the saving which demonstrates the cost effectiveness of the innovative method, it means that the project has **met its success criteria** and thus is considered a success.

Required Modifications to the Planned Approach During the Course of the Project

No changes to the planned approach as declared in the NIA registration document were required. The project delivered the declared scope, within time, budget and satisfied SSEN's quality criteria.

As part of the development process it became apparent that the optimisation algorithm could also answer the question of whether we need to underground the entire section of the target overhead network or only parts that are more cost effective to do. Considering that there was no additional cost to answer this question, the project decided to proceed with this question as well and generate additional learning . The learning is reported in the following sections.

The project also captured the opportunity to investigate whether the optimisation algorithm provided could be used in order to increase the resilience of the network, while resolving the use case of undergrounding existing overhead lines. This additional question was also answered within the project constraints and generated additional learning (see learning outcome 9 – network resilience).

Lessons Learnt for Future Projects

Recommendations on how the learning from the project could be explored further:

The key outcome of the project is that data analytics and optimisation tools can offer benefits to the business need of undergrounding 11kV overhead lines and designing optimal routes for underground cables. The reported benefits are forecasted to be a reduction of 11.33% in capital expenditure (CAPEX) equating to a reduction of £14.73 per meter of

cable to be laid. A range of additional benefits spanning resource efficiency and the facilitation of development scenarios for capital delivery have also been identified as part of the project and are reported.

This may include recommendations of what form of trialling will be required to move the Method to the next TRL.

The current project utilised a data analytics and optimisation tool which was adjusted and further developed in order to be able to handle the use case of undergrounding 11kV overhead lines and designing optimal underground routes. The resulting TRL is 7 and is in line with the target TRL declared at the time of registration of the project. In order to move to TRL 9, further development work is required. Details on further development work required are outlined in the following section. Further to the development work outlined, any additional features would go over and above the core product required in order for savings to materialize, but could be explored at a later stage.

The Network Licensee should also state if the Project discovered significant problems with the trialled Methods.

No significant problems were identified with the data analytics and optimisation tool utilised as part of the method. However, it was realized quite early that additional time in the design and development of the tool to handle the project's use case was required. Such an early realization resulted in customization of the project management methodology which included regular reviews of early versions of the product which resulted in delivering the project in time, within budget and at the required level of quality.

The Network Licensee should comment on the likelihood that the Method will be deployed on a large scale in future.

Considering the successful outcome of the project, it is SSEN's intention to utilise such a tool on a large scale in the future.

The Network Licensee should discuss the effectiveness of any Research, Development or Demonstration undertaken.

SSEN believes that the undertaken project resulted in a conclusive outcome which is now used to inform the future strategy of the company regarding the design of optimal routes for underground cables. Considering that the work undertaken informed future strategies, the NIA project added value to the network operators and demonstrated effective use of customers' funds.

Lessons Learnt from NIA Project

Category 1: Technical Feasibility

No	Lesson Learnt Description	Recommendation
LL1.1	**Background mapping data:** The optimisation tool designs optimal routes via the undertaking of decisions based on data provided. One of the crucial data layers to be used is the background map layer and the forested areas data layer. Through site walks of the designed route by the optimisation tool, it was proven that there were local features (i.e. bushes, stone walls, lines of trees, etc.) not included in the base map and not taken into account in the design of the route. Therefore, it was concluded that a more accurate design will be feasible via the use of high resolution and up to date data of the target area. The more accurate design will conclude with a reduced variation between the designed route (outcome of the project) and the feasible route (outcome of site walk by construction experts).	A variation between the designed route and the actual feasible route is expected. However, it is recommended that an up to date and high resolution source of topographical data (including forested areas) is used in order to incorporate as many topographical features as possible in the design process and reduce the expected variation between the designed and built routes. In addition, up to date mapping data will guide the decision making in order to design routes reflecting current environmental constraints as close as possible.
LL1.2	**Graphical User Interface (GUI):** The current project aimed to develop and trial the optimisation tool in order to fit the use case of undergrounding 11kV overhead lines. The anticipated TRL at the end of the project was 7 and the TRL level was	It is recommended that a staged approach (as the one followed within the project) which demonstrates value for money is considered for product development and trial projects. In such

	accomplished. Considering the need to test and demonstrate the benefits of using such an optimisation tool for underground cable route design, the efforts were focused on achieving the required functionality rather than designing a user friendly tool. At the moment, the optimisation tool requires development of a GUI in order to be able to be used by SSEN teams.	way, no funds are spent on features such as GUI prior to the benefits being investigated and demonstrated. As a next step, the network operator should be looking to develop a GUI that will make the optimisation tool usable.
LL1.3	**Construction Cost Heat Map:** At the initial stages of the project, an external quantity surveyor was contracted in order to provide a heat map of construction cost across the target area. The heat map demonstrated how the construction would vary over the entire network at a resolution of 300m x 300m. However, within the initial versions of the product, it was realized that the product is able to develop a functional heat map based on the design, planning and costing rules provided by SSEN. Therefore, it was concluded that the initial heat map would be used for validation of the tool, but would not be incorporated as it is now considered redundant.	For network operators who wish to pursue such an optimisation tool for the design of optimal underground routes, it is recommended to not input a pre-made heat map of the construction cost (and its variation across the target area), as the data analytics tool is able to produce and utilise such a map via the use of the input rules.
LL1.4	**Input Statutory Data:** In order for the network operators to realize benefits from an optimisation tool in the design of underground cable routes, it is recommended that multiple data sources are incorporated within the decision making process. In the project, data from statutory searches on ecological, environmental and archaeological data were used. Data from local councils were also collected but not utilised by either the traditional or the innovative method and as a result they did not impact the comparison or the benefits.	In order for the network operators to realize the benefits from the optimisation tool, it is recommended to utilise data from as many sources as possible. Although it is not cost effective to undertake site surveys over a huge target area, a desktop search of statutory sites (i.e. Special Areas of Conservation, etc.) is quick, relatively inexpensive and can guide the route design. Finally, it is recommended that data on ecology or archeology are sought from local councils that tend to keep historical data in their records.

Category 2: Project Development & Management

No	Lesson Learnt Description	Recommendation
LL2.1	**Trial Site Selection:** As was demonstrated by the outcomes of the project and SSEN's confidence in the reported outcomes, the selected site for trialing the innovative optimisation tool was successful for satisfying the project's objective and success criteria. The reasons for selecting this site was related to historic fault performance and network topology which would be improved by undergrounding the existing overhead lines and to its scale which would allow a meaningful assessment of the tool to take place.	It is recommended that a similar assessment is undertaken in other innovation projects and the site selection is fitted to the use case being delivered. The scale of the site should fit the business requirement in order to maximize the value generated by the project.
LL2.2	**Development Phase:** The optimisation algorithm offered by the selected vendor had been used in a variety of applications, ranging from optimisation of logistic operations to electric vehicle mobility patterns. However, it is the first time that this algorithm was used in the use case of optimizing the undergrounding of overhead lines. As was expected, the appropriate interface between the SSEN input and the algorithm needed to be developed.	An agile project management approach is recommended to be used in innovation projects involving product design, development and testing. Such an approach would be able to focus the efforts on key priority items and as such allow the delivery of key functionality and scope within time and budget. It also allows the project team to view early versions of the

	What was evident is the fact that the development phase lasted longer in comparison to what was initially forecast. The lesson learnt is that an agile project management approach is best suited in this type of project.	product at an early stage and such fact aids the internal stakeholder engagement.
LL2.3	**Stakeholder Engagement**: The current use case analysed by the project spans the network planning, network design and construction delivery teams within SSEN. In order for the optimisation algorithm to work effectively and produce meaningful outcomes, input from all these teams was required. Early engagement with the respective teams results in a successful project and increased confidence in the acquired outcomes.	The lesson learnt is that all necessary internal stakeholders need to be identified as early as possible and be engaged throughout the project. Such engagement will provide early insight on potential risks, issues or opportunities and foster the use of the tested tool.

Note: The following sections are only required for those Projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

The Outcomes of the Project

Project Background:

As discussed earlier in the report, the project trialed a data analytics and optimisation tool in the use case of undergrounding 11kV overhead lines and designing optimal routes for underground cables. An optimisation tool provided by an external supplier has been tailored to the particular use case of SSEN. The project was able to progress with the trialing of the innovative optimisation tool and derive conclusive outcomes and lessons learnt. The outcomes are reported in this section.

Trial Site:

The site over which the trial of the optimisation tool took place was an overhead feeder with a length of 33.7km. The particular site was selected, prior to the start of the project, for the following reasons:

- ✓ Historic number of faults and potential for improvement by the undergrounding.
- ✓ Network topology and potential for improvement by re-designing as part of the undergrounding.
- ✓ Scale: As the trial site contained a substantial length of overhead lines (33.7km) it provided an opportunity to vary the scale over which the results are analysed. Such fact resulted in SSEN being able to report the variation in savings when different lengths of overhead lines are considered.

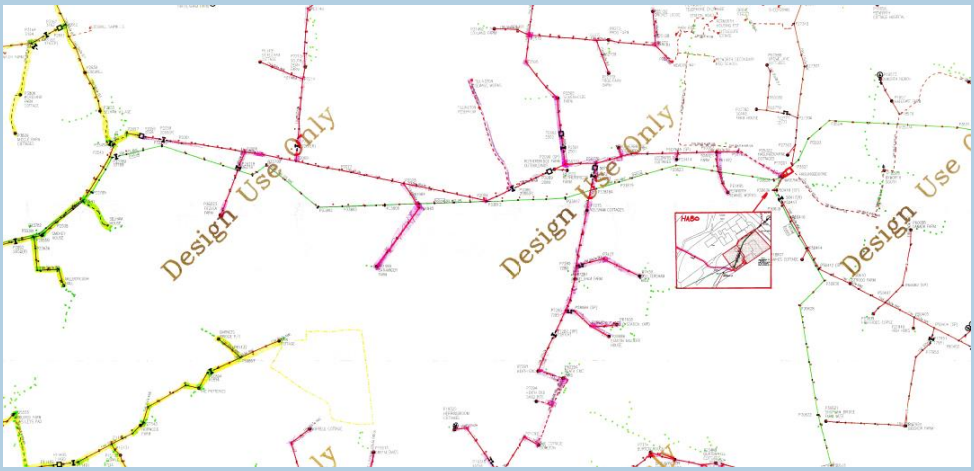

Figure 1: Trial Site of the Network Optimisation Project

Considering the fact that the selected site allowed a meaningful assessment of the innovative optimisation tool to take place and provide confidence in the results to SSEN, it demonstrates that the site selection was successful for the

purpose of the project.

Optimisation Tool:

An external supplier offering a data analytics and optimisation tool was invited to participate in the project where their product would be tested for cost effectiveness against traditional methods. The optimisation tool consists of a core optimisation algorithm encompassing advanced analytic concepts and a library which is fitted to the particular applications used. Historically this optimisation tool has been used in sectors such as logistics and retail and this was the first time that this optimisation algorithm was used in the use case of undergrounding of overhead electricity lines. As a result, the optimisation tool had to be adjusted in order to be able to receive data from SSEN, interpret and use them in the right way and produce the outcomes in the required format. It was realised at early stages within the project that the development effort required was more than initially forecasted. The agile project management approach implemented allowed for all necessary development to take place without impacting the project's schedule or budget.

Input:

The three key deliverables explained previously were input to the optimisation tool and consisted of network planning rules, network design criteria and construction costs. These deliverables outlined how the data will be interpreted, related and used. The data required in order to drive the optimisation process have been collected from a variety of sources and are explained below.

	No	Description	Content
CIVIL ENGINEERING DESIGN	1	**Background map** (SSEN Mapping team)	Topography of site including roads, watercourses, lakes, rivers, bridges and other geographical features.
	2	**Flooding Information** (UK Environment Agency)	The risk of flooding in banded representation over the target area.
	3	**Highway restrictions** (SSEN Street Works team)	Street work restrictions (i.e. section 58) which impacted cost and decision making.
	4	**Tree Cutting Cost** (SSEN Tree Cutting team)	Information on cost of cutting trees in the target part of the network either via surveys (preferred) or via a generic tree cutting cost in the absence of surveys (as was implemented in the current project).
	5	**Forested Areas data** (SSEN Mapping team)	Data on forested areas over the entire area and not only on affected overhead spans.
	6	**Buildings** (Outsourced service)	Information on buildings and locations
	7	**Land Ownership** (Outsourced service)	Information on land boundaries. In the current project only high level information (and not individual land parcels) was utilised.
	8	**Ecological Layer** (Outsourced Service)	Information on statutory areas related to environment and ecological aspects. There is an opportunity to utilise information available from county councils.
	9	**Archaeological Layer** (Outsourced Service)	Information on archaeologically sensitive areas (i.e. Listed Buildings, etc.). There is an opportunity to utilise historically available information from county councils.
ELEC	10	**Electrical Network** (SSEN Mapping team)	Current electrical network including poles, overhead lines, transformers (pole mounted or ground mounted), switches, underground cables.
COMPLIANCE	11	**Historic Fault Information** (SSEN Network Planning team)	Historic fault information and cause per pole, overhead line span, transformer, switch.
	12	**Condition Monitoring Data** (SSEN Network Planning team)	Information collected historically regarding condition of poles, conductors, pole mounted transformers, etc.
	13	**Customer Numbers** (SSEN Network Planning team)	Information on number of customers connected per 11kV pole mounted transformer.

Table 1: Data used by the Optimisation Tool

The data outlined in Table 1 have been collected through desktop surveys which spanned ecological constraints, archeological items, identification of historical faults, street work restrictions, asset costs, as well as other items. The collected data were then provided to the supplier of the optimisation tool in order to convert them in a format that would be acceptable as input to the optimisation tool.

All of the data collected and input in the algorithm reflect the different inputs that are required within the development phase of an undergrounding project, spanning network planning, network design and construction monitoring. The algorithm can take all of these data into account when making decisions regarding the undergrounding of existing overhead lines and as it was proven it resulted in more cost effective routes for underground cables.

Process:

The data were provided to the optimisation vendor, who uploaded them in the optimisation tool which runs the required internal processes in order to provide the required output. The internal processing of the optimisation tool relied on advanced analytics in order to factor multiple factors in the decision making and provide appropriate outputs. The following Key Performance Indicators (KPIs) were factored within the optimisation process when selecting an appropriate route and reported for each output produced.

KPI	KPI Name	Description
1	Capital Expenditure (CAPEX)	The upfront cost (in GBP) required for the development and construction of the designed route. The CAPEX consisted of development costs (i.e. land right payments, crop loss compensation, etc.), asset costs (i.e. cable cost) and construction cost (i.e. laying cable in carriageway).
2	Operational Expenditure (OPEX)	The OPEX measured in GBP consisted of all foreseeable operating costs that will be incurred in the lifetime of the assets (cables or overhead lines) included in the designed route. The OPEX included costs related to inspection and maintenance, refurbishment, tree cutting, fault cost (Interruptions Incentive Scheme (IIS) penalty and rectification cost), etc. The applied horizon for the OPEX in the optimisation tool was 45 years and the OPEX has been discounted in the net present value using a discount rate of 4.5%.
3	Time to Construct	The 'Time to Construct' KPI was measured in days and captured the respective development and construction time required in order to complete the proposed scheme.
4	Construction Risk	The 'Construction Risk' KPI was measured in percentage (0-100%) and provided an indication of the level of risk expected to be encountered during the construction of the proposed scheme. This KPI is mainly dependent on the terrain and conditions of the area over which the cable laying is proposed to take place. For example, a consistent terrain without any ecological restrictions will have lower construction risk than a changing terrain with ecological restrictions.
5	Social Acceptance	The 'Social Acceptance' KPI was measured in a scale of 1-5 and intended to capture the anticipation of customer complaints resulting from the construction and operation of the proposed scheme. This KPI measures the variation of social acceptance from the existing network and could vary from 1 which is the ideal scenario (i.e. all network is undergrounded in non sensitive areas) to 5 which is the worst case scenario (i.e. network in sensitive areas remains overhead).
6	Faults	The 'Faults' KPI was measured in absolute number and intended to provide an indication of the number of faults expected to be incurred over the horizon of 45 years in the proposed scheme. Average fault rates were used for the underground cables, while actual historical fault data were used for the existing overhead network.
7	Network Resilience	The 'Network Resilience' KPI was measured in absolute numbers that reflected the number of customers that are anticipated to be affected by faults per year. This KPI utilizes historic fault information on overhead lines and expected faults for underground cables, as well as the network topology for the proposed scheme. A number of faults are assumed to be occurring in the network subsequently which

		results in a number of customers that will lose supply. This number of customers are annualized and reported.

Table 2: KPIs for Optimisation Tool

A weighted system has been adopted between the KPIs. Within the project, it was decided for the upfront cost (CAPEX) to be the driving factor for optimizing the routes. The network resilience was also provided as a constraint on certain use cases and all other factors were reported as a consequence from the decisions being made in regards to the route design.

Further to the core route optimisation, the project tested the weighted average system of the optimisation tool and it was proven successful, as the optimisation algorithm was able to provide the best route in each of the KPIs (i.e. quickest route, most resilient route, etc.). As a conclusion, the optimisation tool could be used in order to provide options for undergrounding 11kV cables which will then inform the decision making of the network operator.

Output:
The optimisation tool has been offered as a cloud hosted service by the optimisation supplier. As a result the optimisation supplier dealt with the necessary hardware (i.e. servers), software (i.e. operational system) and maintenance. SSEN's interface with the optimisation tool was a web-hosted application which included the background map (GIS master map or satellite image) along with activation options of respective layers (i.e. ecological constraints) and a range of route options computed by the optimisation algorithm. An example of the online interface is provided below.

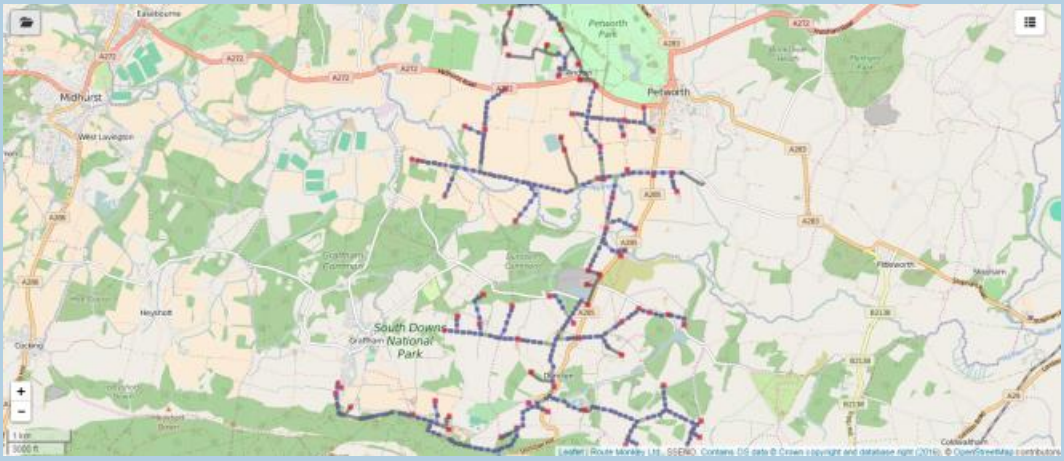

Table 3: Online viewer of optimisation tool

As the current project aimed to develop and trial the functionality of the optimisation tool, no effort was focused in the development of a Graphical User Interface (GUI) which would allow input and output of data. As a result, the optimisation vendor manually had to export the outputs (designed routes) in PDF format that was required by SSEN.

Summary of work completed:
SSEN and the optimisation vendor have developed and configured the optimisation tool in order to underground 11kV overhead lines. The scope was refined over 4 use cases, as described below.

No	Use Case Description
1	**Complete Undergrounding without altering the electrical design:** In this use case, the optimisation tool took as input the 33.7km of overhead lines and kept constant the connectivity between individual segments (i.e. poles or T junctions) in the undergrounding process. As a result and considering the fact that the electrical aspects were not taken into account, this use case identified how optimally a route could be designed by the optimisation tool solely from the civil engineering/ construction perspective. A direct comparison between the innovative route and the baseline route developed by an external vendor took place in order to quantify the benefits of the optimisation tool.
2	**Partial Undergrounding:** In this use case, the optimisation tool answered the question of whether it is cost effective to underground the entire network or only subsets of it. The optimisation tool has been given a range

	of data (including historic fault performance, maintenance costs, etc.) that allowed developing lifetime cost estimation for each overhead line span and the associated lifetime cost for its equivalent underground cable. Utilising financial analysis, the optimisation tool was able to identify which parts of the network are financially beneficial to be undergrounded or to remain overhead. A direct comparison between the outcomes of this use case and the associated analysis by the external vendor, based on TOTEX, was undertaken in order to derive conclusions.
3	**Network Resilience:** In this use case, the optimisation tool addressed the question of how we can improve the resilience of the existing network by developing close loops that will result in a high level of resilience. The tool has been enhanced with functionality to estimate network resilience based on compliance with P2/6 Engineering Recommendation and forecast number of faults that will be incurred. The validation of this use case was undertaken by the external supplier who provided network planning expertise and was able to competently assess the validity of the work produced. Most importantly, this use case served as the predecessor for the development of use case 4 which is the main use case for consideration.
4	**Complete Undergrounding with re-designed electrical network**: In this use case, the optimisation tool addressed the question of how the existing network can be undergrounded while its electrical topology is altered in order to improve network resilience while reducing further the cost of undergrounding. This use case altered the connectivity of the 11kV network (i.e. altered the Single Line Diagram) and allowed an optimal undergrounded section to be designed for the new connectivity model. Considering the project results, this use case has the highest potential to deliver benefits (in comparison to use case 1 which is directly comparable) as it results in reduced CAPEX resulting from the altered electrical design and improved civil engineering design.

Table 4: Use Cases of the Project

Results and Outcomes:

Outcome 1: The developed and trialed optimisation tool can design more cost effective routes in comparison to traditional methods. At the trial site considered which consisted of 33.7km of 11kV overhead line, the optimisation tool resulted in lower unit cost for underground cables in comparison to traditional methods.

The table below demonstrates the quantitative results from the implementation and test of use case 4 in the project's trial site. The use case 4 considers both the electrical re-configuration of the network and also the civil engineering design of the route and it was concluded by the network operator that this is the use case of most relevance and importance to the operations.

Route Description	Km of Overhead line to be undergrounded	Underground Cable to be Laid	Capital Expenditure (CAPEX)	Unit Cost (per overhead line meter)	Unit Cost (per underground cable meter)
Baseline Route (Traditional)	33.7km	35.67 km	£5,276,463.40	£156.57/m	£147.92/m
Innovative Route (Optimisation tool)	33.7km	36.91 km	£4,239,250.80 **-£1,037,212.6**	£125.79/m **-19.66%**	£114.84/m **-22.36%**

Table 5: Quantitative Results from optimising the route in the trial site (33.7km)

Considering the fact that a 33.7km scheme is a major one, it was concluded that it is not likely that such a scheme will materialize frequently in the normal business operations. However, it is evident that improvement will be achieved should this scheme be taken forward. The majority of the schemes that will be designed and constructed will vary between 2 and 9 kms. In order for the results to be applicable to a scheme of reduced length of overhead line to be undergrounded, the entire trial scheme (33.7km) was split in smaller sections that were priced individually. Such a break down to individual smaller areas provided key outcomes that are reported below.

Outcome 2: The optimisation tool has resulted in more cost effective routes in all individual smaller areas considered. Therefore, it is concluded that the use of an optimisation tool for designing routes for underground

cables will result in reduced CAPEX required in order to complete the undergrounding of overhead lines.

The areas considered have lengths of overhead line from 3.72km to 14.14km and the associated reduction in CAPEX varies from -11.33% to -25.56%, as shown in Table 6. It is believed that the greater the scheme considered and thus the available area, the greater the flexibility of the optimisation tool to identify an optimal route and achieve greater benefits.

Outcome 3: The routes designed by the optimisation tool have varying cost efficiencies. The cost saving will depend on the particular environment of the area (i.e. consistent terrain and land coverage) and also on the scale of the scheme considered. It has been concluded that the greater savings will be realized when longer lengths of overhead line are considered for undergrounding.

As shown in table 6, the different areas considered have varying cost efficiency. As it can be seen by table 6, the longer the length of overhead lines considered for undergrounding the greater the savings. This outcome will be used as prompt for the network planning team to be able to select longer sites for further development and construction.

Areas	Baseline CAPEX	Optimisation Tool CAPEX	Difference in CAPEX	kms of UG cable (baseline)	% reduction of CAPEX
Area 1	£ 727,316.19	£ 632,294.74	-£ 95,021.46	**3.72**	**-13.06%**
Area 2	£ 1,296,793.34	£ 1,149,812.28	-£ 146,981.06	**8.61**	**-11.33%**
Area 3	£ 1,307,202.89	£ 1,009,077.73	-£ 298,125.16	**9.18**	**-22.81%**
Area 4	£ 1,945,150.98	£ 1,448,066.05	-£ 497,084.92	**14.14**	**-25.56%**
TOTAL OR AVG	**£ 5,276,463.40**	£ **4,239,250.80**	**-£ 1,037,212.60**	**35.67**	**-19.66%**

Table 6: Quantitative Results from smaller sections (sub-sets of trial site)

SSEN's review of the outcome resulted in selection of area 2 as most representative of the work planned to be carried out over RIIO-ED1 period and will be related to the undergrounding of overhead lines. As a result, SSEN has concluded that the use of an optimisation tool for designing routes for underground cables in response to undergrounding 11kV overhead lines will result in **reduction of 11.33% of required capex and associated achieved unit cost**. As a result, the resulting saving is estimated at **£14.73 per meter of underground cable laid as a response to the undergrounding of 11kV overhead lines**.

Outcome 4: The use of an optimisation tool for route design can result in more informed decisions.

- ✓ The optimisation tool offers the opportunity to assess information from a variety of data sources simultaneously (not possible under traditional methods) and undertake decisions with a beneficial impact. Such statement is evident from the fact that the tool could result in more cost effective routes in comparison to traditional methods.

- ✓ The optimisation tool also offers the opportunity to review the impact of each designed route in the previously described KPIs and alter the weighting of KPIs in order to design routes aligned with the strategic priorities of the network operators. As a result, the optimisation tool could align the strategic priorities with tangible delivery of capital works.

- ✓ The optimisation tool can support portfolio evaluation at a short timeframe. The tool could provide a comparable output between different scenarios considered which can then be compared for delivery achievability and compliance with the company targets.

Outcome 5: An optimisation tool for route design could increase the efficiency of internal teams.
Under the traditional practice, a network planner would design electrically the undergrounding route (which re-configures the network) and a network designer would design physically the route. The range of data utilised is significantly less than the data utilised by the optimisation tool mainly due to limitations of time. The use of the optimisation tool demonstrated that it can handle multiple data simultaneously and have humans reviewing the designed routes as opposed to designing them. Such realization will result in manual processes being converted to advanced automated processes and will result in reallocation of human efforts to the decision making aspect of the

work and not on manual handling. As a result, the available resources will be utilised more effectively and efficiently.

Outcome 6: An optimisation tool could integrate individual team efforts.
As described previously, multiple teams participate in the design, development and construction of a n underground cable route. The use of an optimisation tool could integrate and align all efforts and move away from 'silo' approaches. Such outcome was not fully tested within the project, but engagement with internal stakeholders provides confidence in its realization.

Outcome 7: The optimisation tool will result in designed routes that will deviate from the feasible routes
A variation between the designed route and the feasible route is expected due to the fact that the optimisation tool relies on various sources for data collection, while the feasibility study relies solely on data collected from the site visit. A site walk of the proposed route was undertaken as part of the project and it was evident that local topographical features (i.e. line of trees, stone walls, bushes, etc.) were not factored within the design process. This was due to the fact that this information was not included within the data utilised for the design process. As a result, it is concluded that high resolution and up to date data are required i n order to be able to reduce the variation between the designed and feasible route.

Outcome 9: The data analytics and optimisation tool could handle improvements in network resilience
The work completed by the optimisation tool in respect to use case 3 and 4 has been validated by the external network planner and internal SSEN network planner respectively. It was demonstrated that the optimisation tool was able to clearly articulate the P2/6 ER and internal SSEN network planning standards and implement re-design of the network topology that achieved improvement in network resilience by appropriate design of close loops. The tool was able to factor into the decision making process; the number of customers, the probability of a fault occurring (based on historic information and average fault rates) and decide which sections required improvement.

Outcome 10: The optimisation tool could alter the selection of sites for undergrounding.
The current approach in selecting sites to underground involved looking at the historical fault performance and prioritising which overhead lines to underground. At the trial site of 33.7km overhead lines, the external network planner selected to underground 17.32km based purely on the rationale to underground sections that hav e had a fault occurring in the past 12 years. The innovative approach factored in the decision making process additional financial factors and concluded that only 2.05km is financially preferable to be undergrounded. Such difference resulted in reduced CAPEX which was expected, but also on reduced OPEX. Therefore, the conclusion is that the data analytics and optimisation tool could facilitate strategic priorities (i.e. fault elimination or fault reduction) within the design of capital intensive schemes.

Outcome 11: Further development work is required.
The concept of a data analytics and optimisation tool and its effect on the business decisions have been demonstrated via the current project. However, further development work is required in order to move the product to TRL 9 and be ready for BAU adoption. Details or areas that could be targeted for improvement are listed below:

- ✓ Development of a Graphical User Interface (GUI)
- ✓ Utilise a high resolution up-to-date source of background data
- ✓ Refine rules for route design (civil and electrical engineering)
- ✓ Undertake necessary technical actions (i.e. interfaces, etc.) and training actions (i.e. training manual and training program, etc.) that would allow transition to the BAU.

Outcome 12: Value of Data Analytics and Optimisation software
Through the Network Optimisation Project, it has been demonstrated that data analytics and optimisation software could add value to the operation of network operators. Utilization of advanced analytics which can process numerous data from multiple internal and external data sources, derive trends and conclude to optimal decisions can be utilised in order to drive efficiency in business decisions. As a result, SSEN considers that the use case of undergrounding 11kV overhead lines demonstrated the value of utilizing analytics techniques in solving business problems.

Technology Readiness Levels

The current project aimed to develop and demonstrate the optimisation algorithm offered by the selected supplier and achieve a Technology Readiness Level of 7. It is considered that such development and demonstration has been achieved and the current TRL level is 7.

Planned Implementation

The current project developed and demonstrated a data analytics and optimisation tool and concluded to a Technology Readiness Level of 7. Some high level actions identified in order to move the product to TRL 9 are listed below:

1) Identification and utilization of a mapping source that will be of high resolution and up to date. This will result in designed routes that will be based on actual and up to date topographical features and as a result will deviate less from the feasible route.
2) Development of a Graphical User Interface (GUI). At the current stage, the product has been developed as a functional tool with no user friendly interface in order to phase the spending and ensure value for money. In order for the tool to be utilised by the business a GUI needs to be developed.
3) Further refinement of the applied rules in electrical and civil engineering design is required.
4) Addition of further electrical engineering rules will be required depending on the business appetite for scope expansion in the electrical design aspect.
5) Development of a training manual, training of internal personnel and BAU transition.

It is concluded that the current NIA demonstrated value for money as SSEN is undertaking a tender upon the outcomes of the project and has planned to implement changes in the business operation in order to leverage the benefits that can be offered by data analytics and optimisation tools.

Other Comments

Not Applicable