Project code/Version number:
SGN_GN_04/Resubmission_v1

1. Project summary

1.1. Project title	**Robotic Roadworks and Excavation System (RRES)**
1.2. Project explanation	The project will develop a Robotic Roadworks & Excavation System (RRES) which will use advanced robotics and Artificial Intelligence to lower the cost and improve the efficiency, safety and environmental impact of utility excavations and activity.
1.3. Funding licensee:	Southern Gas Networks and Scotland Gas Networks
1.4. Project description:	*1.4.1. The Problem(s) it is exploring:* The RRES addresses three main problems of gas utility excavations: (a) Labour intensive operations that have high financial and environmental costs due to resource, vehicles, plant and control measures required; (b) Traffic disruption and significant CO2 emissions created by large and heavy equipment; (c) Risk of damaging unknown third party utility infrastructure using conventional excavation techniques, which can lead to loss of supplies, disruption to customers, and significant risk of injury to operatives. *1.4.2. The Method(s) that it will use to solve the Problem(s)* The RRES project will automate the excavation process in both rural (transmission) and urban (distribution) areas using artificial intelligence and advanced robotics. Using below-ground locating sensors, computer vision and “soft-touch” excavation tools will prevent the damage of neighbouring utilities and of the target asset. *1.4.3. The Solution(s) it is looking to reach by applying the Method(s)* The RRES operator will deploy and monitor the system at the designated excavation location. The system will use sensing technologies and tools to detect and excavate around buried utilities and obstacles. Soft-touch tooling will safely prevent damage to buried assets. The system will install a custom-designed Universal Access Fitting (UAF) on the pipe that facilitates a variety of gas main inspection and repair operations through one reusable fitting. The RRES will backfill, perform tamping to specification, and reinstall the original road surface. *1.4.4. The Benefit(s) of the project* The benefits, learning, and improvements include: (a) Higher repeatability; reduced operating costs; (b) Lower risk of damaging buried assets; (c) Reduction in carbon footprint; (d) Reduction in site footprint and less disruption to the public; (e) Lower risk to operatives by removing them from the immediate excavation area; (f) Reduction in excavated material to landfill through reinstatement using the original road surface; (g) Open market for expanding future inspection, maintenance, and repair

	operations; (h) Development and implementation of new intellectual property on behalf of the GB gas consumer; (i) Applicability to both gas transmission and distribution assets; (j) Transferability to other utility and infrastructure sectors		
1.5. Funding			
1.5.1 NIC Funding request (£k)	6,325.674	1.5.2 Network Licensee compulsory contribution (£k)	710.400
1.5.3 Network licensee extra contribution (£k)	0	1.5.4 External funding – excluding from NICs (£k):	200.000
1.5.5. Total project costs (£k)	7,303.770		
1.6. List of project partners, external funders and project supporters (and value of contribution)	Project partners: SGNs primary partner for the RRES project is ULC Robotics. ULC is recognised for its award-winning and cutting-edge robotic technology, innovation and R&D services for energy utilities that work to reduce costs while improving efficiency and safety for energy customers and the general public. They were also the principle partner in the successful 'NIC 2013 - Robotics' project which culminated in the production of the CIRRIS XI™and XR™ robotic systems. SGN and ULC have also engaged the UK Manufacturing Technology Centre (MTC) based in Coventry to participate in this project. The MTC represents one of the largest UK public sector investments in manufacturing. It is a partnership between some of the UK's major global manufacturers, universities such as Birmingham, Nottingham and Loughborough, as well as more than 50 industrial members from across a wide range of industry sectors. The MTC was set up to provide a stimulus for British manufacturing and to deliver manufacturing and process technology support to the industry. Further details of the project partners can be found in Appendix D. External funders: ULC will be contributing £200,000 to the project. Project Supporters: Several additional organisations have expressed their support for the development and ultimate commercialisation of the RRES. Letters of support from each of the Project supporters are provided in Appendix H.		
1.7 Timescale			
	2nd April 2018		26th March 2021

1.7.1. Project start date		1.7.2. Project end date	
1.8. Project manager contact details			
1.8.1. Contact name and job title	Angus McIntosh Innovation and New Technology Manager	1.8.2. Email and telephone number	angus.mcintosh@sgn.co.uk T: 0131 491 823 M: 07966 105 362
1.8.3. Contact address	SGN, Axis House 5 Lonehead Drive Newbridge Edinburgh EH28 8TG		
1.9: Cross sector projects (only complete this section if your project is a Cross sector project, ie involves both the gas and electricity NICs).			
1.9.1. Funding requested the from the [Gas/Electricity] NIC (£k, please state which other competition)	N/A		
1.9.2. Please confirm whether or not this [Gas/Electricity] NIC Project could proceed in the absence of funding being awarded for the other Project.	N/A		
1.10 Technology readiness level (TRL)			
1.10.1. TRL at Project start date	4	1.10.2. TRL at Project end date	8

Section 2: Project description

2.1. Aims and objectives

2.1.1 – The Problem

The vast majority of the gas network's pipeline assets are below ground. Access for inspection, repair, replacement and extension of these below ground assets requires excavation of roads, paths, verges and fields in both urban and rural environments. The excavation and subsequent reinstatement of work sites, to enable these essential activities, represents one of the most significant costs for any utility and is also harmful to the environment.

Disruption caused by roadworks is a primary concern for the public and results in significant social cost.

Figure 1: Typical disruption

Critical infrastructure is installed below ground supplying GB's energy, water and telecommunications, which must be avoided or protected as far as practicable during any excavation activity. Interference damage to these assets can pose significant hazards to operatives, road users, pedestrians and property. Damage to gas pipelines or electrical cables for example, could result in fires, explosions or electrocution, not to mention potentially significant supply disruption to utility customers and businesses. Records of these assets are imperfect. Many were installed long before the digital age or position reference features have changed due to redevelopment over the years. As such asset records and drawings cannot be relied upon as a sole means of asset location.

Safe digging practices are therefore unsurprisingly onerous, expensive and time consuming.


Figure 2: Road breaker tool damage following cable strike

Some examples of the excavation process in both urban and rural environments are provided in Appendix F.

We continually seek to improve our excavation and reinstatement activity as far as possible by both developing and implementing the latest technologies, such as keyhole repair, trenchless techniques and robotic remediation. There are limitations to these technologies however and conventional excavation continues to be a high volume activity. As such this is an important area and opportunity for innovation. See Appendix N for examples of relevant recent and ongoing innovation projects.

2.1.2 – Method

The 21st century has shown trends in factory automation, the miniaturisation of electronics, increased computing power, advances in sensor technologies, and efficient software and algorithms that run on embedded platforms. These advances have enabled robotics to automate a myriad of high precision, conventional manufacturing and industrial processes, saving companies time and money. Through feasibility studies and development work performed over the past two years, ULC and SGN have developed a conceptual method for using robotics to automate the safe and rapid excavation of buried distribution and transmission piping. This methodology utilises a robotic arm, advanced artificial intelligence, sensors, custom tools and a single vehicle to perform these complex operations. The method also enables the robotic installation of an open-source universal access fitting (UAF).

The project will be arranged around development of the following elements:

- Element 1: Development of robotic arm, mobile platform, below-ground sensing, excavation tooling, AI and computing system
- Element 2: Interim integration, shop testing and field testing
- Element 3: Development of mobile operations, automated tool changing system, UAF and associated tooling, support equipment and support vehicle
- Element 4: Final integration, shop testing and field testing

By developing the system with future expansion in mind using an “open source” design philosophy and by sharing the universal access fitting specifications publicly, third-party manufacturers will be encouraged to develop additional tools, processes and procedures for automating roadworks. This strategy will enable quick-to-market solutions and future proofing/expandability that will accelerate the delivery of benefits to the public and to utility companies as new technological advances are implemented.

2.1.3 – Development

The goal of the project is to develop a prototype RRES system that can demonstrate automation of the excavation and reinstatement process and the installation of a Universal Access Fitting (UAF). Two field tests will be executed: one on dead pipe and the following one on a live gas main. Collectively, the two field tests will demonstrate the following:

(a) Transport and setup of the RRES (including a vehicle and a mobile platform with a robotic arm and excavation sensors/tooling)
(b) Removal and reinstatement of asphalt, concrete and soil
(c) Soil vacuum excavation in urban and rural environments
(d) Prevention of damage to buried assets throughout the excavation process
(e) Detection and avoidance of other buried objects
(f) Exposure of the target pipe for operations

(g) Preparation of a low pressure distribution pipe for UAF installation
(h) Installation of the UAF on a low pressure distribution pipe

2.1.4 – The Solution

By developing custom tools for excavation with a focus on minimising the space required to perform operations, it is anticipated that the physical and carbon footprint of excavations will be much smaller than that which is traditionally required, causing less disruption to local businesses and the public. Using machine vision, a suite of sensors and newly developed processing software, damage to natural gas mains and other buried assets will be prevented through careful manipulation of the tools and avoidance of buried assets. Also, by removing workers from exposure to hazards incurred by damaging high pressure natural gas mains or severing of high voltage electricity cables, the robotic solution will minimise risks to operatives, supplies and consumers.

2.1.5 – Cross industry application

The target areas and benefits the development of the RRES will potentially deliver are clearly cross transferable to a number of utility, infrastructure and construction sectors. Excavation in congested urban areas, around hazardous plant or in hazardous environments is a problem faced daily by companies in Great Britain (GB) and across the world.

We have received letters of support from a number of parties interested in cross industry applications as shown in Appendix H.

2.2. Technical description of project

2.2.1 - Overview

The RRES project will yield potentially significant financial, safety, and social benefits by combining modern automation and robotic technologies to solve a daily challenge in the utility and construction sectors. Many of the robotic technologies that will be employed by the RRES have a high degree of technical maturity; for example, drive platforms, robotic arms, tools for coring and lifting, and many of the sensors which are suitable for the RRES application are all commercially available. What makes the RRES innovative is the integration of these commercially available products with advanced processing software, a closed loop sensor system and the implementation of controls designed to support excavation in both urban and rural environments. The robotic industry is currently focusing on developing robots for factory automation, work in hazardous environments, warehouse automation, autonomous driving vehicles and other high volume applications in agriculture and mining. The automation of excavation is a relatively neglected area that has substantial promise to deliver value to utility companies and the consumers.

Prior to submission of the ISP, ULC performed significant research on key robotic technologies, developed concepts of operation for both transmission and distribution works, designed, manufactured and successfully tested an alpha prototype “soft-touch” excavation tool, and identified the critical elements of the system architecture. The RRES concept of operations is summarised below. More detailed concepts of operations for both distribution and transmission works can be found in Appendix B.

- In distribution works, the RRES will focus on automating excavations in urban environments, followed by the optional installation of a universal access fitting which will enable a variety of operations to be performed. Once the UAF has been installed and the target work performed, the system will backfill and tamp the soil to reinstate the excavation as per specification.
- In transmission works, the RRES will perform active sensing, dig trial holes to confirm the location of the main, and will then excavate the complete "danger zone" around the pipe over a specified length.

The RRES project will kick off with a review and update of the existing concept of operations, system specifications and the preliminary system architecture (Figure 3).

Figure 3: Simplified Systems Components

Work will then commence on development of individual robotic subsystems, followed by integration and testing of the subsystems and culminating in system testing. The technical methods specific to the selection, integration and testing of the individual robotic technologies for the RRES are broken down by project Element in the sections below. Further information on the planned system architecture for the RRES and on key RRES technologies is provided in Appendix J. The technical solutions employed may evolve over the course of the project based on technologies and learnings generated through concurrent engineering of the RRES subsystems

2.2.2 – Element 1: Technical description

Element 1 of the project focuses on the selection and development of the robotic arm, mobile platform, below-ground sensing module, excavation tooling, and the computing platform needed to command and control the RRES.

2.2.2.1 – Robotic arm evaluation and testing

The RRES will employ a commercially available industrial arm to control the position, velocity, force and torque of several tools, or end effectors, each performing different tasks. The arm selected may be of a conventional configuration with multiple rotational joints, which provides the most flexibility with motion control, or may be of a Cartesian configuration with three translational degrees of freedom, which would simplify AI development and allow for increased load capability.

It is anticipated that selection of the robotic arm will include the following tasks:

- Develop robotic arm specification
- Engagement with the MTC to support the identification and evaluation of robotic arm technology for use in the RRES application
- Research and evaluate commercially available robotic arms for mechanical and software suitability
- Procure robotic arm
- Perform programming and shop testing

2.2.2.2 – Mobile platform evaluation and testing

A commercially available mobile platform will be selected to facilitate movement of the RRES around a job site and deployment of the system to remote areas. It is expected that the platform will be a rugged treaded vehicle with a wide base and high torque delivery. The robotic arm will be mounted to the mobile platform, as will the suite of tools required for performing operations and on-board computing.

It is anticipated that the following activities will be performed during development of the mobile platform:

- Develop specifications for mobile platform
- Research and evaluate commercially available platforms for suitability (weight, size, power)
- Source platform and modify as needed to meet specifications
- Develop or procure software and hardware for operation of the platform
- Integrate and perform shop testing

2.2.2.3 – Computing system development

A computing system will be developed for the RRES to handle various forms of data input, process information, facilitate communication between subsystems, and orchestrate the different operations performed by the system. Software will be developed and is anticipated to include a graphical user interface, communications modules, a database, and report generation capabilities.

It is anticipated that development of the computing system will include the following tasks:

- Develop computing system specifications
- Evaluate and select hardware for main control and communication systems
- Source and assemble electronic components and perform shop testing
- Code generation to enable integration and testing of various subsystems
- Software testing and debugging

2.2.2.4 – Below-ground sensing development

The RRES will employ a combination of sensors and other hardware to detect and avoid a wide range of buried assets and to identify the target asset. These sensors may include ground penetrating radar, electromagnetic sensors, acoustic sensors, LIDAR, and cameras. Potential technologies were researched and evaluated prior to ISP submission, and the initial focus of the next phase of sensor development will be to review and test high potential technologies in greater detail. The sensors may be packaged within a standalone module, or they may be integrated directly into the excavation tooling.

To accurately determine the location of the RRES's end effectors in space, it is anticipated that 3D sensing techniques using LIDAR and/or stereo vision will be used to generate a point cloud of the environment. The RRES will utilise these references to localise the actions performed by different end effectors and to map features of the excavation relative to the surroundings.

The sensor module will scan during the excavation process and will enable the RRES tooling to avoid or navigate around obstacles while performing the excavation. If the obstructions detected during operation are large enough to impede the RRES tooling from reaching the target asset, or if the system encounters a situation outside of its operating parameters, the operator will be notified to provide intervention or redirection.

It is anticipated that development of the below-ground sensing and end-effector positioning capabilities will include the following tasks:

- Develop below-ground sensing specifications
- Engagement with the MTC to support the identification and evaluation of sensing technology for use in the RRES application
- Continue evaluation of sensors researched in previous phases of the RRES project, and identify any new sensors discovered during system development
- Develop software for sensor and vision processing and perform bench tests as needed
- Develop software for controlling robotic arm, end effectors, and tooling in relation to operating environment
- Develop software which enables closed loop feedback between buried object/utility identification sensors and control system
- Develop software for generating 3D point cloud map and toolpath
- Perform detailed electrical design, including schematic design, circuit card layout, and firmware programming
- Perform shop testing and update software and hardware as needed

2.2.2.5 – Excavation tooling development

A "soft-touch" vacuum excavation tool prototype was developed prior to ISP submission that agitates and removes soil without damaging objects during excavation (See Appendix J for additional details). This tool, coupled with the ability to sense buried utilities and objects, will enable a redundant safety feature in the excavation operation. The prototype developed previously will provide a starting point for additional design and process improvements. The excavation tooling will be developed with a focus on distribution system excavation activities. Once the initial design has been successfully tested and demonstrated to enable fast, accurate and damage free excavation in distribution piping systems, the tool will be tested in transmission environments. Learning and results of testing in both environments will be presented and recommendations for next steps will be provided.

Additional tools may be developed under Element 1 to support the excavation process. This tooling may include saws for cutting and/or coring asphalt and concrete, a lifting device for removing cores in urban environments, and a tamping device to compress soil to specification after it is backfilled. It is expected that the vacuum excavation tool could also be used to backfill holes in urban environments with the soil that was collected during excavation. Individual tools may employ local articulation that supplements or extends the range of motion or torque provided by the robotic arm.

It is anticipated that the following tasks will be performed as a part of tooling development:

- Develop specifications for excavation tooling
- Evaluate commercially available tools and/or perform mechanical and electrical design of custom tools
- Source commercially available tools and modify as needed and/or fabricate and assemble custom tools
- Develop motor drive systems, electronics and motion control software for actuation of each tool

2.2.3 – Element 2 – Technical description

Throughout the course of Element 1, test fixtures and environments will be developed to enable the testing of individual components. This continuous cycle of design into test will enable quick concept validation and will reduce risk in the project while achieving faster learning.

After the Element 1 subsystems have been developed, manufactured and tested individually, integration will be performed and the capability of the prototype RRES system will be assessed. The Element 1 system will include a robotic arm, mobile platform, sensors, control software and electronics, mechanical components and excavation tooling. The integration process will include the fabrication of interfaces between subsystems, assembly of components, hardware, cabling, and pneumatics along with software programming and debugging. Support equipment needed to operate the RRES and to monitor excavation activities will be selected, procured and integrated for testing.

Updates to the system will be made through an iterative testing and learning process. Testing activities will culminate with the robotic arm performing small excavations from a stationary position while detecting and avoiding predefined buried obstructions throughout the excavation process. It is anticipated that tool changing would be manual during this phase of testing.

Once off-site factory testing at ULC is complete, the prototype system will be shipped from the US to the UK for an initial field test. The first field test will be performed on decommissioned infrastructure (not attached to a distribution or transmission system) and will focus on evaluating the prototype system’s capabilities. Officials from the Health and Safety Executive (HSE), OFGEM and other stakeholders will be invited to witness field testing and provide feedback. The results of field testing will be thoroughly documented and will inform continued development under Element 3.

2.2.4 – Element 3 – Technical description

Under Element 3, the remainder of the subsystems critical to the operation of the RRES will be selected or developed. These will include AI software for performing operations on the mobile platform, an automated tool changing system, a universal access fitting and corresponding tooling, support equipment, and a support vehicle.

2.2.4.1 – Mobile operations development

The AI developed under Element 1 will need to be adapted to enable larger excavations to be performed in conjunction with the mobile platform. Whereas the base of the robotic arm will be stationary during operations completed in Element 1, the fully-developed RRES will be able to move the base of the robotic arm to different locations using the mobile platform. Additional software and hardware development will be performed to enable a series of small excavations to be combined to form a single larger excavation. This capability is intended to provide the RRES with the ability to excavate within the danger zone along the length of transmission mains.

It is anticipated that development will include the following tasks:

- Develop specifications for mobile platform motion planning and control
- Perform additional software and hardware development to enable mobile platform control
- Update toolpath generation and 3D mapping software for use on mobile platform
- Update sensor processing software for use on mobile platform
- Test software, debug and update as needed

2.2.4.2 – Automated tool changing development

A system will be developed for the robotic arm to facilitate quick connects and disconnects with a range of end effectors. It is expected to include receptacles for individual tools, motion planning software, and the selection or development of a robotic arm-to-tool interface. This interface, at a minimum, will provide a solid mechanical lock between the robotic arm and end effectors, and will provide a reliable connection during operation. The interface may also deliver power, communication, pneumatics, or rotational motion to the end effectors, depending on the end effector's functional requirements.

It is anticipated that development of the automated tool changing system will include the following tasks:

- Create conceptual designs
- Review design concepts and down-select
- Perform detailed mechanical design, including 3D CAD models, 2D drawings, electronics packaging
- Perform detailed electrical design, including schematic design, circuit card layout, and applicable firmware programming
- Manufacture prototype, including machined and moulded components, circuit cards, and wiring
- Perform shop testing and modify design as needed

2.2.4.3 – Universal Access Fitting (UAF) development

A custom universal access fitting (UAF) will be developed for use on distribution pipes (<7 bar). The fitting will be designed to simplify robotic installation and facilitate a wide range of typical inspection and repair activities. Potential operations that would be enabled by the UAF include the insertion of camera equipment, the insertion and deployment of flow stop equipment, water extraction, internal stent pipe repair, and leak detection. Tooling will be procured or developed to facilitate a robust installation method. It is expected that tooling will include a surface preparation device, a device for handling the fitting and attaching it to the pipe by means such as bonding or fusing, and a pressure test device to verify the integrity of the fitting. Once developed, tooling will be integrated with the robotic arm and programming will be performed to enable the system to perform installation activities.

It is anticipated that development of the UAF and appropriate tooling will include the following tasks:

- Develop UAF specification and select best pipe material/sizes for early testing
- Develop specifications for UAF installation tooling
- Create design concepts for UAF and associated tooling
- Review design concepts and select optimal designs
- Perform detailed mechanical design, including 3D CAD models, 2D drawings for UAF and tools
- Perform detailed electrical design, including schematic design, circuit card layout, and firmware programming for UAF installation tools (as appropriate)
- Develop control software to enable operation of each tool
- Manufacture prototype fittings and prototype tools for shop and field testing
- Perform shop testing on prototype fittings and tools

2.2.4.4 – Support equipment development

The RRES will rely on several pieces of support equipment to execute tasks. Whenever possible, support equipment will reside in the vehicle from which the RRES will be deployed. It is anticipated that this support equipment will include a tether connected to the RRES that will supply power, communication, and pneumatics, a reel cart for storage of the tether, an operator user interface for monitoring and operating the RRES (as needed), and auxiliary elements such as a generator, power supplies, a high-power vacuum system, and a pneumatic pump. Commercially available systems will be selected to meet RRES specifications and, whenever possible, that are able to fit into the vehicle.

2.2.4.5 – Support vehicle development

Specifications will be developed for a vehicle that will transport and contain the RRES and support equipment onsite. A focus will be on optimizing the size and configuration of the vehicle, process and system to work in urban environments. After the RRES transport vehicle layout is generated, different chassis configurations will be reviewed and a vehicle configuration will be selected. The transport vehicle will be sourced and support equipment will be integrated into the vehicle.

2.2.5 – Element 4: Technical description

After Element 3 development and subsystem testing is completed, the full RRES system prototype will be integrated and tested. Hardware, electronics and software developed and tested under Elements 1 and 2 will be modified in preparation for deployment during the second field test. The subsystems developed under Element 3 will be added to the system incrementally and programming and iterative shop testing will be performed. The system will then be shipped to the UK for the final round of field testing, which will likely be performed on live natural gas pipe. The capabilities of the complete RRES will be evaluated against the project specifications, and the results will be documented accordingly.

2.3. Description of design of trials

Testing will be performed on each RRES subsystem to validate design integrity and to demonstrate the capability and progression of the RRES throughout the development cycle. Prior to the start of individual component development, specifications will be created for each subsystem to ensure that they will deliver the desired project outcomes. Test plans and procedures will be generated to evaluate the capabilities of subsystems relative to their specifications and to mitigate project risks. Testing will be conducted in accordance with test plans and procedures for both component-level and system-level testing. Test reports will be generated following testing to safeguard the learnings captured for any future work.

Test plans and procedures will employ the scientific method such that parameters are quantified and results can be replicated consistently. This will ensure that the results tabulated during testing will be statistically sound. Test plans and reports will include documentation of soil conditions, the size, material and depth of buried utilities, temperature and humidity conditions, and other applicable parameters. ULC has previously constructed a “mock roadway” with asphalt, concrete, soil and buried assets which meets the specification of a city street, and has extensive experience in building out test environments for numerous other projects. Under the project, specific test conditions will be defined and developed based on surveys of excavation sites. In the future, more soil conditions and pipe materials and sizes will be added to the portfolio of tests, better equipping the RRES to handle a wide range of environments.

The RRES project has an ambitious scope, seeking to incorporate advanced robotic technologies with the goal of achieving a technological readiness level (TRL) of 8. The RRES project has been structured such that the system’s capability will be augmented incrementally over the course of the project. Taking this approach enables learnings to be captured as the project progresses and allows the capabilities of the system to be expanded over time. For instance, the degree to which RRES operations are automated will increase gradually over the course of the project. If technical complexities prevent certain aspects of the project from progressing to full maturity, the remaining elements of the system can still be developed and commercialised, and the system’s value will still be demonstrated.

2.4. Changes since Initial Screening Process (ISP)

We have made a small adjustments to the total project cost required due to a re-evaluation of the independent audit requirements for the project. Each aspect will be tendered separately rather than paying to retain a technical service for the entire project duration. Additionally, the funding request has gone down slightly due to a £200k contribution to the project from our project partner ULC. We have also reorientated the tasks under each of the Elements following a secondary project planning exercise as the new breakdown does a better job of distributing resources and managing risks earlier in the project.

Section 3: Project business case

3.1. Introduction

The RRES project will, following implementation, potentially deliver a range of financial, safety and environmental benefits to SGN and the other Gas Distribution Networks; social benefits will also flow to the wider UK populace and other utility sector industries. Our solution delivers value through the machine automation of a range of labour-intensive field works activities. Our business case is built upon improvements in efficiency, safety, and repeatability relative to current practice.

In making our assessment of both quantitative and qualitative benefits, reference has been made to leading sustainability cost/benefit approaches being developed and demonstrated as part of the EPSRC-funded "Assessing the Underworld" Project[1].

Specifically our approach is to quantify the direct and indirect cost savings likely to accrue to networks (and consumers through the IQI sharing mechanism) following network-wide deployment of the technology, together with associated Environmental (Mt CO2e) and Social Cost benefits (where calculable).

Our appraisal makes separate consideration to the benefits likely to accrue to distribution (<7bar, urban) and local transmission (>7bar, rural) excavation and work activities undertaken on the GB gas distribution network. In line with the staged approach to technology development, we have appraised separately the benefits arising from automated excavation/reinstatement versus asset work activities.

3.2. Approach

Our project is highly innovative; although some promising sub-components have been identified, specified, developed and/or tested as part of earlier development under NIA, the integrated system is yet to be demonstrated. Our approach therefore is to use the direct and indirect cost savings projections in our analysis to guide a target price for the developed technology solution, likely to be delivered into network companies as an operational service by 3rd parties. We are presenting our Business Case in the form of a number of 'Methods' shown in the table below:

Benefits case	Network benefits		Environmental benefits	Social benefits
	Direct	Indirect		
a) Robotic automation of current Core-and-Vac system for excavation and reinstatement (Urban)	Method 1	Method 3	Method 4	
b) Robotic 'soft-touch' capability to allow wider application of Core-and-Vac technology (Urban)	Method 2			
c) Robotic automation of routine inspection / maintenance / repair work activities (Urban)	Method 5	Method 7	Method 8	

[1] EPSRC Project EP/K021699, Assessing the Underworld (ATU), University Of Birmingham

d) Robotic automaton of main / services replacement work activities (Urban)	Method 6			
e) Robotic automation of the Excavation and Reinstatement process for LTS pipelines (Rural)	Method 9			
f) Robotic automation of specific work processes on high pressure pipelines (Rural)	Method 10			
g) Application of the technology in other utility sectors to reduce unit costs of provision to GDNs		Method 11	Method 12	

Presenting our analysis in this way allows the separation of monetised benefits directly attributable to deployment of the solutions on the GB gas network (Network Benefits), and those wider environmental and social benefits accruing to both business, commerce and the population at large.

Our base-case (counterfactual) comparator is current core-and-vac distribution excavation practice coupled with in-core asset repair and maintenance activities performed manually with long handled tooling. We assume an iron mains replacement programme complete by 2032 and an enduring gas transportation system to 2050.

Compliant with the completion of tables at Appendix A, cost savings relative to current practice are shown cumulatively in years 2020, 2030 and 2050 (£NPV discounted at 3.5% to 2048, 3% thereafter) pre-IQI sharing, with Environmental benefits shown cumulatively as MtCO2e. The figures at Appendix A have been compiled assuming an equal split of gross benefits between networks and technology providers (i.e. are net of implementation costs) and are probability weighted to reflect technical and commercial risks. Where other environmental benefits arise (for example, reduction in NOx and particulate matter arising from reduced vehicle movements) these have been described qualitatively in the table and supporting text below.

Detailed financial models for each Method are provided in Appendix E and Use Case studies providing qualitative and visual comparisons of current methods with the RRES methods are provided in Appendix F.

3.3. Benefits' appraisal

3.3.1 - Materiality of capacity release

We have considered carefully the issue of network capacity released through implementation of RRES and have concluded there is not a material case to be made either at GDN scale, or by escalation to the NTS. We have confined our analysis therefore to the considerable financial, environmental and social benefits accruing to the project's outcomes.

3.3.2 - Minimum scale for benefits' realisation

Unlike SGN's previous and current NIC projects (Robotics, Opening up the Gas Market, Real-Time Networks), a key feature of RRES is the niche demonstration of a wide range of robotic technologies rather than a sub-network level demonstration of a single solution. At the project level, therefore, the benefits are quite small. In up-scaling to addressing say 25% of 140,000 uncontrolled emergencies per annum across SGN however, the benefits are proportionately higher, and material. We have taken as a starting point therefore benefits appraisal at the licensee level. Method specific scaling factors are included to estimate value at GB level.

3.4. Method realisation

3.4.1 - Method 1: Reducing the direct costs of core-and-vac excavation and reinstatement through robotic automation

In Method 1 we consider the potential improvement in work efficiency of the current core-and-vac excavation/reinstatement process and the anticipated direct cost savings attainable through robotic automation. We are targeting material improvements over current practice through quicker asset location and marking, reduced set-up time, avoidance of 'dry' holes, and faster excavation via an integrated extraction assembly.

Our starting point for financial assessment is the post-field trial benefits' appraisal of the Core-n-Vac process used in the capex investment case for procurement of SGN's fleet of 6 off 7.5 tonne vehicles with integrated core-and-vac capability. In 2017/18 prices the base case cost per repair was estimated at £904, compared with a 43% reduction with core-and-vac to £514, with the bulk of savings attributable to reinstatement. Adding back an average cost of capex for the machines implies a service price of £708.

We have projected a +20% improvement in productivity for the robotic system; this generates value by displacing excavations that would otherwise be conducted using traditional methods. We have assumed replacement of current core-n-vac technology for joint repair, fracture repair, and mains/services connections. Peak work volume of ~30,000 excavations per annum is projected by 2026.

We forecast Net Value of £1.9m by 2030 (7.0m GB-wide) at a service excavation price of £725.

3.4.2 - Method 2: Robotic 'soft-touch' capability to allow wider application of Core-and-Vac technology (urban)

The benefit of method 2 is assumed to be realised by extending the applicability of the core-n-vac process by 25% beyond the work volumes described in Method 1. This extension of capability is to reflect the superior spatial access of the remote vehicle, enhanced asset locating capability, reduced safety concerns in asset-congested areas, and better unit costs compared with current machine capability. In this way we are valuing the direct costs savings of 'doing excavations where no current core-and-vac can go'.

Sensitivity studies (Appendix E.2.) show that to realise this benefit a higher service premium would be tolerable (as the base case is traditional excavation methods). At a service price of £750 Method 2 returns a value of £4.2m by 2030 (£15.4m GB-wide).

3.4.3 - Method 3: Indirect cost benefits of robotic excavation and reinstatement (urban)

Commensurate with the level of robotic excavation activity described in Methods 1 and 2, we have considered the likely indirect cost savings arising from (i) reduction in damage to buried assets caused by excavation activities, (ii) cost of personnel injury and, (iii) work management charges, including TMA and Lane Rental costs. We have constrained the value to 2032 to reflect the strong link to distribution repair and repex activities. Details of our analysis are at Appendix E.

Taken together we estimate a net value of £4.36m by 2030 (£24.46m GB-wide) arising from a reduction in indirect costs.

3.4.4 - Method 4: Environmental and Social benefits of robotic excavation and reinstatement (urban)

Please see Section 4.a.1.

3.4.5 - Method 5: Robotic automation of routine inspection/maintenance/repair activities (urban)

A second stage of RRS development under NIA determined a shortlist of work operations (beyond joint repair) to guide the early development of RRES. Beyond the basic excavation process this included (i) fitting of a main repair clamp, (ii) insertion of camera for internal pipe survey/leak detection, (iii) flow stopping, and (iv) water extraction. Activities (ii) – (iv) are assumed to be facilitated through a Universal Access Fitting (UAF) – itself akin to a repair clamp with an integral throat/valve assembly to provide live access to the main. Our approach to valuing this Method therefore is to consider the likely direct cost savings attributable to fitting an equivalent number of repair clamps with the robotic device.

We have estimated the NPV at licensee level at 2030 to be in the range £0.6m to £0m (£2.0m to £0m) when the cost of service ranges from £100 to £200 per UAF fitted (Appendix E.5.). This is relatively low and reflects the likely taper on mains repair activity out to 2032.

3.4.6 - Method 6: Robotic automaton of main/services replacement work activities (urban)

In Method 6 we explore the potential benefit of extending robotic automation to pipe and services replacement. In our iCore programme funded under NIA we have demonstrated in the field the successful deployment of in-core directional drilling to 25m (for pipe up to 75mm in diameter) and the fusion of service tees using Long Handled tooling (LHT). Replacement of Tier 1 pipes and related services will continue to be major part of our Totex to 2032, and we have therefore valued this method on the potential direct costs savings on 20% of the ~93,000 service relays and transfers conducted per annum as part of Tier 1mains replacement activity (Appendix E.6.).

The Method is estimated to provide net value at 2030 of between £4.4m and £1.2m in the service price range £25 to 75 £/service (£16.1m to £4.4m GB-wide). This is in addition to any excavation benefit. Details are provided at Appendix E.6.

3.4.7 - Method 7: Indirect costs of robotic automation of work activities (urban)

We believe there would be a small but material indirect cost reductions owing to robotic automation of work activities (Appendix 7). A number of our asset strikes are due to work activities other than excavation, and we foresee reductions in technical training hours and in equipment capex deployed by our workforce, however these are likely to be smaller than the indirect cost benefits of the excavation process itself (Method 3).

We have constrained benefits arising to 2032 as most of the work activities are associated with the iron mains replacement programme. Taken together these indirect cost savings release value of £1.3m by 2030 (£4.9m GB-wide).

3.4.8 - Method 8: Environmental benefits of the robotic automation of work activities (urban)

We apply the same logic as Method 4 in assessing the environmental and social benefits of reducing the time of standard work processes of Methods 5 and 6, but take benefit for all (rather than marginal) excavation work as the base case comparator in all cases is hand tool operation. We have no benchmark to calculate specific CO2 savings; savings will accrue as for excavation through reduced vehicle movements, therefore we have taken CO2 benefits to be conservatively ¼ of those saved through excavation (see Appendix E.8.). We plan to revisit this when further progress is made with the development programme. Social costs of delay reductions do however include a monetary value for environmental benefits.

3.4.9 - Method 9: Social benefits of the robotic automation of work activities (urban)

Across SGN we have some 3,125km of steel pipelines transporting gas from NTS offtakes and system entry points to the lower pressure tiers of our network. Operating at pressures between 16 and 72bar (major hazard sites) the pipelines demand higher levels of safety assurance. We carry out a range of excavation works around these assets to inspect/repair pipeline coatings, repair/replace cathodic protection equipment, and refurbish network block valves and associated vent piping.

Our safe working procedures prohibit the use of mechanical excavators within the ‘danger zone’ of the pipeline defined as encroachment beyond 0.6m to the perimeter and extending to ground level and within 1.5m of fittings. In challenging industry current practice we have assumed the robotic excavator could replace these hand excavations (Appendix E.9.). We have also assessed the direct value to networks from automation of current hand excavation practices around ancillary fittings and the digging of trial holes to confirm asset locations.

Our calculations show, at a probability success of 70%, that a premium hire rate over twice the current rate for large vacuum excavators could return a NPV in 2030 of £6.5m at licensee level (£17.0m GB-wide).

3.4.10 - Method 10: Robotic automation of excavations and reinstatement for LTS Pipelines (rural)

We have considered the extension of robotic repair clamp technology to LTS pipelines and associate equipment such as standpipes. We believe this to be the most ambitious technical application for the robot (but in principle is extensible from fracture repair on distribution mains) and for that reason plan to revisit the benefits case for LTS repairs following a review of programme progress, and a more robust assessment of the probability of success. Our value assessment for robotic excavation will, we believe, be the major benefit to LTS pipeline operations (Method 9).

3.4.11 - Method 11: Application the technology in other sectors to reduce unit costs

In this Method we give consideration to the wider application of the robotic vehicle in adjacent utility sectors, and the potential impact on production volume of the vehicle - and ultimately the unit cost or day rate for the vehicle. We have received wide support for our innovation initiative from representative bodies across the utilities sector, and this gives us some confidence in the materiality of this unit cost argument – however it is subject to uncertainty. It is our intention to pro-actively share learning from this project in the wider utilities space to facilitate cost efficiencies for gas network users.

We have estimated the overall market size for excavation days (based on data from the TfL LR scheme monitoring) for electric, Water, and telecoms utilities combined is 2x that for gas alone.

To estimate the potential impact on Gas Network users we have looked at the value created if unit service rates could be reduced by £5, £10, and £15. Our mid-range view is an additional NPV of £1.2m by 2030 (£4.5m GB-wide).

3.4.12 - Method 12: Environmental and social benefit of the application of the technology in other sectors

Please see Section 4.a.2.

3.4.13 - Benefits to GB gas consumers

We have applied the IQI sharing metric (average 35% GB-wide) to demonstrate the direct GB consumer benefit over RIIO-GD2 if our business plan is realised. This is shown in more detail in Section 4.b relative to target savings. Consumer benefits of £26.08m are forecast over the RIIO-GD2 period. With regard to social and environmental cost savings, the project is shown to deliver benefits of some £360m by 2030, compared with £80.2m of direct/indirect savings to gas network users and consumers.

A detailed breakdown of the method appraisals and calculations can be found in Appendix E along with the Financial Benefits table in Appendix A.

Section 4: Benefits, timeliness, and partners

(a) Accelerates the development of a low carbon energy sector and/or delivers environmental benefits whilst having the potential to deliver net financial benefits to future and/or existing customers

4.a.1 - Method 4: Environmental and social benefits of robotic excavation and reinstatement (urban)

We have made reference to formative work in North America (where core-and-vac excavation is more prevalent) in assessing both GHG and NOx reductions (Appendix E.4.). CO2 reductions arise owing to the reduced number of vehicle movements used in the marginal number of excavations credited to the robotic vehicle; these emission reductions double when making an allowance for the much-reduced cement content and volume of reinstatement materials. We estimate the benefit of this method GB-wide is equivalent to taking over 26,000 new cars off the road for a year.

Social benefits will arise from the implementation of RRES through (i) reduced societal impact of utility strikes, and (ii) reduced traffic and pedestrian delays to both business and public. We estimate these together deliver some £55m NPV to the UK economy by 2030 (£202m GB-wide).

We are confident also that in setting an operating performance target for the robot that the vehicle will deliver much reduced noise and particulate pollution to the local environment.

4.a.2 - Method 12: Environmental and social benefit of the application of the technology in other sectors

With other utility sectors having an addressable market twice that of gas, this represents an opportunity to increase around 8 fold, relative to SGN, the environmental and social benefits across the GB utilities sector. We have not included these figures in our summary table at Appendix A, but on the above basis the net benefits generated through application in other utility sectors would be around £730m by 2030, with carbon emission reduced by 186,000 te CO2e.

We've calculated this by using the social benefits calculations of Methods 4 plus 8 and applying a 70% probability factor to a whole market value eight times that of SGN's activities.

4.a.3 – Further analysis

Social cost calculations were based on "A Web-Based Social Cost Calculator for Utility Construction Projects" by John C. Matthews and Erez N. Allouche of Louisiana Tech University. In this paper, the authors outline a method for estimating the social costs of construction projects, including costs due to traffic delays, pedestrian delays, increased carbon emissions, and other costs.

Information on a typical excavation for roadworks was used to estimate the social cost which would be avoided if the robotic system outlined in this proposal were used rather than conventional methods. Based on input provided by the project team and local authorities, the social cost has been calculated using the following methodology, incorporating costs due to traffic delays, pedestrian delays, and CO_2 emissions.

Traffic delay time in seconds (T_D) is given by the equation below, requiring inputs for green signal time (g), traffic cycle time (c), lane group saturation (X), number of affected hours per day (H), and lane group capacity (u). The delay times for peak and off-peak hours, passenger vehicles and heavy goods vehicles, are each calculated separately.

[redacted]

The social cost of traffic disruption (C_{TDP}) is given by the equation below, requiring inputs for delay time (T_D), peak vehicle traffic for both passenger vehicles and heavy goods vehicles (v_{pv}, v_{hv}), estimated hourly rate per passenger vehicle and heavy goods vehicle (HR_{PV}, HR_{HV}), number of affected hours per day (H), and number of construction days (D). The delay costs for peak and off peak hours are calculated separately.

[redacted]

The social cost of pedestrian delays (C_{PD}) is given by the equation below, requiring inputs for the number of affected pedestrians (P), the time needed to navigate around construction (T_{PD}), the number of construction days (D), and the estimated average hourly wage (HR_{PD}).

[redacted]

The social cost of increased carbon emissions (C_{AP}) is given by the following equation, requiring inputs for the number of additional tonnes of CO_2 emitted (C_{EIN}) and the cost per tonne of CO_2 (C_{CO2}).

[redacted]

The following inputs assumptions were used in the equations to calculate social costs for a typical excavation site.

Traffic Delays	
Annual average daily traffic (vehicles per day)	5348
Length of time for construction (days)	5
Peak traffic hours affected by construction (hours/day)	6
Off peak traffic hours affected by construction (hours/day)	18
Heavy vehicle traffic as % of total traffic	0.5
Traffic signal green time (seconds)	30
Traffic signal cycle time (seconds)	120

Pedestrian Delays	
Average wage for pedestrians (£/hour)	23
Estimated daily pedestrian traffic (pedestrians)	4100
Time needed to navigate around construction zone (seconds)	120

Pavement Restoration	
Original cost of pavement construction (£ / m^2)	£600
Pavement designed service life (years)	20
Age of pavement (years)	10
Area of destroyed pavement (m^2)	4

Carbon Emissions	
Tonnes CO2 produced	0.32
Cost of CO2 emissions (£/tonne)	17

Additionally, reduction factors were applied to lower the calculated costs and provide conservatism to the estimates. The calculated social costs for performing this excavation using conventional methods are shown below:

Conventional Excavations - 5 days	
Cost Due to Traffic Delays	£4,104.29
Cost Due to Pedestrian Delays	£392.92
Cost Due to Pavement Restoration	£272.37
Cost Due to Increased CO2	£5.44
Total Increased Social Cost	**£4,775.02**

The main source of the social cost is due to traffic delays. If the RRES were used rather than conventional methods, the time needed to perform the work could be reduced to one day. The resulting traffic delay cost for one day of work is shown below:

RRES Excavation - 1 day	
Cost Due to Traffic Delays	**£820.86**

When compared to the traditional method, the estimated potential social cost savings of the RRES are significant.

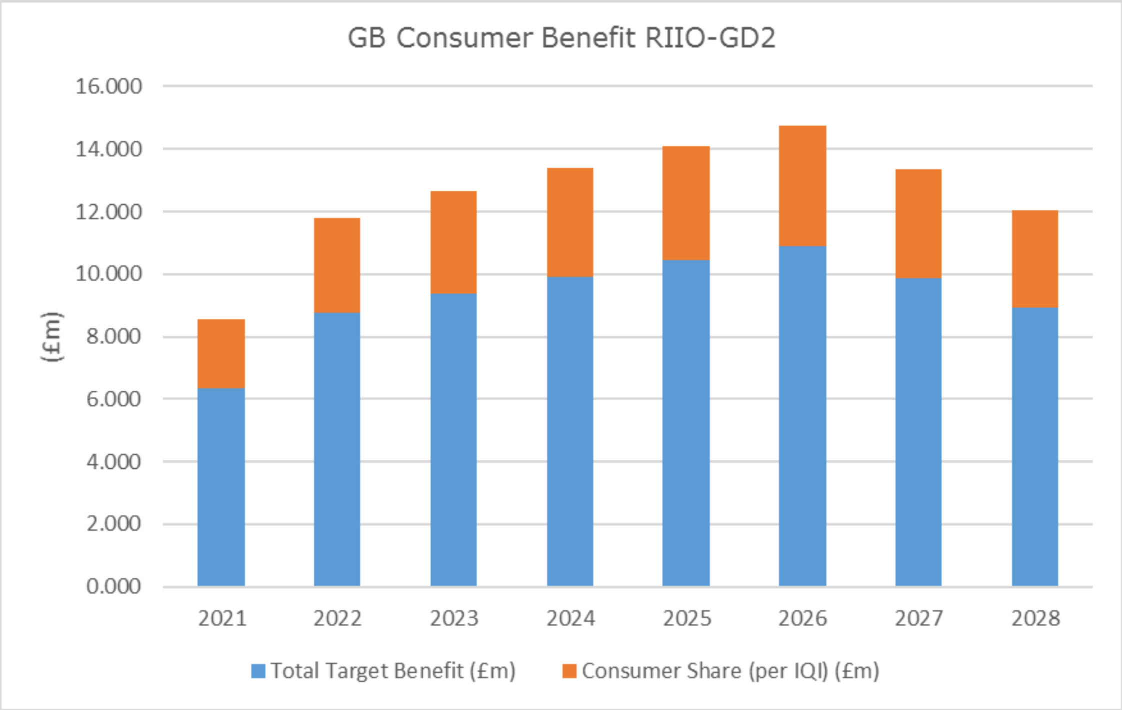
(b) Provides value for money to gas customers

We have used the results of our analysis to calculate the annual benefits to GB gas consumers over the RIIO-GD2 period, assumed to run from 2021/22 for a period of 8 years. Our figures are based on Methods 1,2,3,5,6,7,9,10, and 11 as presented (wider social benefits to consumers Methods 4,8, and 12 are not included in these figures).

Based on an average IQI of 35%, total benefits accruing to GB consumers amount to £26.08m; as a reminder, these are net of any implementation or buy-back services for robotic services and recouping of the full project cost within 3 years of successful implementation.

	2021	2022	2023	2024	2025	2026	2027	2028	Total GD2
Total Target Benefit (£m)	6.331	8.749	9.363	9.926	10.441	10.912	9.881	8.909	74.513
Consumer Share (per IQI) (£m)	2.216	3.062	3.277	3.474	3.655	3.819	3.458	3.118	26.080

The chart below shows the data in graphical form:



(d) Is innovative (ie not business as usual) and has an unproven business case where the innovation risk warrants a limited Development or Demonstration Project to demonstrate its effectiveness

This project will utilise cutting-edge robotics, advanced custom tooling and artificial intelligence to revolutionise the way that utility and industrial companies perform excavations and operations. Many of the capabilities to be developed under the project, from the identification of below-ground infrastructure to the automated installation of pipe fittings, represent innovations when compared with the current approaches and technologies used by utilities. Due to the comprehensive changes to the as-is processes required through the use of advanced robotics to perform operations, and the uncertainty of success, this project would not be possible under business as usual activities. The complexity of developing and integrating innovations in AI, sensors, robotics, control software, communications and data management form the key technical challenges and risks for this project. Development and trialing of the RRES under this project provides a means for evaluating the effectiveness of the system and for establishing the necessary procedures to ensure that the system can be commercialised upon completion of the project. Ultimately, development and demonstration under this project will allow us to bring to bear safety, financial, social and environmental benefits that would not otherwise be pursued.

(e) Involvement of other partners and external funding

There are two key Project participants; ULC Robotics and SGN.

ULC Robotics provides technology development, contracted services, and innovative products to gas and electric utilities that work to reduce operations and maintenance costs while meeting the increasingly complex demands of the regulators, energy customers, and the general public.

ULC Robotics has a proven track record of success in robotics and routinely executes multiple complex robotics research and development projects simultaneously. They have expertise in project management, mechanical engineering, electrical engineering, sensor development and application, programming, user interface development as well as manufacturing, assembly and testing. Since ULC Robotics has unique experience in the commercial deployment of live gas pipeline robotics, they are considered an appropriate partner to commercialise and deploy the technologies developed under the Project.

Additional suppliers will be sought at various stages of the project. The cost for this aspect has been estimated as part of the funding assessment, but will be subject to a competitive process where appropriate.

ULC Robotics is currently working with us to deploy the NIC 2013 Robotics CIRRIS XI™and XR™ systems. The learning gained from the design, development, testing and commercialisation of the systems will be fully utilised in this project.

Further to a period of comprehensive stakeholder engagement we have set out an innovation strategy to do a number of things which includes the following which the project aligns to:

- Improve the way in which we work to be more efficient, more customer focussed, less disruptive while carrying out road works and reduce our carbon footprint

To support our innovation strategy, we adopt both a proactive and reactive approach to idea generation. We run a suggestions scheme, called Ignite (Ignitescheme@sgn.co.uk), for our staff, our project partners, suppliers and anyone else who wishes to make a suggestion, offer a new product or share an idea. We are also proactive in seeking new innovations and project partners, through our industry watch; our external memberships with greater access to SMEs; and most successfully through challenging our ever increasing array of project partners to come up with solutions to our industry issues.

This proposal from ULC Robotics is a good example of this proactive approach in action. We provided detailed problem statements and definitions, to address which, they have proposed this project. Our problem statements are available externally on both the Energy Network Associations (ENA) websites and on our own external website.

We continually prioritise the ideas and develop projects for both the NIA and NIC based on their scale, feasibility, potential to add value to the UK gas consumer and support our outputs under RIIO GD1. The project proposals are subject to a challenge and review at our Innovation Board, which reports to our Executive. Having followed this process, we believe the robotics project to be of significant scale and potential to be considered under the NIC.

(f) Relevance and timing

All utilities face an ongoing challenge in safely managing excavation activities. This will continue for the life of the assets as they are pushed to return their maximum value for the GB customer.

This focus on safety by utilities has driven down the instances of serious harm from incidents like cable strikes and LTS pipeline incursion but as the statistics plateau it is apparent that human factors around complacency and manually operated machinery remain a stubborn and immovable barrier to achieving a zero rate outcome.

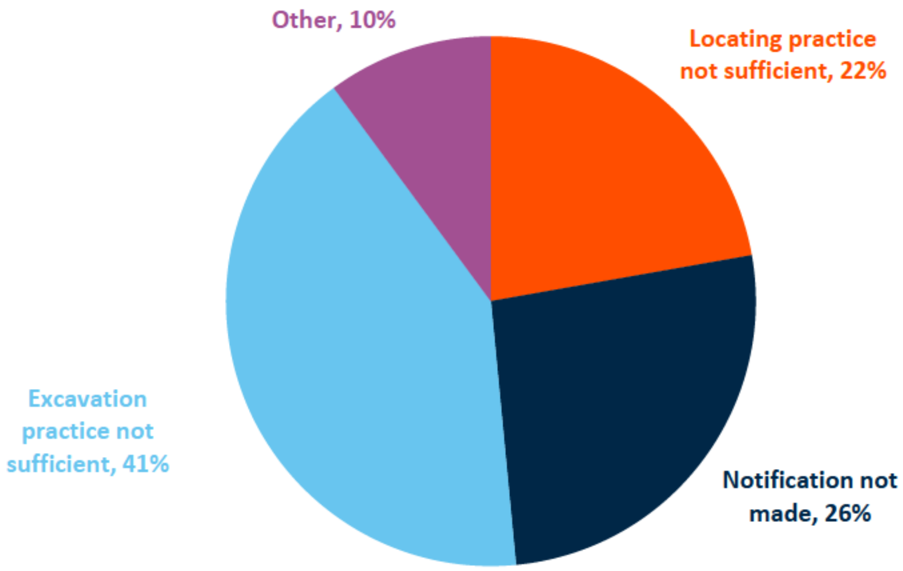


Figure 4: Root causes of cable strikes[2]

These are issues that the utility industry face now, not potentially in the future. We believe this ongoing requirement, coupled with recent advancements in automation, AI and robotics make this the optimum time to pursue a project of this nature.

[2] Metje, N, Ahmad, B & Crossland, SM 2015, 'Causes, impacts and costs of strikes on buried utility assets' Institution of Civil Engineers. Proceedings. Municipal Engineer, vol 168, no. 3, pp. 165-174. DOI: 10.1680/muen.14.00035

Section 5: Knowledge dissemination

5.1. Learning generated

Our project seeks to develop a demonstration Robotic Roadworks & Excavation System (RRES). The project will install sensing technologies, an Artificial Intelligence engine with associated hardware and software and robotic tooling onto a fully integrated mobile platform. If successful, the project will demonstrate the potential to; challenge the orthodoxy of human visual confirmation of buried infrastructure, allow unhindered access to precise buried utility locations, eliminate accidental damage during excavation and remove the risks associated with uncovering already damaged infrastructure, an emerging challenge for the GDNs and DNOs. Of specific interest to GB GDN and UKT stakeholders will be:

(a) Integration of modern techniques, technology, and automation into routine operations performed by the GDNs.
(b) Removal of damage risk through the use of soft-touch excavating methods and advanced machine vision and sensing capability.
(c) Development of more repeatable methodology for performing routine excavation and operational works.
(d) Reduction in site footprint required to excavate in urban environments.
(e) Reinstatement of the original road surface, avoiding excavated material going to landfill
(f) Providing an open market means for expanding additional future inspection, maintenance and repair operations.
(g) Development and implementation of new intellectual property on behalf of the GB gas consumer.
(h) Reducing manual labour while increasing the technological capabilities of UK's utility workforce

It is important that learning opportunities generated by this project are effectively disseminated to the GDNs and UKT as well as the wider gas industry. Inclusion can also be afforded to DNOs, Water Utility operators, national and international standards bodies, academia, local authorities and other key stakeholders such as the ENA, NJUG, IGEM and Ofgem.

5.2. Learning dissemination

Our knowledge dissemination plan involves both internal and external parties and this is detailed in Appendix L.

5.2.1 - Internal dissemination

Knowledge dissemination within SGN is essential to the success of all innovation projects. Structured communication regarding the project will ensure the ongoing engagement of staff allowing the outcomes of the project to be adopted within the business in the future. Methods for internal dissemination will include the following:

- A dedicated intranet webpage detailing the project scope and progress.
- Project briefing presentation given to relevant employees at project start and end using SGN Team Talk as the medium
- An article outlining the project will be produced for our in-house magazine 'SGN Mail' and intranet site.

- Development of new and revision of existing management and work procedures in accordance with our Safety Management Framework (SMF).
- Inclusion of our graduate trainees in project delivery as part of their accredited training scheme
- A project steering group
- Internal reports

The change of methodology for general excavation will require new working procedures to be developed and further training of staff to be conducted. These will be developed and published in accordance with our Safety Management Framework (SMF).

This project will have an interface with a number of business units, particularly Network Planning, Gas control, Operations and Network Construction. A project steering group has been established with representation from all the key business areas to ensure both support and learning dissemination.

5.2.2 - External dissemination

We believe that learning dissemination is the most powerful form of network collaboration. During our chair of the Gas Innovation Governance Group (GIGG), we established a collaborative conduit for this very purpose.

We have already carried out significant stakeholder engagement in the development of this project proposal, which has shaped its structure and intended outcomes. As a minimum we will:

- Publish a dedicated webpage via SGN.co.uk, mirroring our previous and continuing NIC projects;
    - https://www.sgn.co.uk/Oban/
    - https://www.sgn.co.uk/Robotics/
    - https://www.sgn.co.uk/real-time-networks/
- Provide regular updates to industry collaboration groups, specifically GIGG and the Gas Network Collaboration Forum (GNCF).
- Deliver project presentations and articles to relevant industry bodies, such as ENA, IGEM, EUA, NJUG and the Pipeline Industries Guild.
- Deliver presentations at the LCNI and other industry conferences, such as Utility week Live
- Publish periodic progress reports to Ofgem (see Appendix C)
- Hold a specific presentation day for the DNOs highlighting cross industry application
- Hold a specific presentation day for wider industry including Water and Telecom Utilities highlighting cross industry application
- Encourage Partner Dissemination

5.3. IPR

We have an agreement in principle where both parties are fully committed to the default IPR position. At this stage, we do not know what specific forms of additional IPR will be created and consequently require registration, if any. The new sensing technologies that will be employed are commercial products, albeit packaged and configured to achieve a specific outcome. As part of the software design and data management and control process, detailed analysis is necessary and will be dependent on the solution pursued. This may employ a combination of commercial and bespoke products.

It is proposed if and where IPR are to be registered, that it will be done by ULC, following transfer of any foreground IPR created by SGN.

Upon successful completion of the Project, royalties would be due from ULC (from direct utilisation of the system), if the system is rolled out. These will be paid to SGN, subject to an evaluation of their true commercial value, on either a per unit basis (e.g. per unit manufactured and utilised), or an annual basis. An agreement in principle is already in place, which will streamline the project start and will ensure the best value for the GB gas customer.

Income from royalties, minus any costs incurred in maintaining and managing IPR, would be returned to customers in proportion to their funding. SGN would retain the remaining portion (equivalent to our funding contribution) as profit. For this project, this would be 10%. SGN would calculate and declare this Returned NIC Royalty income in our regulatory returns on an annual basis.

Under the provisions within the contract between both parties, ULC will be required to comply with the NIC governance document. ULC will grant to the Network Licensees and the Parties: an irrevocable, perpetual, world-wide, non- exclusive royalty-free right and licence to use, access, copy, maintain, modify, enhance and create derivative works of any Relevant Foreground IPR (including any Relevant Background IPR contained therein) within their network.

A key section of the NIC governance relates to Relevant Foreground IPR. Under the NIC document, Relevant Foreground IPRs are defined as Foreground IPRs that other Licensees will need to utilise in order to implement the Methods (the proposed way of solving a problem - the obstacle or issue that needs to be resolved in order to facilitate the low carbon future and/or provide some environmental benefit to customers) developed in the project.

Network Licensees will only have the right to use Relevant Foreground IPRs within their network royalty free. They cannot sell or grant sub licences to Relevant Foreground IPRs.

Where access to a participant's Background IPR is required to undertake the project, the participant shall grant a non-exclusive licence to this background IPR (Relevant Background IPR) to the other participants, solely for the purposes of the project during the term of the project. The Network Licensees will also be granted a licence for any Background IPR required to utilise any Relevant Foreground IPR for which they receive a licence.

5.3.1 - Commercialisation

There are two points of consideration regarding this project, commercialisation of the developed RRES within its existing capabilities and the ongoing development of the open source tooling, opening up the RRES's operational range of end to end capabilities and further cost and safety benefits. It is anticipated that the 'as developed' system could be rolled out following the completion of development and commercialisation. A commercial appraisal and recommendations will be made as part of the Project. This could take the form of the following examples:

5.3.1.1 - Scenario 1: Capital purchase

Upon completion of the project, ULC makes units of the RRES available to all GDNs and their contracted service suppliers. A target price for purchase of the RRES will be determined which can yield positive cost benefits for gas customers.

This target unit pricing will be used during the development process to guide critical design features. ULC will act as an agent on behalf of SGN and register/protect foreground IP, which will then be assigned to SGN. SGN will issue an exclusive licence for the IP to ULC for the duration of the project and for eight years following completion.

Royalties will be paid by ULC to SGN for any RRES sold to any other user or undertaker (including other GDNs). The royalty should reflect the true commercial value of the IP. SGN will then return royalty to the GB gas customers, in proportion to their funding, via the Returned NIC Royalty mechanism.

5.3.1.2 - Scenario 2: Bought in service

Upon completion of the project, ULC establishes a GB based service provision function or a third party purchases/leases them from ULC. A target price for purchase of the RRES will be determined which can yield positive cost benefits for gas customers.

The IP position outlined in scenario 1 remains the same for this scenario, with royalties paid by ULC to SGN for any use of the RRES.

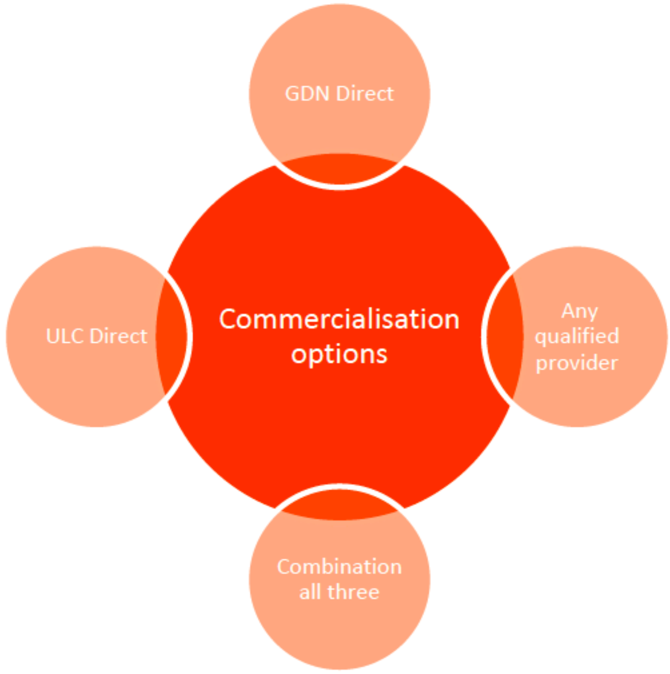


Figure 5: Commercialisation options

5.3.2 - Open Source tooling

ULC will also provide royalty bearing licenses to other qualified suppliers allowing the development of new and novel tooling allowing the RRES to expand its end-to-end capabilities in the field. By developing the system with an open source philosophy, expansion of the system into other operations and markets can be achieved; thus future proofing the system. As a critical part of this tooling development is the software and AI integration to the system, it is currently unclear how this will be managed and the final arrangements will be determined at a later stage in the project as the design matures. It may take the form of software tools to enable RRES licensees to develop new control applications, but could also be a software development service provision from ULC. Either way, it will be designed to stimulate the market and ensure the best value return for the GB gas customer.

5.3.3 - Benefits in kind

In addition to ULC's £200k contribution towards the project, and to aid sharing of the benefits with the wider industry, SGN will support ULC to showcase the RRES to GDN's and DNO's. ULC will run a free three day event inviting network operators to come together to:

- Learn about the technologies and methodologies used within the project
- See demonstrations of the system
- Have hands-on interaction with the demonstrator system
- Discuss how to implement system in Q&A sessions with ULC experts
- Better understand the safety and financial benefits of the RRES

This will help other network operators understand the use cases supported by the RRES and understand the benefits to their business. In addition, we will prepare a storyboard of example uses of the RRES to underpin the presentation of the benefits and demonstrations that will be showcased through other joint industry events.

Section 6: Project Readiness

6.1. Introduction

The Robotics Roadworks and Excavation System (RRES) concept was originally conceived in 2015 and submitted to SGN by ULC in confidence in response to a generic problem definition and 'call for innovation'. Following a review of prior art, SGN engaged ULC to carry out a feasibility study to develop further and evaluate the concept of automating roadworks operations. This included a further technology review to understand the state of the art. The feasibility study showed promising results, and the effort to further develop the concepts was continued with a particular focus on the sensing aspects, both in terms of asset location and 'soft touch' capability. The RRES design and architecture matured, the operating methodology was refined, and we believe the sensor/soft touch research performed under NIA has significantly increased the likelihood of success of the project.

The activities that were performed leading up to the submission of the ISP are listed below:

- Developed Initial Design Concepts
- Researched Locating and Mark Out Technologies
- Developed Preliminary Operating Procedures
- Generated Detailed Considerations for Operation
- Researched Component Technologies
- Developed Preliminary Cost Benefit Analysis (CBA)
- Initiated Global Search for Partners
- Shortlisted Robotic Operations
- Researched and Evaluated Above Ground Locating Sensor Technologies
- Researched and Evaluated Below Ground Sensor Technologies
- Developed Conceptual System Architecture and Mechanical Design
- Researched Excavation Methods, Developed Tooling, and Performed Testing
- Developed Conceptual Design of a Universal Access Fitting

In addition to the work carried out under this project, as part of our drive to 'revolutionise roadworks', we have executed a number of bespoke agreements with local authorities to allow trial of multiple coring/non-conventional excavation techniques.

Upon completion of these activities, it was determined that the technical maturity, risk, and scope of work was sufficient to pursue the NIC bid process to fully develop the prototype RRES.

6.2. Summary of Project Readiness

The RRES team has been working for nearly two years to develop the preliminary concepts and to reduce project risk through early design, hands-on testing, and component evaluations. The following are the reasons why the RRES team is ready to start the project:

(a) Robotic enabling technologies are readily at the disposal of the team; the availability of these technologies reduces the overall risk of the project. The key enabling trends that are making this possible are:
   (i) Modularisation and Component Availability: Robotic component vendors have grown in numbers and have begun to modularise solutions such as

modules integrating motors and drives, modules integrating motors and gearboxes, and modules integrating controllers and drives. Additionally, industrial robotic arms and mobile drive platforms are commercially available. This makes it easier to incorporate robotic solutions at lower cost and lower risk. Robotic arms have been used in critical, high volume, manufacturing environments for pick and place, welding, packaging, assembly and other operations. These arms need to be transitioned to high volume utility work to enable the next generation of excavation tooling.

(ii) Sensor Technologies: The rapid development of new sensor technologies due to advances in optics, signal processing, electronics packaging, nanotechnology, and computation are yielding smaller and more capable sensors for sensing the environment and below-ground objects.

(iii) Rapid hardware prototyping: 3D printing has reduced the cost and time associated with complex mechanical design and manufacturing.

(iv) Artificial Intelligence and Computer Vision: A number of new computing platforms (hardware and software) have evolved recently that enable ease and affordability of development, testing and integration of machine learning and computer vision algorithms into robots. This has been made possible by increased computing power in smaller computers.

(b) ULC has become a member of the Manufacturing Technology Centre (MTC), which houses some of the most advanced industrial robots and manufacturing equipment in the world. The MTC also provides Subject Matter Experts to assist companies in improving productivity, reducing costs, embedding innovation and de-risking the use of technology. The experience and resources of MTC will be used on the RRES project to lower risk and to accelerate product development.

(c) ULC has a track record of working collaboratively with GB GDN's utilising NIA funding to develop and implement advanced robotic technology, the most notable being Large CISBOT. The system is used to remotely remediate large diameter metallic mains, significantly reducing disruption, cost and the impact on the environment. ULC and SGN developed, trialled and subsequently deployed Large CISBOT on a commercial basis. To date, 14km of large diameter metallic mains have been remediated across SGN's networks as part of an ongoing programme.

(d) ULC is near the end of completion of the NIC Robotics project started in February 2014. Under this project, two advanced robots (CIRRIS XI and XR), along with cutting edge sensor technology, were developed. This has now progressed into a commercial pilot program to inspect and remediate 16km of Tier 3 cast iron main using only robotic systems. Additional robotic systems developed under the NIC Robotics project will be ready for field trial in Q4 of 2017. Team members and the project manager have extensive experience working on the NIC project and will be available to support and advise the RRES project.

(e) Certain key aspects of the project have been matured in prior phases including the robot architecture, a prototype “soft-touch” excavation tool and method, identification of sensor technologies for below ground sensing, identification of sensors for providing feedback for motion planning and obstacle detection, evaluation of robotic arm capabilities, and the development of concepts for an open-source UAF. These activities have lowered the risk of the project.

(f) Significant stakeholder engagement has been carried out to support the concept development. Support letters from stakeholders and other utilities have been received (provided in Appendix H)

(g) Project risks have been identified and mitigation plans have been developed. Further details are provided in Appendix I.

(h) A project plan has been generated that demonstrates the ability to complete the project in 3 years (Appendix C).

From the beginning of the RRES conceptualisation, the technology has been matured to Technology Readiness Level (TRL) 4.

The table below describes the technology elements that make up the RRES and provides justification for the estimated TRL for each element. The TRL for the whole system is chosen as the lowest TRL of any of the technology elements. Appendix K provides a timeline for maturing the TRL for each system to 8 based on captured risks and the project plan.

Item	Technology Element	TRL	Justification
1	Robotic Arm	5	Robotic arm technology is used daily in manufacturing operations around the globe to perform precision, highly repeatable operations. Research has shown that commercially available arms can be used for roadworks applications. The considerations for arm selection include payload carrying capability, accuracy and reach. Additionally, robot arm manufacturers and 3rd party software vendors develop applications to plan the motion of robot arms, reducing the resources required for toolpath generation.
2	Mobile Platform	4	ULC has developed mobile platforms on various robots for carrying payloads and providing support and structural integrity to fulfil robotic missions. These mobile platforms have been operated in high temperature and high humidity environments typically inside pipes. Additionally, commercially available mobile, tracked platform systems are available on the market which may be selected and customised for use in this project.
3	Support Equipment including Generator, Vacuum Pump and Compressor	8	These components are commercially available. Generators, vacuum pumps, and compressors are standard systems used commercially.
4	Communications	6	Providing operator control and receiving sensor data can be carried out over wired or wireless communication systems. ULC has many years of experience developing custom tethers for wired communication and has developed tethers for use in excavated areas. Robust, commercially available wireless communication systems and video capture and display systems can be procured and customised.
5	Operator Interface	6	ULC has developed custom operator interfaces for utility inspection and repair applications. A representative control panel is used for the CIRRIS robot. The technologies used for this are readily available. Development of a new interface would require the design, integration and test of a new custom operator interface using off-the-shelf components. Additionally, custom

			programming will be performed to enable safe and efficient operation of the system.
6	Below Ground Sensing and Sensor Data Processing (including Video Cameras)	4	Several technologies have been used by the construction and utility industry such as Ground Penetrating Radar. Such a system can be purchased as a finished product or customised for use under this project. The real-time processing of the sensor data to detect objects will require custom software and algorithm development. While object detection and identification algorithms have been developed for many applications, this will be a new application that will require the use of standard and non-standard algorithms for the detection and identification of buried objects.
7	Tooling/End Effectors and Interfaces	4	Custom end effectors, tools and interfaces are slated to be developed. An open access UAF will be developed to accommodate tools from various 3rd party manufacturers. Certain tools may be available commercially. Design, development and testing will be performed for the other tools and end effectors.

6.3. Project team

The project team's organisation structure, showing lines of reporting can be found in Appendix D.

Team members were identified after reviewing the skill sets required and competence levels. ULC Robotics has over 15 years of experience developing custom robotic systems for inspection and repair of assets for energy and utility companies. ULC Robotics retains a highly skilled, specialised workforce. In addition, ULC has highly experienced engineering, fabrication and technical field resources outside of the direct project team which will support the design, fabrication, testing and delivery of the system.

As part of the proposal, we have ensured that our project team is in a position where members can commence project work by April 2018, are aligned to the specific project deliverables and are able to commit to and meet their scope of work and defined outputs.

6.4. Project schedule

The project plan sets out the best approach and timescales that the project team has determined to generate the highest likelihood of success. The plan identifies the four main project Elements, including additional work tasks broken down under each. This detailed project plan can be found in Appendix C. The plan will be revised again before the start of the project to reflect additional details developed during the time from Project Award announcement to Project Start. Multiple development and procurement workstreams will be executed in parallel to minimise the project duration and so that subsystems can be specified, designed or procured, and tested in concert with one another. Parallel development increases the likelihood that the integrated system will function as intended. As an example, consider the development of the RRES below-ground sensing capability. Generally, sensor performance is significantly influenced by the method and process of deployment. Evaluating the performance of sensors mounted on the robotic arm will enable the most efficient, accurate and reliable outputs to be achieved during testing.

As per Figure 6, multiple stages during this parallel development process, learnings from the development and testing of one subsystem will inform the selection, procurement activities and development related to others. For instance, as specifications for excavation tooling, such as the subsystem's weight and size, are being developed, they will inform the selection of an appropriate robotic arm (deployment method) based on parameters such as load capability and range of motion.

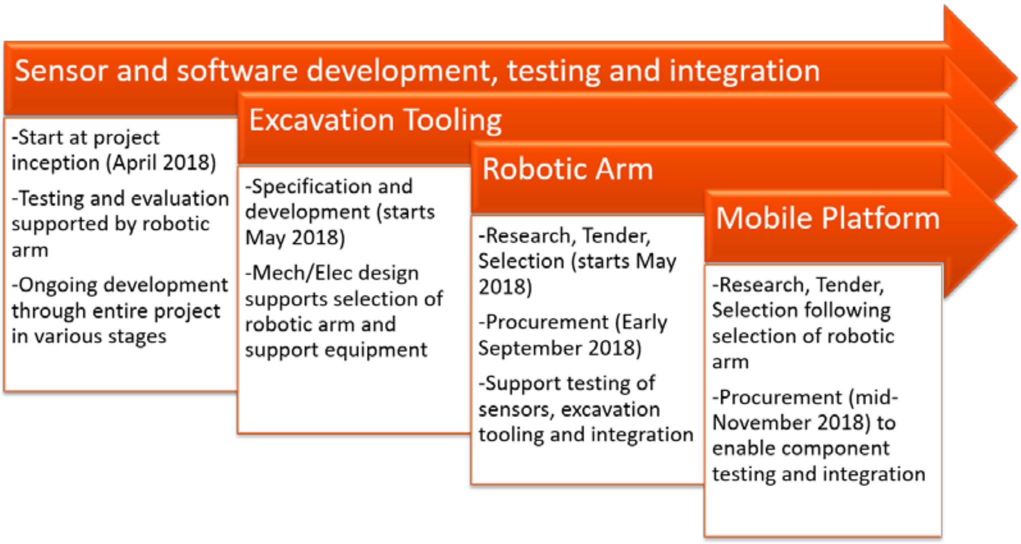


Figure 6: Development/Procurement Workstreams

6.5. Project risks

A risk register has been developed and can be found in Appendix I.

The risk register will be used by the Project Manager, Project Director, and Project Steering Group to continually review Project risks, their mitigating action(s) and controls, and to ensure that risks are managed in priority order. The risk model describes the methodology for determining an uncontrolled risk score. However, if control measures are applied, aimed at reducing the hazard and/or mitigating the risk, it should be possible to produce a controlled risk score that is lower than the uncontrolled risk.

The risk management process is a continuous process that includes risk identification, analysis, mitigation planning, mitigation plan implementation, and tracking as shown in the Figure 7.

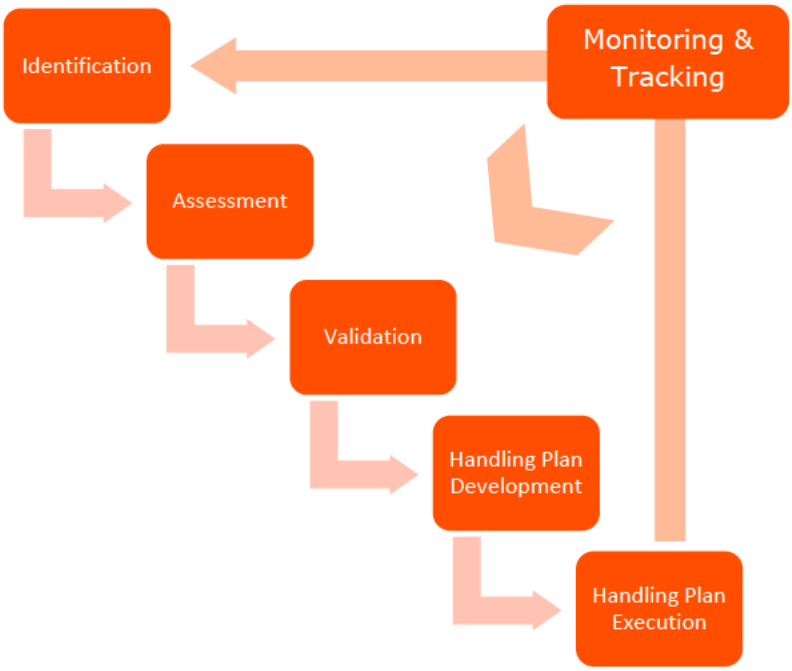


Figure 7: Risk Management Process

The risk management approach that will be used to ensure that risks are continually identified, reviewed and handled appropriately is:

- Risks will be identified by both ULC Robotics and SGN.
- A risk escalation process will be followed wherein certain risk types will be elevated up through the project team depending upon the resources required to handle the risk.
- Risk owners will be assigned to each risk who will be held accountable to manage the mitigation activities.
- Risk mitigation activities will be tracked in the project schedule.
- Key technical parameters or key performance indicators will be tracked as part of the risk management activities.

The general approach for risk control is:

- Early prototyping: The nature of a risk will be evaluated by building and testing early in the project.
- Manage scope creep: The key to making prototyping successful, as a risk-control tool, is to minimise the addition of new requirements to the system after the prototype has been tested.
- Incremental development: The concept of incremental development is to split the development of high risk portions of the project and give them more time to mature.
- Use of Standard Items/Software Reuse: Standard interfaces, components, sensors, boards, assemblies, and software modules will be used to the largest extent possible. Standard items will have to be evaluated first to verify that they can be used in the roadworks environment and operations.
- Use of mock-ups, modelling and simulation: Mock-ups, models, simulations, and testbeds will be developed as early as possible in the project to explore design options and to resolve design uncertainties. System performance and sensitivity can be estimated through modelling and simulation.

- Employment of a technical service provider to evaluate key risks and provide independent technical input throughout the course of the project

Hazard and risk assessments will be undertaken by SGN Asset Management, Engineering Policy and Safety, Health and Environment teams before any on site operational activities take place. Recognised Hazard Identification (HAZID) and Hazard Operability Study (HAZOP) methodology will be used and verified by an independent technical service provider. These risks will be documented in the project risk register and separately as part of detailed site specific assessments.

6.6. Accuracy of project costs, schedule, risk, and benefits

The project costs have been calculated by ULC Robotics and SGN's project teams. ULC Robotics have developed numerous robotic systems and uses a bottoms-up and top-down cost estimation methodology. The overall budget will be managed by the SGN Project Manager with in-house financial resources support.

The schedule has been formulated using the input of the project team members and ULC's executive leadership. A similar top-down approach was used to develop the tasks. Durations are estimates based on best judgement by understanding the level of technological maturity and skill of the labour. While the overall schedule duration will stay the same, the detailed tasks and order of tasks may be changed to accommodate new ideas, methodologies and risks.

The risk assessments have been developed through engagement with the project team members and our Operational staff. The risks assessments have been based on quantifiable impacts which reduce the subjectivity of the assessments. Risks once identified and defined were vetted through executive leadership. Risk Management is a continuous process and new risks are expected to be identified during the course of the project.

Since the concept was scoped, we have carried out a strict internal verification process. The process started with NIC project suggestions being shortlisted at the Innovation Board. This board is made up of the heads of each function across SGN and its purpose is to engage in delivering innovation throughout the business and to provide executive level control and guidance. Furthermore, it:

- Identifies and agrees focus areas to focus innovation in order to maximise the potential benefits
- Imbeds innovation throughout the company
- Ensures innovation projects are adequately supported by all business functions
- Raises awareness of projects and removes any blockages or barriers to implementation
- Supports implementation in to business as usual practice and tracks the effectiveness of deployed technologies.

The Board meets on a monthly basis to review progress against the budget and plan, support major deliverables. Following recommendation at the Innovation Board meetings, it was determined that this project would add significant value to network licensees throughout GB. The proposed bid has also been presented to both SGN's executive team and SGN's Board, who are fully committed to it. An Investment Paper was submitted to SGN's Investment Committee and approval issued to progress the RRES bid.

This is a highly complex and technically challenging project. The potential financial benefits if successful are compelling, however this is an unproven technology, therefore we will continuously review the probability of success and any changes to the financial benefits.

The overall budget will be managed by a Finance Manager supporting the project team. They will be responsible for managing all costs and constructing and delivering the reporting requirements as part of the project.

We will run a robust financial tracking and reporting system in line with our current internal policies and frameworks. As per the Ofgem requirements, the project finances will be held in a separate Project Bank Account which will meet the following requirements:

- Show all transactions relating to (and only to) the Project;
- Be capable of supplying a real time statement (of transactions and current balance) at any time;
- Accrue expenditures when a payment is authorised (and subsequently reconciled with the actual bank account);
- Accrue payments from the moment the receipt is advised to the bank (and then subsequently reconciled with the actual bank account);
- Calculate a daily total; and
- Calculate interest on the daily total according to the rules applicable to the account within which the funds are actually held.
- SGN will engage with our financial auditors, to alert them of their potential responsibilities should this Project be awarded the funding.

6.7. Prior learning

ULC Robotics is partnered with SGN on an existing Robotics project awarded NIC funding in 2013. In this project, ULC and SGN have to date successfully completed each SDRC milestone on schedule. Throughout this process, key learning has been generated and captured for dissemination and for future work.

We have also commercialised both the CISBOT and the recently developed CIRRIS XI (still under pilot) systems developed under NIA and NIC respectively.

Numerous options and scenarios were considered looking at different commercialisation options at various stages in the project. We have learned how to approach system development with commercialisation in mind and have been able to successfully deliver systems that are ready for field deployment. We have leveraged this prior learning to improve the project structure and plan for the RRES project.

6.8. Project learning if take-up is lower than anticipated

If the take-up from the other Network Licensees is lower than anticipated, there will still be sufficient scope to use the learning generated from this Project in the future if they wish. From our perspective, we believe that this will not influence the outcome of the

Project and the cost benefit targets set will still largely be achieved, along with learning and improvement in the following areas:

- Robotic technology that has been field trialled and tested.
- Below ground sensing development and object detection that can be used on other projects.
- Development of “soft-touch” excavation tools that can be further developed to be operated manually.
- The research and development for using robotic arms for excavation.
- Deployment of a remotely controlled mobile platform to job sites.
- Open interface for tooling that will lead to opportunities for local commercial establishments to develop new products.
- Detailed understanding of robotic capability.
- Detailed sensor capability and combination review.
- New methodology for deploying robotic solutions for distribution and transmission mains.
- Commercial appraisal of robotic methods

6.9. Project termination

The Project utilises a tried and tested project management methodology with the scope and Project Plan clearly defined upfront with four main Elements. Each of these Elements has then been broken down into a set of predetermined tasks that influence the realistic but challenging project timescales.

As shown in the project plan (Appendix C) and in Section 9, a total of ten project deliverables with associated go/no go Stage Gates have been proposed. These are situated at critical dates in the Project and allow SGN to put the Project on hold and revise its status or terminate the Project should SGN believe that it will fail to deliver the objectives.

Technical descriptions of what should be completed at each go/no go stage are detailed in Section 9. These key deliverables and the general progress of the project will also be documented in the Project Progress Reports.

Section 7: Regulatory issues

We do not anticipate a requirement for any derogation, licence consent, licence exemption or any change to the current regulatory arrangements in order to carry out this project. The RRES will potentially displace existing technologies to speed up and make existing operations safer so no additional customer impact is perceived. If successful, the developments proposed in AI and machine vision in particular may drive changes in relevant industry-recognised best practice and guidance. We have engaged and will be engaging with key industry stakeholders during the course of the project to ensure the outcomes are recognised and integrated.

Section 8: Customer impact

8.1. Customer interactions

At SGN we pride ourselves on our customer focus. Our philosophy of putting the customer first will be at the heart of this Project.

Our customer's requirements are based around safety, reliability, annual running cost and efficiency. As part of our commitment to providing the highest quality of service, we will keep our customers informed and updated throughout the duration of this Project, deal with any issues fully and resolve them quickly, and always listen to our customers and understand their needs.

8.2. Customer impact

We do not anticipate that the customer will be impacted adversely during the course of the project or demonstrations. The impact is designed to be positive as we will be field trialling at a location where we are intending to work on our asset anyway and the method proposed is designed to be less disruptive than the current method.

Any failure of the system would require us to revert back to known techniques with no additional disruption to the customer.

We will work within and meet our internal obligations to our customers as well as all our obligations to the guaranteed standards of service (GSOS) as laid out by the regulator.

8.3. Customer engagement plan

Part of this Project will involve interaction with our customers as so far as explaining the works within their proximity. The Project will comply with the conditions relating to the customer engagement and data protection act as set out in NIC Governance Document. Examples of flyers we may design for the Project are given in Appendix G.

We will prepare and publish (via our website) a detailed Customer Engagement Plan of how we will engage with, or impact upon, relevant customers as part of the Project.

The final customer engagement plan will include:

- a communications strategy which sets out inter alia:
    - any proposed interaction with a customer or proposed interruption to the supply of any customer for the purposes of the Project, and how the Customer will be notified in advance;
    - on-going communications with the customers involved in the Project; and
    - arrangements for responding to queries or complaints relating to the Project from relevant customers;
- Information for the Priority Services Customers who may be involved in the Project and how they will be appropriately treated (including providing information to any person acting on behalf of a Priority Services Customer in accordance with condition 37 of the Gas Supply Licence, where applicable);
- Details of any safety information that may be relevant to the Project; and
- Details of how any consent that may be required as part of the Project will be obtained.

8.4. Managing customer enquiries

Looking after our customers is an essential part of our business. For this reason a number of communication channels have been selected to ensure that the management of customer questions/queries is responsive, confidential and convenient.

Customers will be able to ask questions or raise queries related to the project using the following channels:

- Telephone – SGN operates a customer enquiry service that is continuously staffed and can be contacted 24 hours a day/7 days a week on 0800 912 1700.
- SMS - For customers wishing to receive a call back service, an SMS can be sent to dedicated number, this will ensure an SGN representative will call the customer back as soon as possible.
- Project Webpage - The Project webpage will be the main source of information for the Project for our stakeholders and customers. All aspects of the Project will be hosted on this site, including all customer focused information (e.g. field trial locations, customer pamphlets, contact details, FAQs etc.) will be uploaded on the site and available to download.
- Written Correspondence - Customers will be able to contact the Project team by sending a letter to a dedicated address.
- Email – Our customers can contact the Project team at a dedicated project email address which will be set up.
- Social Media – We regularly update our Facebook and Twitter page to inform customers about forthcoming project and progress of existing projects. Our in-house communications will utilise these channels of communication to engage with our customers
- You Tube – We plan to create a You Tube video to let customers see and understand what we are aiming to achieve. We have found You Tube to be a successful communication for past NIC and NIA Projects we have undertaken.

8.5. Customer incentives

The Project will impact on all customers within the field trial locations. A comprehensive period of stakeholder engagement will be carried out, with local authorities, schools, businesses and community groups. However, due to the reduced level of disruption, anticipated by design, there are no incentives built into this Project for our customers.

Section 9: Project deliverables

Deliverable 1		Deadline	Funding
Review System Specifications		**15/05/2018**	**12%**
Evidence	Review has been conducted with stakeholders at SGN and ULC. Specifications document has been generated describing capabilities (in order of priority) to be developed under the project, as mutually agreed upon by SGN and ULC.		
Project Learning	To generate the specifications for the project, substantial research, evaluation and engineering will be performed to determine the performance parameters for the system that will be targeted during the development process. Learning related to process automation, sensor and future system capabilities and applications will be generated and finalised. These learnings will guide the whole of the project.		
Ongoing Project Progress	• Reallocation of resources to project and hiring/onboarding of new staff to support project • Project Kickoff and mobilisation • System Specification Development and engineering analysis • Initial review of high potential sensors identified during Phase 2 • Engagement with third-party manufacturers and MTC on project work scope		

Deliverable 2		Deadline	Funding
Source Vendor for Robotic Arm		**05/09/2018**	**11%**
Evidence	Robotic arm specification development and technology evaluation have been completed. Suitable vendor has been selected through a competitive procurement process and a purchase order has been submitted.		
Project Learning	The robotic arm will serve a pivotal role in the execution of all RRES operations; the level of resources dedicated to performing research, analysis and process development for candidate robotic arms is commensurate with the important role it plays in the project. This process will result in learnings specific to the performance parameters for the robotic arm and the resultant implications for integrating the robotic arm with sensors and tooling. The selection of a robotic arm vendor, technology and in committing to the purchase of this key component holds substantial weight in achieving success in the overall project goals.		
Ongoing Project Progress	• Engagement with MTC on Study relative to Sensors and Robotic Arm Technology • Design and Fabrication of testing environment • Development of sensor specifications • Research, evaluation and selection of sensor technology for below ground sensing • Software development for sensors and vision processing • Development and planning of test plan for individual/sensor camera shop testing • Develop specification for excavation tooling • Perform mechanical and electrical design for excavation tooling		

Deliverable 3		Deadline	Funding
Source vendor for mobile platform		**14/11/2018**	**7%**
Evidence	Mobile platform specification development and technology evaluation have been completed. Suitable vendor has been selected through a competitive procurement process and a purchase order has been submitted.		
Project Learning	Selecting a vendor for the mobile platform will involve developing subsystem specifications and researching and evaluating a wide range of potential platforms to determine which will best meet the specifications. The platform itself will need to be capable of relocating the mobile portion of the RRES system (sensors, end		

	effectors, robotic arm, etc.) to the work site, supporting its weight and the resultant forces of the operation and in maintaining stability through the process. This portion of the project will generate learnings specific to the mechanical and electrical layout of robotic components while taking into consideration factors such as robot weight, size and power requirements.
Ongoing Project Progress	• Begin procurement of select sensors and visions system • Ongoing software development for sensors and vision processing • Perform mechanical and electrical design for excavation tooling • Begin development of Graphical User Interface • Installation of robotic arm in test environment • Ongoing sourcing for support equipment

Deliverable 4		Deadline	Funding
Order commercially available and custom electronic components for RRES onboard computing and communication		**28/12/2018**	**3%**
Evidence	Computing system specification development has been completed. Electrical schematics and PCB designs have been documented. Purchase order has been submitted.		
Project Learning	As illustrated in the project plan, the scope of the computing system development is smaller in scale than other project deliverables, and the funding contribution has been updated accordingly. Fewer learnings will be generated by the completion of this specific deliverable since the technology is better understood and the development risk is lower than for other subsystems.		
Ongoing Project Progress	• Ongoing programming and testing of robotic arm in test environment • Ongoing sensor testing and software development for data acquisition and visualisation • Complete mechanical and electrical design of excavation tooling • Ongoing sourcing for support equipment		

Deliverable 5		Deadline	Funding
Complete shop testing of prototype excavation tooling		**28/05/2019**	**15%**
Evidence	Shop testing has been conducted to evaluate the capability of excavation tooling employed by the robotic arm. A test report has been submitted.		
Project Learning	Testing of prototype excavation tooling represents an essential portion of the RRES project. Successful completion of this deliverable will yield learnings that directly benefit the GB gas customer - as the technology developed and demonstrated could be utilized as a part of the RRES or as a standalone system. To achieve this Deliverable, substantial mechanical, electrical and software development will be performed and a working prototype excavation tool will be tested. Because of its importance to the project, significant resources have been allocated to developing and optimising this capability.		
Ongoing Project Progress	• Ongoing programming and testing of robotic arm in test environment • Ongoing sensor testing and software development for data acquisition and visualisation • Ongoing software development for sensor and vision processing • Electrical and mechanical design of sensor module • Fabrication and assembly of sensor module • Receipt and testing of mobile platform • Ongoing sourcing for support equipment		

Deliverable 6		Deadline	Funding
Complete shop testing of sensors and vision systems		**06/08/2019**	**8%**

Evidence	Sensors and vision systems have been evaluated, and procured through a competitive procurement process. Testing is underway and a test report has been submitted documenting the capabilities of each component relative to specifications.
Project Learning	Evaluation, selection and validation of sensors and vision systems for the automation of RRES operations is expected to be an ongoing effort throughout the duration of the project. This Deliverable Milestone will occur at approximately the half way point in the project and will provide substantial learning. This process will provide valuable insights regarding which technologies are accurate, consistent, rugged, and ultimately suitable for the RRES operating environment.
Ongoing Project Progress	• Shop testing of sensor module along with modifications discovered during testing • Ongoing mobile platform testing • Software development for closed loop feedback between sensors/cameras and control systems • Software development for robot end effector control • Integration of support equipment along with design of interfacing hardware and electronics • Begin full system assembly and integration • Development of specifications for mobile operations • Begin software development for mobile operations

Deliverable 7		Deadline	Funding
Complete off-site testing of below-ground sensing capability		**04/02/2020**	**10%**
Evidence	Sensor module has been developed and fabricated. Sensor module has been tested in an offsite environment in conjunction with the robotic arm. A test report has been submitted, documenting the detection and visualisation capabilities of the system.		
Project Learning	This deliverable represents the second focused specifically on the development of below ground sensing capability and in integrating the most promising sensor and vision technologies; both in hardware and in software. Testing of the integrated sensor module will result in learning regarding coordination of RRES tooling, articulation of the robotic arm, and detection of buried infrastructure using sensors and will mark a ground-breaking achievement for the project.		
Ongoing Project Progress	• Ongoing sensor module testing and software development • Complete system integration with support equipment • Offsite testing along with ongoing software and hardware development to enable sensor integration, data acquisition and closed loop feedback/control • Modifications and improvements determined during off site testing in preparation for offsite testing • Planning for interim field test along with preparations for shipping integrated system UK • Mechanical and electrical design for automated tool changing • Updates to sensor processing software for use in mobile operations		

Deliverable 8		Deadline	Funding
Perform interim field test of prototype RRES (Element 2)		**26/05/2020**	**9%**
Evidence	The RRES system has been deployed in the UK in a non-live gas environment to evaluate the capabilities of the system. A final report has been submitted outlining system capabilities and recommended next steps.		
Project Learning	Several months of the project are devoted to integration and shop testing leading up to interim field testing. This deliverable encompasses sourcing of materials, fabrication of hardware, assembly, testing, and hardware and software modifications. The interim field testing of the prototype RRES will generate key		

	learnings regarding the integrated system's readiness for field testing, its effectiveness as an excavator and its capability for detecting buried infrastructure.
Ongoing Project Progress	• Ongoing offsite testing and preparations for interim field testing • Design and fabrication of spare parts to support interim field testing • Training of ULC staff in preparation of field deployment • Development of documentation to obtain approval for field deployment • Relocation of system and ULC team from US to UK for interim field testing • Ongoing updates to sensor processing software for use in mobile operations • Mechanical and electrical design related to UAF • Begin tether design and sourcing

Deliverable 9		**Deadline**	**Funding**
Fabricate and test universal access fitting		**18/08/2020**	**9%**
Evidence	Prototype universal access fittings have been developed and manufactured for specified pipe material and size. Testing has been conducted to evaluate the fitting design/fitness for purpose and the reliability of the process. A test report has been submitted highlighting results.		
Project Learning	Development and testing of the universal access fitting will focus on performance goals related to robotic installation and open-source tooling. Learnings generated in these areas will enable the widespread use and uptake of the RRES, and the deliverable reflects investment of project resources and importance of its outputs.		
Ongoing Project Progress	• Plan and execute the return of the system to US • Design, selection and sourcing of vehicle chassis for second field trial • Evaluate and source vendor for tether • Design and fabricate tether reel and operator console • Ongoing software development and modifications identified during interim field testing • Begin full system integration		

Deliverable 10		**Deadline**	**Funding**
Perform field test of full RRES		**26/03/2021**	**16%**
Evidence	The RRES system has been deployed in the UK in a live gas environment to evaluate the capabilities of the system. A final report has been submitted outlining system capabilities and recommended next steps.		
Project Learning	Testing and demonstration of the complete RRES is planned on a live gas environment which represents the culmination of all the development work contained within preceding project deliverables. Preparation for field testing will entail the selection, development and procurement of support equipment as well as fabrication, assembly, integration, testing and debugging of the complete robotic system. Additionally, operational planning and the methodology for system use will be created and learnings will be captured regarding the overall system effectiveness and its path to commercialisation.		
Ongoing Project Progress	• Ongoing sensor, hardware and software development and modifications identified during interim field testing • Complete full system integration • Integration of RRES with UK vehicle chassis • Ongoing offsite testing and preparations for interim field testing • Generate documentation and obtain approvals to perform field trial • Design and acquire spare parts for field trial • Training of ULC staff in preparation of field deployment • Relocation of system and ULC team from US to UK for interim field testing		

Deliverable 11	**Deadline**	**Funding**

Comply with knowledge transfer requirements of the Governance Document.		Project End	N/A
Evidence	1. Annual Project Progress Reports which comply with the requirements of the Governance Document. 2. Completed Close Down Report which complies with the requirements of the Governance Document. 3. Evidence of attendance and participation in the Annual Conference as described in the Governance Document.		
Project Learning	N/A		

Section 10: List of Appendices

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Appendix A: Benefits Table

KEY:

Method	Method name
Method 1	Robotic automation of current Core-and-Vac system for excavation and reinstatement (Urban)
Method 2	Robotic 'soft-touch' capability to allow wider application of Core-and-Vac technology (Urban)
Method 3	Indirect cost benefits of robotic excavation and reinstatement (urban)
Method 4	Environmental and Social benefits of robotic excavation and reinstatement (urban)
Method 5	Robotic Automation of routine inspection/maintenance/repair activities (urban)
Method 6	Robotic Automation of main/services replacement activities (urban)
Method 7	Indirect costs of robotic automation of work activities (urban)
Method 8	Environmental and Social benefits of the robotic automation of work activities (urban)
Method 9	Robotic Automation of the Excavation and Reinstatement process for LTS pipelines
Method 10	Robotic Automation of specific work processes on high pressure pipelines
Method 11	Indirect benefits from application the technology in other sectors to reduce unit costs of provision to GDNs
Method 12	Environmental and Social benefit of the application of the technology in other utility sectors

Gas NIC – financial benefits

Scale	Method	Method Cost (£m / yr)	Base Case Cost (£m / yr)	Probability Weighted NPV (£m)			Cross Reference		
				2030	2040	2050	Variability / Range 2030 NPV (H to L)		Additional Detail
Licensee Scale (Southern and Scotland GDNs combined)	1	2.393	2.447	1.910	2.186	2.353	4.004	0.678	Appendix E.1.
	2	0.648	0.780	4.189	4.796	5.162	5.339	2.820	Appendix E.2.
	3	57.532	58.341	4.358	5.064	5.064	4.358	4.358	Appendix E.3.
	4	8.789	12.853	55.192	66.254	72.130	55.192	55.192	Appendix E.4.
	5	0.273	0.416	0.571	0.751	0.874	0.701	0.441	Appendix E.5.
	6	34.044	34.856	2.789	3.300	3.300	4.384	1.412	Appendix E.6.
	7	6.110	6.343	1.341	1.546	1.546	1.341	1.341	Appendix E.7.
	8	13.979	18.153	43.128	49.541	53.349	43.128	43.128	Appendix E.8.
	9	0.891	2.375	8.066	13.785	17.837	9.680	6.453	Appendix E.9.
	10	-	-	-	-	-	-	-	Section 3
	11	-0.035	0.000	1.232	1.411	1.518	1.848	0.616	Appendix E.10.
	12	-	-	-	-	-	-	-	Section 3
	Total	124.624	136.563	122.776	148.633	163.133	129.975	116.439	
GB-Wide, all licensees	1	8.783	8.980	7.009	8.024	8.636	14.695	2.488	Appendix E.1.
	2	2.378	2.863	15.374	17.601	18.944	19.594	10.349	Appendix E.2.
	3	211.142	214.110	24.464	28.748	28.748	24.464	24.464	Appendix E.3.
	4	32.255	47.170	202.555	243.152	264.717	202.555	202.555	Appendix E.4.
	5	1.002	1.527	2.095	2.755	3.208	2.573	1.618	Appendix E.5.
	6	124.940	127.923	10.234	12.110	12.110	16.089	5.182	Appendix E.6.
	7	6.110	6.343	4.922	5.674	5.674	4.921	4.921	Appendix E.7.
	8	51.304	66.620	158.280	181.814	195.792	158.280	158.280	Appendix E.8.
	9	2.351	6.270	21.295	36.392	47.090	25.555	17.036	Appendix E.9.
	10	-	-	-	-	-	-	-	Section 3
	11	-0.127	0.000	4.522	5.177	5.572	6.782	2.261	Appendix E.10.
	12	-	-	-	-	-	-	-	Section 3
	Total	440.139	481.805	450.749	541.446	590.489	475.508	429.155	

Gas NIC – carbon and/or environmental benefits

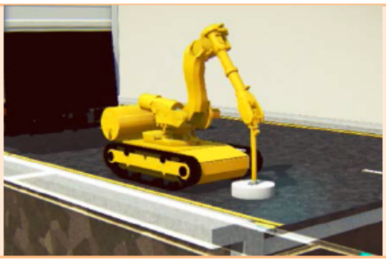
Scale	Method	Method Cost (£m/yr)	Base Case Cost (£m/yr)	Probability Weighted Environmental Benefit (te CO2e)			Cross Reference		
				2030	2040	2050	Variability/Range 2030 NPV (H to L)		Additional Detail
	4	48	596	14581	18796	22682			Appendix E.4.
	8	69	855	10875	13049	14937			Appendix E.8.
	12	-	-	-	-	-	-	-	
	Total	117	1451	25456	31845	37619			
	4	177	2186	53514	68983	83241			Appendix E.4.
	8	254	3140	39911	47889	54820			Appendix E.8.
	12	-	-	-	-	-	-	-	
	Total	431	5326	93425	116871	138061			
Other Environmental Benefits not expressable as tCO2e	Methods 4 and 8 combined reduce NOx emissions by ~ 700 te at GB level by 2030.								

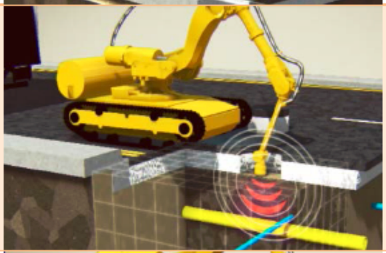
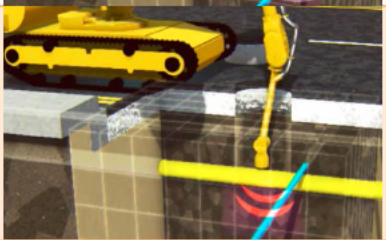
Appendix B: Concept of Operations

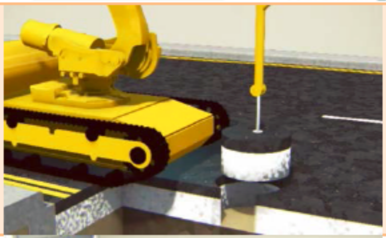
The RRES will be developed to perform both distribution and transmission works for natural gas utilities. This section provides descriptions of the processes by which the RRES will perform these operations, illustrating the adaptability of the system to different environments. In the future, the system and technology developed under this project can be applied to a multitude of additional operations and industries.

B.1. Distribution Concept of Operations

During distribution works, the RRES operates in an urban environment, where the footprint of operations has a significant impact on the public and where there is often a high concentration of buried infrastructure in a small area. The concept of operations for the RRES in urban environments is shown below.

Description	3D Conceptual Image
RRES Operations Truck arrives on site.	
Specialised lift gate safely lowers the robot onto the street. The transport vehicle may be moved to a less traffic sensitive location within the maximum travel range (which will be determined under the project).	
The RRES travels to the chosen excavation location and employs appropriate sensing technology (such as Ground Penetrating Radar (GPR) and induction, acoustic and Electro-Magnetic (EM) sensors) to scan the street surface for utilities, cables, and obstacles prior to the start of excavation.	
Data from utility maps may be entered prior to the start of works. Additionally, sensor data is processed through the AI engine, which begins building a 3D model of the work area. This data enables the AI engine to determine that the ground immediately below the sensor head is clear of buried utilities, debris, and obstacles. An operator inside the RRES Operations Truck monitors the operations and performs manual intervention if necessary.	
Once the excavation location has been confirmed to be clear, the robot cuts the street surface safely.	

Once the road section has been removed, the robot lifts the road section and place it aside.	
With the asphalt cleared, the robot re-scans the work area with sensors to see if additional data can be obtained from the work area.	
A soft-touch soil-lift excavator, combined with high-efficiency vacuuming, allows the robotic system to excavate rapidly with unprecedented precision and confidence that buried infrastructure will not be damaged. The excavated material will be retained for reinstatement.	
Sensors and machine vision act as the robot's eyes and ears—feeding information to the AI engine that allows the system to identify and avoid buried infrastructure while it works. The auger design prevents moving parts from coming into contact with pipes, service lines and cables while specialized edging protects infrastructure against scrapes.	
Once the pipeline is exposed, the robot will be able to install a universal access fitting (UAF) which may be used to carry out a wide array of gas operations and maintenance (O&M) tasks. Alternately, the system may be used to simply perform excavation without installing a UAF to support other works.	
The robot will use the soil removed during the excavation process to backfill the excavation. Alternatively, the robot can backfill using an approved alternative reinstatement material.	
A tamping tool on the robot compacts the soil to meet the reinstatement specification. Once compacted, the robot continues to backfill and tamp the soil until the backfill process is complete.	

The robot may be used to apply a grouting mixture into the work site reinstating the roadway.	
Once the operation is complete, the robot returns to the RRES Operations vehicle.	

B.2. Transmission Concept of Operations

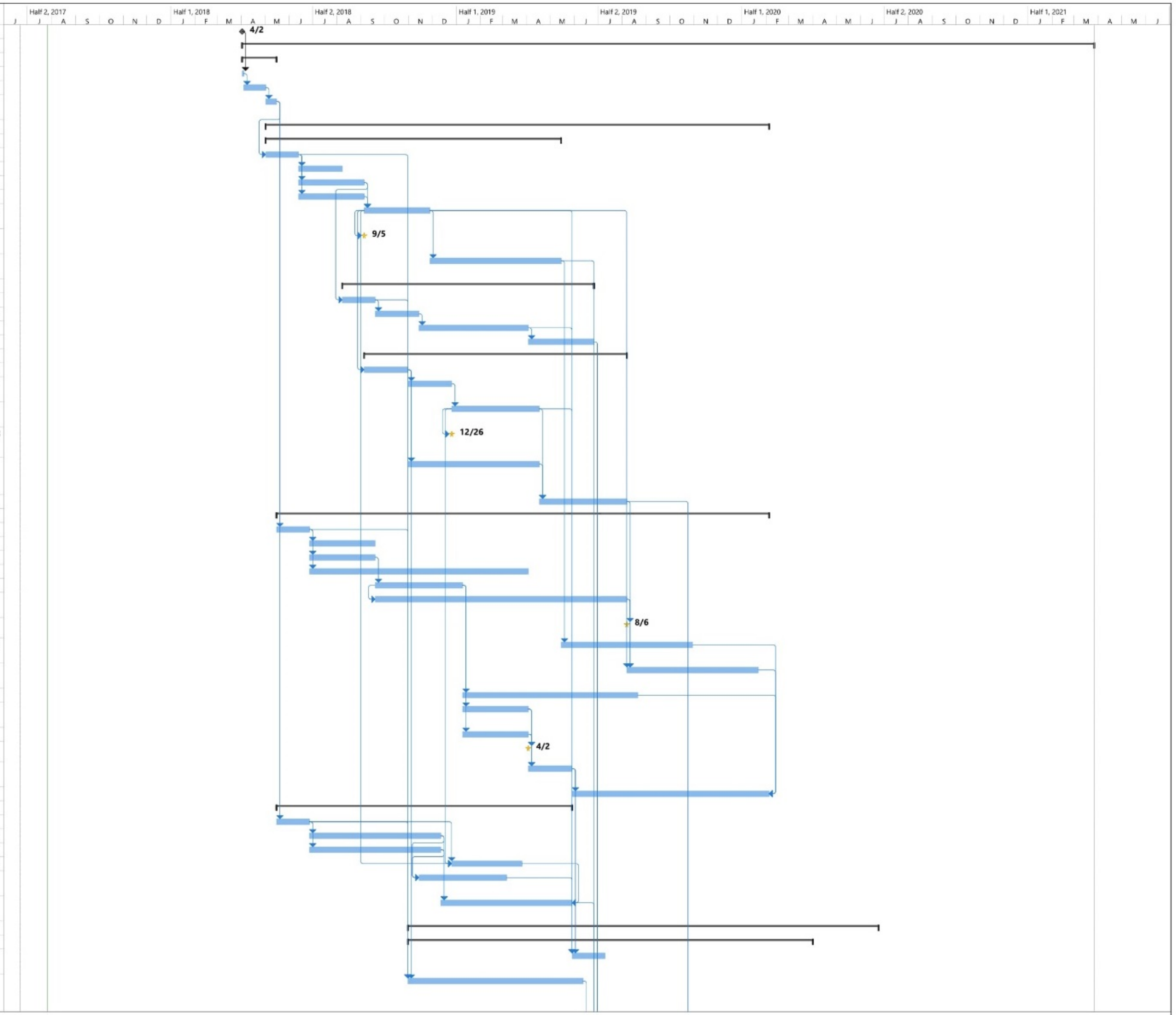
Transmission works, unlike distribution works, typically occur in rural environments. While transmission pipelines are isolated from other buried infrastructure, they pose unique challenges to natural gas utilities. These pipelines often operate at higher pressures where the consequence of inflicting damage to the pipe is far greater, and the size of the excavation required is larger by convention. The environments in which transmission pipelines are located can also be difficult for large trucks to access. The concept of operations below depicts some of the key differences between transmission and distribution environments:

Description	3D Conceptual Image
The RRES transport vehicle is parked in an accessible location. The operator remotely navigates the RRES from the vehicle to the excavation site. Data from utility maps may be entered prior to the start of works. The RRES scans the work area, and can excavate trial holes as needed to verify the location of the main or standpipes.	
The RRES uses the soft touch excavation system to begin clearing the soil above and around the transmission pipe that falls within a region known as the "danger zone". The excavated soil can be deposited a safe distance from the pipe, where larger excavation equipment can assist the RRES in completing the full excavation.	
As is the case with distribution works, sensors and machine vision are employed by the RRES to create a 3D point cloud to visualize the excavation environment and avoid buried infrastructure. Careful attention is paid to detecting and avoiding fittings and standpipes that are susceptible to damage in transmission environments.	

![ofgem logo] ![RIIO NIC Network Innovation Competition logo]

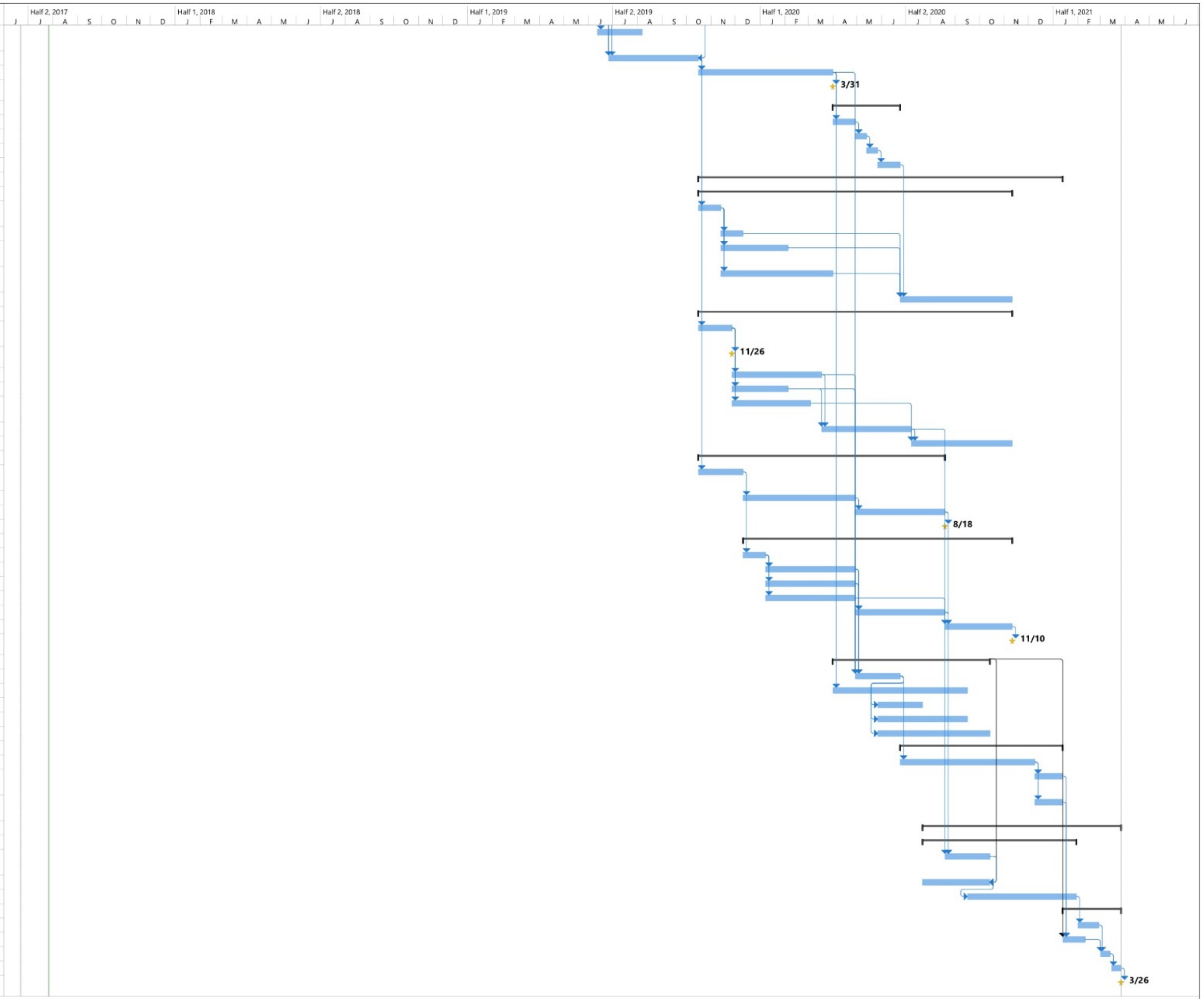
Appendix C: Project Plan

ID	Task Name	Duration	Start	Finish
1	Project Start	0 days	Mon 4/2/18	Mon 4/2/18
2	**RRES NIC Project**	**780 days**	**Mon 4/2/18**	**Fri 3/26/21**
3	**Requirements Development**	**32 days**	**Mon 4/2/18**	**Tue 5/15/18**
4	Project Kickoff meetings	2 days	Mon 4/2/18	Tue 4/3/18
5	High level system specification development	4 wks	Wed 4/4/18	Tue 5/1/18
6	Preliminary system specifications report presented to SGN for review and modified as needed (PD1)	10 days	Wed 5/2/18	Tue 5/15/18
7	**Element 1**	**460 days**	**Wed 5/2/18**	**Tue 2/4/20**
8	**Robotic arm evaluation and testing**	**270 days**	**Wed 5/2/18**	**Tue 5/14/19**
9	Develop robotic arm specification	6 wks	Wed 5/2/18	Tue 6/12/18
10	Engage MTC in research study on robotic arms	40 days	Wed 6/13/18	Tue 8/7/18
11	Research and evaluate commercially available arms	12 wks	Wed 6/13/18	Tue 9/4/18
12	Design and fabricate excavation test environment	12 wks	Wed 6/13/18	Tue 9/4/18
13	Procure robotic arm and install in ULC test environment (PD2)	12 wks	Wed 9/5/18	Tue 11/27/18
14	Project progress report 1 - robotic arm research and evaluation	0 days	Wed 9/5/18	Wed 9/5/18
15	Perform initial programming and testing in test environment	6 mons	Wed 11/28/18	Tue 5/14/19
16	**Mobile platform evaluation and testing**	**230 days**	**Wed 8/8/18**	**Tue 6/25/19**
17	Develop specifications for mobile platform	6 wks	Wed 8/8/18	Tue 9/18/18
18	Evaluate commercially available mobile platforms	8 wks	Wed 9/19/18	Tue 11/13/18
19	Procure mobile platform (PD3)	5 mons	Wed 11/14/18	Tue 4/2/19
20	Perform design modifications and shop testing	3 mons	Wed 4/3/19	Tue 6/25/19
21	**Computing system development**	**240 days**	**Wed 9/5/18**	**Tue 8/6/19**
22	Develop computing system specifications	2 mons	Wed 9/5/18	Tue 10/30/18
23	Evaluate hardware for main control and communications systems	2 mons	Wed 10/31/18	Tue 12/25/18
24	Source and assemble electronic components and perform shop testing (PD4)	4 mons	Wed 12/26/18	Tue 4/16/19
25	Project progress report 2 – Computing system specification document and documentation of system design	0 days	Wed 12/26/18	Wed 12/26/18
26	Develop code for Graphical User Interface, status reporting, database, communications, and signal processing	6 mons	Wed 10/31/18	Tue 4/16/19
27	Test software, debug and update	16 wks	Wed 4/17/19	Tue 8/6/19
28	**Below ground sensing development**	**450 days**	**Wed 5/16/18**	**Tue 2/4/20**
29	Develop below-ground sensing specifications	6 wks	Wed 5/16/18	Tue 6/26/18
30	Engage MTC in research study on sensors	12 wks	Wed 6/27/18	Tue 9/18/18
31	Research and evaluate sensor technologies	12 wks	Wed 6/27/18	Tue 9/18/18
32	Develop software for sensor and vision processing	40 wks	Wed 6/27/18	Tue 4/2/19
33	Procure sensors and cameras	16 wks	Wed 9/19/18	Tue 1/8/19
34	Perform shop testing on individual sensors/cameras (PD6)	46 wks	Wed 9/19/18	Tue 8/6/19
35	Project progress report 4 – Test plan/report for individual sensor/camera technologies	0 days	Tue 8/6/19	Tue 8/6/19
36	Develop software for locating robot end effector in 3D space	24 wks	Wed 5/15/19	Tue 10/29/19
37	Develop software for closed loop feedback between sensors/cameras and control system	24 wks	Wed 8/7/19	Tue 1/21/20
38	Develop software for sensor data visualization	8 mons	Wed 1/9/19	Tue 8/20/19
39	Perform detailed mechanical design for sensor module	3 mons	Wed 1/9/19	Tue 4/2/19
40	Perform detailed electrical design for sensor module	3 mons	Wed 1/9/19	Tue 4/2/19
41	Project progress report 3 – Sensor module design documentation	0 days	Tue 4/2/19	Tue 4/2/19
42	Fabricate components for sensor module and assemble	2 mons	Wed 4/3/19	Tue 5/28/19
43	Perform shop testing on sensor module (PD7)	9 mons	Wed 5/29/19	Tue 2/4/20
44	**Excavation tooling development**	**270 days**	**Wed 5/16/18**	**Tue 5/28/19**
45	Develop specifications for excavation tooling	6 wks	Wed 5/16/18	Tue 6/26/18
46	Perform detailed mechanical design	6 mons	Wed 6/27/18	Tue 12/11/18
47	Perform detailed electrical design	6 mons	Wed 6/27/18	Tue 12/11/18
48	Develop software for excavation tooling system	3.2 mons	Wed 12/26/18	Mon 3/25/19
49	Source and fabricate tool components	4 mons	Wed 11/14/18	Tue 3/5/19
50	Perform shop testing of prototype tool (PD5)	6 mons	Wed 12/12/18	Tue 5/28/19
51	**Element 2**	**430 days**	**Wed 10/31/18**	**Tue 6/23/20**
52	**Integration of Element 1 subsystems**	**370 days**	**Wed 10/31/18**	**Tue 3/31/20**
53	Design and fabricate interfacing hardware and electronics	6 wks	Wed 5/29/19	Tue 7/9/19
54	Ongoing sourcing of support equipment for prototype system including generator, vacuum, power supplies and interconnects	8 mons	Wed 10/31/18	Tue 6/11/19



Page 1

ID	Task Name	Duration	Start	Finish
55	Assemble support equipment deployment system for first field test	8 wks	Wed 6/12/19	Tue 8/6/19
56	Assemble prototype RRES system	4 mons	Wed 6/26/19	Tue 10/15/19
57	Perform shop testing of RRES prototype system	6 mons	Wed 10/16/1	Tue 3/31/20
58	Project progress report 6 – Test plan/report for shop testing of prototype RRES	0 days	Tue 3/31/20	Tue 3/31/20
59	**Field testing in inert environment**	**60 days**	**Wed 4/1/20**	**Tue 6/23/20**
60	Pack and ship system and support equipment to UK	1 mon	Wed 4/1/20	Tue 4/28/20
61	RRES system initialization and setup	2 wks	Wed 4/29/20	Tue 5/12/20
62	Perform field testing (PD8)	2 wks	Wed 5/13/20	Tue 5/26/20
63	Return system to ULC in New York	1 mon	Wed 5/27/20	Tue 6/23/20
64	**Element 3**	**325 days**	**Wed 10/16/1**	**Tue 1/12/21**
65	**Mobile operations development**	**280 days**	**Wed 10/16/1**	**Tue 11/10/20**
66	Develop specifications for mobile platform motion planning and control	4 wks	Wed 10/16/19	Tue 11/12/19
67	Perform detailed electrical design	4 wks	Wed 11/13/1	Tue 12/10/19
68	Update toolpath generation and environment mapping software for use on mobile platform	12 wks	Wed 11/13/19	Tue 2/4/20
69	Update sensor processing software for use on mobile platform	20 wks	Wed 11/13/19	Tue 3/31/20
70	Perform shop testing with mobile AI software	20 wks	Wed 6/24/20	Tue 11/10/20
71	**Automated tool changing development**	**280 days**	**Wed 10/16/1**	**Tue 11/10/20**
72	Develop specifications for tool changing method and system	6 wks	Wed 10/16/19	Tue 11/26/19
73	Project progress report 5 – Automated tool changing specification document	0 days	Tue 11/26/19	Tue 11/26/19
74	Perform detailed mechanical design	16 wks	Wed 11/27/1	Tue 3/17/20
75	Perform detailed electrical design	10 wks	Wed 11/27/1	Tue 2/4/20
76	Develop software for tool acquisition, transportation and removal	14 wks	Wed 11/27/19	Tue 3/3/20
77	Source and fabricate components and assemble	4 mons	Wed 3/18/20	Tue 7/7/20
78	Perform shop testing	18 wks	Wed 7/8/20	Tue 11/10/20
79	**Universal Access Fitting (UAF) development**	**220 days**	**Wed 10/16/1**	**Tue 8/18/20**
80	Develop UAF specification and select target pipe material and diameter	8 wks	Wed 10/16/19	Tue 12/10/19
81	Perform detailed mechanical design of fitting	5 mons	Wed 12/11/1	Tue 4/28/20
82	Fabricate and test fittings (PD9)	4 mons	Wed 4/29/20	Tue 8/18/20
83	Project progress report 7 – Test plan/report for UAF	0 days	Tue 8/18/20	Tue 8/18/20
84	**UAF tooling development**	**240 days**	**Wed 12/11/1**	**Tue 11/10/20**
85	Develop specifications for UAF tooling	4 wks	Wed 12/11/1	Tue 1/7/20
86	Perform detailed mechanical design	4 mons	Wed 1/8/20	Tue 4/28/20
87	Perform detailed electrical design	80 days	Wed 1/8/20	Tue 4/28/20
88	Develop software for toolpath generation	80 days	Wed 1/8/20	Tue 4/28/20
89	Source and fabricate tool components	4 mons	Wed 4/29/20	Tue 8/18/20
90	Perform shop testing of prototype tool and UAF fitting	12 wks	Wed 8/19/20	Tue 11/10/20
91	Project progress report 8 – Test plan/report for UAF tooling	0 days	Tue 11/10/20	Tue 11/10/20
92	**Final support equipment development**	**140 days**	**Wed 4/1/20**	**Tue 10/13/20**
93	Develop specifications for support equipment	8 wks	Wed 4/29/20	Tue 6/23/20
94	Design and source tether	6 mons	Wed 4/1/20	Tue 9/15/20
95	Design and fabricate reel cart	8 wks	Wed 5/27/20	Tue 7/21/20
96	Design and fabricate operator consoles	4 mons	Wed 5/27/20	Tue 9/15/20
97	Source miscellaneous components	5 mons	Wed 5/27/20	Tue 10/13/20
98	**Support vehicle development**	**145 days**	**Wed 6/24/20**	**Tue 1/12/21**
99	Source vehicle chassis in UK	6 mons	Wed 6/24/20	Tue 12/8/20
100	Design and fabricate interfaces between vehicle and support equipment	5 wks	Wed 12/9/20	Tue 1/12/21
101	Design and fabricate interfaces between vehicle and RRES (including docking station and ramp)	5 wks	Wed 12/9/20	Tue 1/12/21
102	**Element 4**	**178 days**	**Wed 7/22/20**	**Fri 3/26/21**
103	**Integration of subsystems developed under Elements 1 and 3**	**138 days**	**Wed 7/22/20**	**Fri 1/29/21**
104	Design and fabricate interfacing hardware and electronics	8 wks	Wed 8/19/20	Tue 10/13/20
105	Assemble full RRES system	12 wks	Wed 7/22/20	Tue 10/13/20
106	Perform shop testing	98 days	Wed 9/16/20	Fri 1/29/21
107	**Field testing in live gas environment**	**53 days**	**Wed 1/13/21**	**Fri 3/26/21**
108	Pack and ship system to UK	1 mon	Mon 2/1/21	Fri 2/26/21
109	Assemble vehicle in UK	4 wks	Wed 1/13/21	Tue 2/9/21
110	RRES system initialization and setup	2 wks	Mon 3/1/21	Fri 3/12/21
111	Perform final field testing (PD10)	2 wks	Mon 3/15/21	Fri 3/26/21
112	Project progress report 9 – Test plan/report for final field testing	0 days	Fri 3/26/21	Fri 3/26/21



Appendix D: Partners and Organisational Charts

D.1. Partners

D.1.1 - ULC Robotics

ULC Robotics, located in Hauppauge, New York, specializes in developing unique solutions to the technical challenges facing the energy industry. ULC Robotics provides technology development, contracted services, and innovative products to gas and electric utilities that work to reduce operations and maintenance costs while meeting the increasingly complex demands of the regulators, energy customers, and the general public.

In addition, ULC has been a world leader in the development of no dig, low dig and trenchless technology for more than 15 years. Our experience includes developing and commercializing methods, processes and tools for micro-excavation, permit free valve box reinstatement and No Dig Cathodic Protection Anode Installation.

ULC has expertise in project management, mechanical engineering, electrical engineering, sensor development and application, programming, user interface development as well as manufacturing, assembly and testing. Based on ULC's extensive knowledge and experience in developing, testing and providing service solutions to the gas and electric industries, ULC is the ideal partner to work with on bringing this innovative technology into commercial readiness.

D.1.2 - Manufacturing Technology Centre

The Manufacturing Technology Centre (MTC) develops and proves innovative manufacturing processes and technologies in an agile, low risk environment, in partnership with industry, academia and other institutions. It focuses on delivering bespoke manufacturing system solutions for its customers.

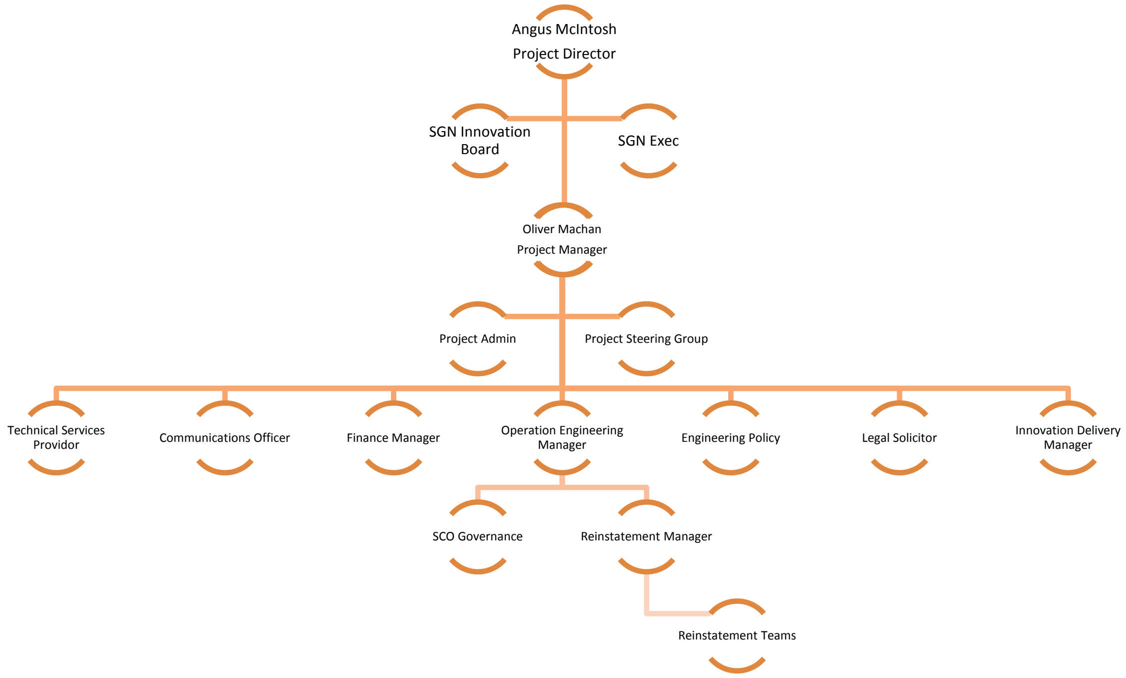
The MTC operates some of the most advanced manufacturing equipment in the world, and employs a team of highly skilled engineers, many of whom are leading experts in their fields. This creates a high-quality environment for the development and demonstration of new processes and technologies on an industrial scale.

The MTC's areas of expertise are directly relevant to both large and small companies, and are applicable across a wide range of industry sectors. The MTC's members include global manufacturing companies from multiple sectors. Research partners include the University of Birmingham, University of Nottingham, Loughborough University and TWI Ltd.

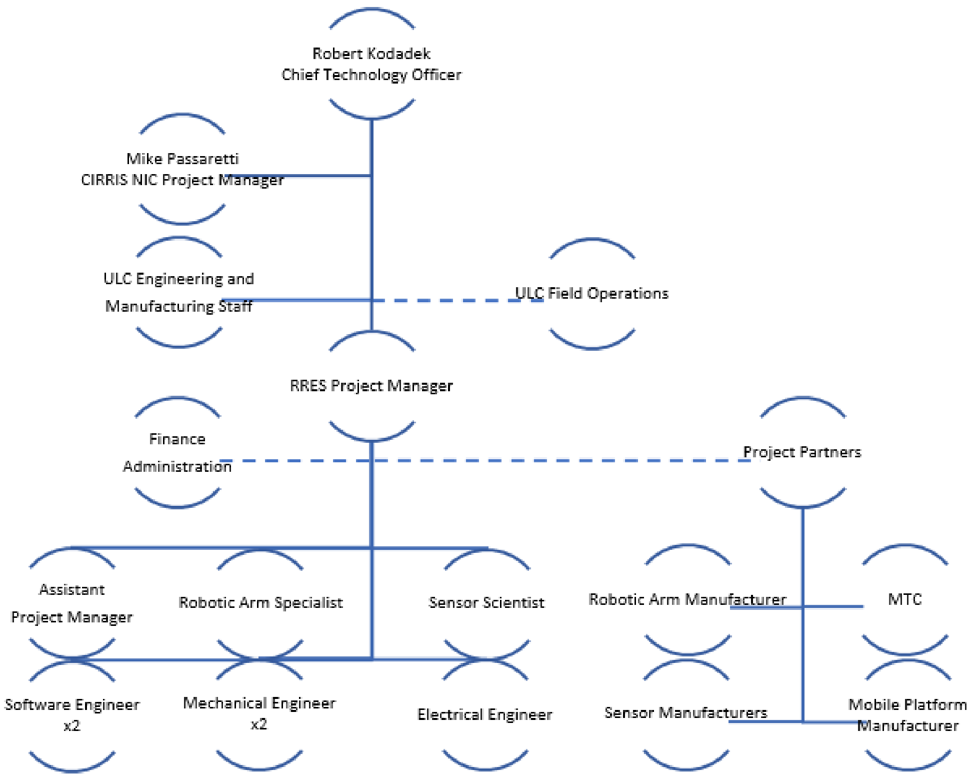
The MTC is part of the High Value Manufacturing Catapult, supported by Innovate UK.

D.2. Organisational Charts

D.2.1 – SGN



D.2.2 – ULC Robotics



Appendix E: Cost Benefit Analysis and Social Cost Calculations

E.1. Details of Method 1 Appraisal

Our starting point for this and other CBA calculations is our post-field trial capex investment case for the procurement of our fleet of 6 off 7.5 tonne vehicles with integrated core-and-vac capability. These vehicles reduce the cost per excavation from £904 to £514, or £389/excavation (£347 in 2011/12 prices), with the bulk of this accruing to reinstatement savings. The cost comparison was based on man-hours and contracted or sub-contracted reinstatement costs on an average escape repair excavation of 1.5m3 in a type 3 or 4 carriageway.

Allocating the finance cost of the vehicles over 3 years adds a cost of £194 per excavation. Therefore our base costs for current core and vac technology are estimated as:

- Current service cost of repair excavation by traditional methods = £904 £/excavation
- Current service cost of repair excavation by Core-and-Vac method (including machine capex) = £708
- Current capex-free service cost of repair excavation by Core-and Vac = £514.

As a basis for Method 1 benefits appraisal we have considered a conservative 20% increase in machine productivity of the robot brought about by

- Faster location and marking of utility assets
- An integrated agitation/extraction assembly
- Avoidance of manual rigging and lifting work

In this mode the robot acts as an automated locating, coring, excavation and reinstatement machine with no credit for robotic repair or asset intervention.

To assess whether there is enough enduring repair work addressable by core-and-vac, we have analysed or joint failure data by Tier over the 5 year period 2008 to 2013:

Diameter Banding	Joint Failure Count (per annum)	% by Tier
Tier 1 (3" to 8")	32,102	72
Tier 2 (9" – 16")	8,392	19
Tier 3 (18" to 48")	3,871	9
All Pipe Sizes	44,365	100

The benefits of the core-and-vac approach are best realised in congested urban areas where there is a bias towards larger diameter mains (reflecting field trial). Our original capex investment case was based on 25% overall applicability of the core-and-vac system; for this analysis we have assumed that 50% of Tier 2/3 joints are addressable in this way, and 15% of Tier 1, to give an overall addressability close to the original figure of 25%. This implies a repair potential work volume by core-and-vac of up to 4815 Tier 1 and 6132 Tier 2/3, or 10,947 total jobs/annum.

The current 6 vehicle fleet undertakes up to 10 repairs per vehicle per week for 48 weeks, a total of 2,880 repairs per annum (therefore no current deficit of addressable work). Our assumption is that a robotic replacement of the current fleet could push this to 3,456 per annum (+20%). The robotic vehicle delivers value in displacing excavations that would otherwise need to be carried out by traditional methods.

Implementation is assumed from 2021 as an early output of the development programme. To project forward in time we have assumed that Tier 1 joint repairs are not required from 2032 (although the PE system will require some intervention and repair), and that applicability to Tier 2/3 falls from 50% to 25% to reflect their repair by other internal methods and the staged replacement/relining of these large diameter mains, offset by the general ageing of residual assets. The addressable market across SGN for robotic joint repair work (excavations/annum), to allow credible time for staged implementation, is therefore assumed to change from current day levels as follows:

Period	Joint Repair Excavations
2021 to 2026	3,456 rising to 10,947
2027 to 2032	10,947 falling to 3,066

We have included also in this Method the excavation fracture repair volumes of Method 5 and the mains/services work volumes of Method 6 as follows:

Period	Fracture Repair (excavations)	Mains/Services (excavations)
2021 to 2026	0 rising to 1300	0 rising to 18,600
2027 to 2032	1300 falling to 0	18,600 falling to zero

As a pure higher efficiency excavation device the aggregate annual excavation numbers assumed to be undertaken by the robot machine are as follows:

Period	All RRES Excavations
2021 to 2026	3,456 rising to 30,847
2027 to 2032	30,847 falling to 3066
2032 - 2050	3066

We have looked at the sensitivity of the net value over a range of service prices at licensee level:

Price Per Repair Excavation	NPV (£m)		
	2030	**2040**	**2050**
708	4.004	4.584	4.934
725	1.910	2.186	2.353
735	0.678	0.776	0.835

At £708/excavation SGN is retaining all the value of improved robotic efficiency at no price premium. Note that in comparison to Method 2, a generally lower price is required owing to the limited efficiency improvements over those already attained with current Core-and-Vac technology.

E.2. Details of Method 2 Appraisal

The benefit of method 2 is assumed to be realised by extending the applicability of the core-n-vac process by 25% over the work volumes of Method 1. This extension of capability is to reflect the superior spatial access of the remote vehicle, enhanced asset locating capability, reduced safety concerns in asset-congested areas. In this way we are valuing the direct costs savings of 'doing excavations where no current core-and-vac can go'.

In the peak year, some additional 7,700 robotic excavations are being carried out in instances where the only counterfactual method is traditional excavation. All else equal, Method 2 can therefore sustain a higher service cost than Method 1. NPV sensitivity at licensee level is shown below.

Price Per Repair Excavation	NPV (£m)		
	2030	**2040**	**2050**
708	5.339	6.112	6.579
750	4.189	4.796	5.162
800	2.820	3.229	3.475

Taking into consideration any reduction in indirect costs for Methods 1 and 2 would shift the allowable charge upwards to attain the same net benefit. The related indirect costs are considered separately in Method 3, and the social/environmental benefits in Method 4.

E.3. Details of Method 3 Appraisal

Commensurate with the level of activity described in Methods 1 and 2, we have considered the likely indirect cost savings arising from (i) reduction in damage to buried assets caused by excavation activities, (ii) cost of personnel injury and, (iii) work management charges, including TMA costs. This reflects the robotic vehicle's superior asset location and sensing capabilities (not present on current core-and-vac vehicles) and its more efficient operation.

E.3.1. Damage to buried assets

We have examined our safety and environmental accident log for the period April 2016 to March 2017 to assess the potential reduction in damage to third party assets caused by the excavation or reinstatement process. Relevant data in this regard are as follows:

Asset Type	Freq. of Damage (p/a)	% In Highway	Excavation Related	Work Process Related	Potential Avoidance Using RRES
HV cable	2	100	1	1	1
LV cable	54	100	39	15	39
SF Cable	71	100	71	0	71
SVC Cable	86	75	60	5	60
Other Utility	121	100	90	10	90
Total	**334**	**87.4**	**261**	**31**	**261**

The potential avoidance needs to be seen in the context of the total number of excavations undertaken each year. Based on our joint leakage repair/fracture frequency and service renewal (mains and non-mains related) we estimate this to be around 110,000 per annum, giving a 'damage fault rate' of 0.3% or 0.24% for those potentially avoidable through robotic excavation.

For the direct cost of repair we have made reference to recent work by the University of Birmingham[1] who have estimated, measured and modelled the direct, indirect and social costs of utility strikes:

(i) Average direct cost (DC) of repair (all utilities) = £3,738 / strike
(ii) Multiplier for indirect costs (IC) = 3.68
(iii) Multiplier for social costs (SC) = 25.6

SGN Public Liability claims for 2016 record an average claim for electrical cable damage of £789 for a range of strikes on both electrical supply and telecommunications infrastructure. Taking this data together, we have assumed a mid-range cost of £1500 for the direct costs of utility strike repair, giving an indirect burden on energy network users of 3.68 x £1500 = £5,520 per utility strike (social costs are accounted for in Method 4).

For SGN this implies an annual cost to energy network users of £1.844m per annum (where we don't distinguish between these costs and the insurance premiums to recover same). For the volume driver we have based our estimation of benefits on the aggregate volume of robotic excavations carried out (21,300 per annum) and their relative impact in reducing (by around 50) utility strikes in any year.

E.3.2. Cost of Injury to Personnel

HSE monitoring stats indicate a very low level of LTI as a result of all work activities (1 1-3 day LTI and 2 1-7 day LTIs in 2000 recorded incidents). The effective use of PPE during excavation prevents asset strikes and other incidents becoming LTI events despite the material level of events reported. We note also a small number of excavation damage incidents caused by the inappropriate use of the current core-n-vac machines. We have excluded any monetary costs of LTIs from our analysis, but note the potential of the robot to reduce the micro-mort count of field staff by eliminating all strikes during the excavations it conducts.

E.3.3. Work management, TMA and Lane Rental charges

For this specific Method we have assumed that some efficiencies in work management have already been realised during the implementation of current core-and vac practice. For this Method we have assumed a further saving of 0.5% of work management costs from 2021 to reflect the reduced workload in logistics and contract management as core-and-vac excavation grows from around 3,000 per annum to a peak of ~30,000 per annum by 2026. We expect also that the automation of work processes will reduce

[1] "What do Utility Strikes Really Cost?", University of Birmingham, Dept. Civil Engineering, Jan 2016, (EPSRC) iBuild: Infrastructure Business Models

training requirement for operatives, but have not included this in our quantification. (Training efficiencies for operatives are considered in Method 7).

We are targeting that the robotic street works device will reduce TMA and Lane Rental charges by working quicker and with greater consistency to (a) reduce the number of lane rental days incurred in London and Kent (and other schemes as they may arise) by 15%, currently costing £0.6m/year, and (b) reduce the risk of S74 overstay charges (£0.4m) by 10% for permitted works.

Taken together we estimate a net value of £4.36m by 2030 (£24.47m GB-wide) arising from a reduction in indirect costs.

E.4. Details of Method 4 Appraisal

We focus in Method 4 on two important value-creating mechanisms in Method 4 shared by both network users and the wider populace - environmental and social benefits of core-and-vac robotic excavation.

The assessment of benefits over traditional forms of excavation and reinstatement is most mature in North America and Canada where the technology has been deployed (and evaluated) in greater numbers than in the UK. We have made reference to the work of the Gas Technology Institute and Utilicor Technologies Inc[2] in assessing both GHG and NOx reductions from reduced vehicle movements and equipment use.

Social benefits will arise from the implementation of RRES through (i) reduced traffic and pedestrian delays to both business and public users of the highway, and (ii) reduced societal impact of utility strikes. We are confident also that the robotic vehicle will deliver much reduced noise and particulate pollution to the surrounding or passing public.

E.4.1. Environmental Benefits

In comparison to traditional methods, Core-and-Vac delivers an excavation and reinstatement service with many fewer vehicle movements (otherwise needed to transport the various location, mark-out, excavation teams, spoil removal, aggregate delivery). Of course the recycling of spoil and core reinstatement are excellent examples of sustainable practice, effectively valued through the reduced cost of vehicle movements, reduced time in the street, and spoil sent to landfill.

Our reference document has identified a GHG impact of 27kg CO2 for Core-and-Vac versus 165kg CO2 per excavation for traditional methods (i.e. a factor of around 1/6th for the core-and-vac process). If the savings in CO2 of (cement-based) reinstatement materials are included this extends to 31 and 383kg respectively. The same reference identifies relative NOx levels of 1.0 and 0.2 kg. This North American data point was derived comparing a 2' x 4' excavation with core-and-vac, so we have used the figure at face value mindful of potentially differing vehicle fuel economies and excavation sizing

[2] "A cost saving strategy for minimizing pavement restoration costs", GTI and Utilicor Technologies Inc., IGRC Conference 2014.

between the geographies. We have applied this to the marginal excavations in Method 1 and the new market excavations identified in Method 2.

With a probability weighting of 80%, we have identified some 15,000 tCO_2e saving to 2030 (54,000 GB-wide) for the marginal number of excavations and reinstatement conducted by the robotic vehicle. GB-wide this is equivalent to taking over 26,000 new cars off the road for a year.

Importantly for air quality standards the Method also reduces NO_x emissions GB-wide by 400 te by 2030.

E.4.2 Social Benefits

We have made comparison with a delay cost study undertaken by Brighton and Hove Council for the CISBOT[3] robot. This effectively replaces a number of standard excavations with fewer ‘key-hole’ access excavations to perform internal joint repair. Based on a combination of real traffic and pedestrian measurements, and DfT data, for two different roads this reduces average delay costs by around £1674. Of course this number is subject to uncertainty (size of excavations, traffic and pedestrian volumes). Brighton and Hove HA have also used a study conducted by Halcrow for DfT, and reviewed by the Regulatory Policy Institute in 2008[4], to perform a CBA on their road permit scheme. Their study implies a cost per utility works of £4,551 (2017/18 prices). We have then looked at the annual returns from a number of permit schemes (including TfL and Greater Manchester) to deduce an average work duration for utilities of 5 days over a range of works types. This implies a day cost for disruption of £910/day and we have used this figure in our analysis, however the number is not too important as any reasonable figure serves to highlight the enormous social impact of street works. (A study commissioned by ULC Robotics yielded £820/day).

We have also included out to 2032 the social costs of asset strikes, for example in loss of electricity service caused by gas operatives and the ensuing loss of business, and have made recourse to the Birmingham University study[3] to so this. Related mostly to Tier 1 mains replacement, we have estimated the benefit to 2032 of reducing around 50 strikes per annum at £38,400/strike.

The social benefits return some £55m NPV to the UK economy by 2030 (£202m GB-wide).

E.5. Details of Method 5 Appraisal

A second stage of RRS development under NIA determined a shortlist of work operations (beyond joint repair) to guide the early development of RRES. Beyond the basic excavation process, this included (i) fitting of a main repair clamp, (ii) Insertion of

[3] CISBOT – Financial benefits analysis of CISBOT system use on Western Road and King’s Road in Brighton, Swift Argent, May 2017.
[4] RPI, Review of the Regulatory Impact Assessments accompanying the introduction of the Traffic Management Permit Scheme (England) Regulations 2007

camera for internal pipe survey/leak detection, (iii) flow stopping, and (iv) water extraction. Activities (ii) – (iv) are assumed to be facilitated through a Universal Access Fitting (UAF) – itself akin to a repair clamp with an integral throat/valve assembly to provide live access to the main. Our approach to valuing this method therefore is to consider the likely direct cost savings attributable to fitting an equivalent number of repair clamps to cover all the above work activities.

The fitting of clamps is primarily an intervention on CI mains; there will be a residual level of works required post 2032 on completion of the iron mains replacement programme, for example to carry out repairs to T2/T3 mains and PE mains subject to TPI or other failures. In assessing this need, we have reviewed SGN's legacy data on mains failures:

Pipe Tier (IMRRP)	Pipe Fractures		Joint Failures	
	Per annum	Per annum/km	Per annum	Per annum/km
Tier 1	2860	0.38	32,102	4.21
Tier 2+3	207	0.09	12,263	5.58

From this we have constructed an assumed work load for the installation of repair clamps with UAF adaptor:

Work Activity	Units Required Per Annum 2022	Enduring Level Post 2032
Fit repair clamp to main	1,000	300
Install Flow stop	200	20
Conduct camera survey	50	20
Extract water following ingress event	50	20
Total	**1,300**	**360**

Any benefit from joint repair technology is excluded.

The robot is assumed to deliver a 50% reduction in man hours required to undertake this task with the resultant present value of direct savings by 2030 of £0.8m (£3.0m GB-wide) with a probability of success of 80%.

Our initial view is that this relatively low volume of work and would be bought as a service to maintain an economy of scale. The following table shows the NPV sensitivity to service price at licensee level (assuming free issue of the repair clamp itself, and the excavation already in place):

Price Per RRES install of UAF (£)	NPV (£m)		
	2030	2040	2050
25	0.701	0.921	1.073
50	0.571	0.751	0.874
75	0.441	0.580	0.675

This value would be in addition that attributable to the robotic excavation.

E.6. Details of Method 6 Appraisal

In Method 6 we explore the potential benefit of extending robotic automation to pipe and services replacement. In our iCore programme funded under NIA we have demonstrated in the field the successful deployment of in-core directional drilling to 25m (for pipe up to 75mm in diameter) and the fusion of service tees using Long Handled tooling (LHT). Replacement of Tier 1 pipes and related services will continue to be major part of our Totex to 2032, and we have therefore valued this method on the potential direct costs savings on the circa 93,000 service relays and transfers conducted per annum on Tier 1 mains.

Some pipe cutting and surface scraping issues were noted in the trial of LHT and it is assumed that the robot can address this with appropriate development of the digital tooling. Further we restrict or value analysis to the percentage of service pipe relays and transfers not amenable to simple insertion methods (assumed to be 20%), and have targeted a cost reduction of 5% of the average allowable revenue for our Tier 1 population (as the cost allowance for service relays is bundled with the Tier allowances). No emergency-led service relays are included.

Relevant data:

- Total Service relays per annum = 60,000 (2016 annual report)
- Total Service transfers per annum = 33,000 (2016 annual report)
- % addressable by robotic vehicle = 20
- Tier 1 allowed workload to 2032 = 956 km/annum
- Tier 1 allowed mains and associated service costs = £174.3m / annum
- Tier 1 allowance per main/service job = £1,874 (note: approximately 10m of pipe is replaced per service relay/transfer; cost allowances are bundled)
- Target cost efficiency = 5% = £93.70 per service
- (Non-discretionary cost allowance per domestic service not related to mains replacement = £1605/service)

Although we have not included any benefit beyond 2032 in our calculations, we expect the RRES to be deployed in new connections activity beyond this date.

Deployment is assumed from 2022. We consider the deployment in this environment to be challenging from a technical perspective and has assigned a probability of success of 60%.

At this level of activity a fleet of 10 vehicles would be required across SGN if the service connection work could be completed in 1 hour.

Again we consider the pricing of this service bought from a service provider and its impact on NPV at licensee level:

Price Per Service Relay/Transfer (£)	NPV (£m)		
	2030	2040	2050
25	4.384	5.187	5.187
50	2.789	3.300	3.300
75	1.193	1.412	1.412

E.7. Details of Method 7 Appraisal

We believe there would be a small but material indirect cost reduction owing to robotic automation of work activities described in Methods 5 and 6. A number of our asset strikes are due to work activities other than excavation, and we foresee reductions in technical training hours and in equipment capex deployed by our workforce, however these are likely to be smaller than the indirect benefits of the excavation process itself (Method 3).

SGN outsources some 10,460 (non-apprentice) trainee days per annum at an average cost of £112 per trainee day (RIIO-GD1 business plans, 2017/18 prices). We have assumed a net reduction of 10% in these days to reflect the automation of work activities and the consequent reduced need for personnel training.

As per Method 3, we have identified a number of work process-induced utility asset strikes (31 per annum caused mostly by moling and vacuum excavation) and have pro-rated a reduction in this on the relative amounts of planned robotic versus total work activities.

As the robotic service is bought back from specialist contractors, we have assumed a 2% reduction in capital equipment currently required by the manual workforce in repair and replacement activities.

We have constrained benefits arising to 2032 as most of the work activities are associated with the iron mains replacement programme. Taken together these indirect cost saving release value of £1.3m by 2030 (£4.9m GB-wide).

E.8. Details of Method 8 Appraisal

We apply the same logic as Method 4 in assessing the environmental and social benefits of reducing the time of standard work processes of Methods 5 and 6, but take benefit for all (rather than marginal) excavation works as the base case comparator in all cases is hand tool operation. Our work duration saving is aligned to Method 3 in assuming that a typical works (after excavation) might be reduced from 1 to 0.5 days.

We have no benchmark to calculate specific CO_2 savings between manual and robotic work methods - savings will accrue as for excavation through reduced vehicle movements, therefore we have simply taken CO_2 benefits to be conservatively ¼ of those saved through excavation. Our rationale is that 50% of the excavation saving is in reduced cement consumption, and we have assumed a further 50% reduction on the residual figure (giving a work-related saving of 0.09 kg CO_2 per robotic works).

We plan to revisit this when further progress is made with the development programme. Social costs of delay reductions do however include a monetary value for the environmental benefits.

We have also included a small benefit for the relatively few work-related asset strikes (around 3 avoided per annum based on our HSE data) that could conceivably be avoided through robotic methods at this activity level.

As with Method 4, the social benefits to reducing time in the street are very large – NPV of £43m by 2030 (£158m GB-wide). Carbon emission reductions are 11,000 te by 2030 (40,000 te GB-wide), and NOx is reduced by 340 te.

E.9. Details of Method 9 Appraisal

Across SGN we have some 3,125km of steel pipelines transporting gas from NTS offtakes and system entry points to the lower pressure tiers of our network. Operating at pressures between 16 and 72bar (major hazard sites) the pipelines demand higher levels of safety assurance. We carry out a range of excavation works around these assets to inspect/repair pipeline coatings, repair/replace cathodic protection equipment, and refurbish network block valves and associated vent piping.

We identified the following LTS works for our RIIO-GD1 period that require below-ground intervention:

- Refurbish pipelines (16km)
- Refurbish Nitrogen Sleeves (85)
- Refurbish Valves and associated equipment (280)

Our safe working procedures prohibit the use of mechanical excavators within the 'danger zone' of the pipeline defined as encroachment within 0.6m to the perimeter of the pipeline and extending to ground level (and within 1.5m of any fittings).

We have calculated a volume of excavation required under the following conditions as typical of LTS pipeline excavation works:

- Rate of robotic vacuum excavation in danger area around pipe = 4 m3/h (for average soil difficulty)
- Equivalent rate of hand digging = 0.25m3/h
- Depth of cover on pipeline = 1.5m
- Pipeline diameter = 1.0m
- Danger zone clearance = 0.6m

The above give a volume per excavation of 5.5m3/m (net of pipeline volume) and an annual volume of excavation required (2km linear length/year) of 11,031 m3/year.

We have also assumed trials holes (normally hand dig) required: 2 per 50m of pipeline, 4.5m3 each, giving an annual volume of 360m3.

Excavation around equipment is strictly by hand. With a minimum clearance of 1.5 m, this entails up to 10.6 m3 of excavation by hand per intervention, and totalling a further 484 m3/year of hand excavation.

We expect our robotic approach to be sophisticated enough to displace all the above hand excavation (subject to safety risk assurance), giving both a cost and time reduction.

Unlike distribution, where the core-and-vac machines are highly specialised for keyhole application (and undertake several thousand excavations and reinstatement per year from a depot-based centre), at LTS level work volumes are lower, and are geographically dispersed. We have therefore restricted our net value analysis to consider buy-back of the service from a specialised contractor. We have assumed that work volumes are constant out to 2050 (but note they may accelerate as the asset ages further). Further, when performing excavation of equipment pits and trial holes, because the RRES could in theory complete this in less than one full day, we have assumed the system would be effectively deployed elsewhere on an hourly basis.

We have assumed a probability of success of this method of 70% to reflect the difficult challenge of changing industry safe working practices and procedures for LTS pipelines.

The following table shows the sensitivity of NPV at licensee level to the hourly hire rate; implementation is assumed to start in 2021.

Hourly Hire Rate (£/h)	Implied Hire Day Rate (£/8h day)	NPV (£m)		
		2030	2040	2050
200	1,600	9.680	200	1,600
300	2,400	8.066	300	2,400
400	3,200	6.453	400	3,200

Typical 'dumb' vacuum excavator hire rates are £1,100 to £1,500 /day, therefore successful development of the technology for LTS application could support a high premium for the service.

We have not considered savings in reinstatement costs that are more apparent for urban rather than rural settings where spoil can be stored locally with little cost penalty. We have scaled to GB-wide figures using the ratio of total LTS and Storage Capex to that expended by SGN (RIIO-GD1 Final Proposals), giving a scaling ratio of 2.64.

E.10. Details of Method 11 Appraisal

In this Method we give consideration to the likely impact of the wider application of the RRES in adjacent utility sectors, and the potential impact on production volume of the vehicle - and ultimately the unit cost or day rate for the vehicle. We have received wide support for our innovation initiative from representative bodies across the utilities sector, and this gives us some confidence in the materiality of this unit cost argument – however it is subject to uncertainty. It is our intention to pro-actively share learning from this project in the wider utilities space.

We have examined the latest monitoring report on lane rental charges levied by TfL[5] as an indicator of where robotic street works technology might yield biggest benefit and to gauge relative works activity of the various undertakers. Overall the market size for excavation days in the TFL LR Zone for electric, Water, and telecoms utilities combined is 3 times that for gas alone.

[5] TfL Lane Rental Scheme, Monitoring Report April 2015 to March 2016, Version 2.0

Sector	# Works	# Days	Days/Work	Total Charges Recovered (£m)
Water	241	912	3.8	1.501
TfL	165	4,598	27.9	7.615
Telecomms	147	326	2.2	0.460
Electric	135	592	4.4	0.926
Gas	131	997	7.6	1.324
Total/Average	**819**	**7,425**	**9.1**	**11.827**

In broad terms gas and water are similar disruptors (in days) of the TfL LR zone, with Telecomms and Electric being 0.3 and 0.6 in respectively in relative terms. Alternatively, Electric, Water and Telecomms sectors are 2 times larger than Gas in isolation (and ~4 times larger than SGN assuming the TfL are shared between SGN and Cadent Gas – relevant to Method 12).

To estimate the potential impact on SGN Network users we have looked at the value created if unit service rates could be improved between £5 and £15 applied over the volume rates described in Method 1.

Reduction in Service Price Through Wider Application (£/excavation)	NPV (£m)		
	2030	**2040**	**2050**
5	0.616	0.705	0.759
10	1.232	1.411	1.518
15	1.848	2.116	2.277

Our mid-range view is an NPV of £1.2m by 2030 at licensee level (£4.5m GB-wide).

E.11. GB Consumer Benefit

We have used the results of our analysis to calculate the annual benefits to GB gas consumers over the RIIO-GD2 period, assumed to run from 2021/22 for a period of 8 years. Our figures are based on Methods 1,2,3,5,6,7,9,10, and 11 as presented (wider social benefits to consumers Methods 4,8, and 12 are not included in these figures).

Based on an average IQI of 35%, total benefits accruing to GB consumers amount to £26.08m; as a reminder, these are net of any implementation or buy-back services for robotic services.

	2021	2022	2023	2024	2025	2026	2027	2028	Total GD2
Total Target Benefit (£m)	6.331	8.749	9.363	9.926	10.441	10.912	9.881	8.909	74.513
Consumer Share (per IQI) (£m)	2.216	3.062	3.277	3.474	3.655	3.819	3.458	3.118	26.080

Appendix F: CBA Use Case Study Descriptions

F.1. Overview

The following sections demonstrate the operations used in the CBA to enhance the context.

F.2. Comparison of RRES with Traditional Roadworks

F.2.1 - Case (a): Robotic automation of conventional and core-and-vac systems for excavation and reinstatement (Urban)

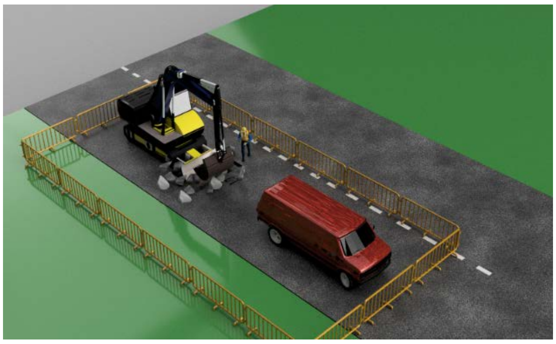
Operation: **Removal of Surface Material**

Description:
Once the area to be excavated has been identified, operatives will carry out a non-intrusive above ground survey to detect all below ground plant in the area. Radio detection and in some cases Ground Penetrating Radar are used, with the results of the survey spray marked onto the road surface to indicate the location of any third party utilities, street light cables, and telecommunications lines.

The street surface and sub structure will then be removed by breaking out the ground using handheld pneumatic breaker guns or in most cases a conventional mechanical digger with a breaker and bucket. Once removed, the material is stored on site for collection.

When compared with the RRES, use of conventional equipment requires a much large site footprint to allow direct access by an operative to the plant being operated on. This process is more disruptive to the public due to the noise, dust, larger site footprint and the time it takes to carry out the operation. The material used must be removed to site for recycling or disposal, significantly increasing the environmental impact of the operation.

Traditional



RRES

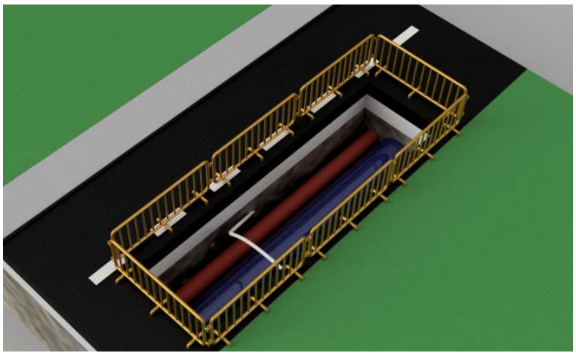
F.2.2 - Case (b): Robotic 'soft-touch' capability to allow wider application of core-and-vac technology (Urban)

Operation: **Soil Excavation**

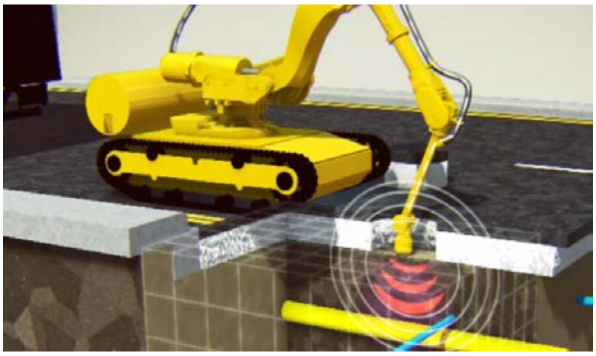
Description:
Conventional excavation, when compared with the RRES, requires a much larger excavation to allow direct access for operatives to carry out repairs or install fittings. Due to the larger excavation footprint and the amount of gas and third party plant exposed within them, the risk of damage is high. If there is too much third party plant in the excavation, the process must be carried out manually by the operatives using hand tools. This process is time consuming, physically taxing and carried out in hazardous environments.

The RRES core removal technique, 'soft-touch' excavation capabilities and automated above ground tooling will significantly reduce the footprint of the excavation and the risk to third party damage.

Traditional



RRES

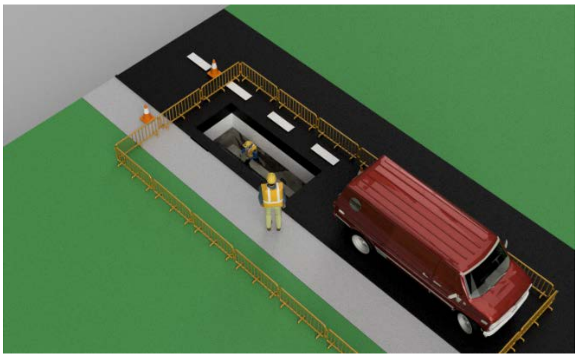


F.2.3 - Case (c): Robotic automation of routine inspection / maintenance / repair work activities (Urban)

Operation: **Inspection, Maintenance and Repair**

Description:
Conventional inspection, maintenance and repair activities requires operatives to enter the excavation, which can be confined and hazardous, to perform operations directly. The RRES removes this requirement, performing the operation from above ground. This reduces the size of the excavation, the duration of the process and the risk to the operative.

Traditional



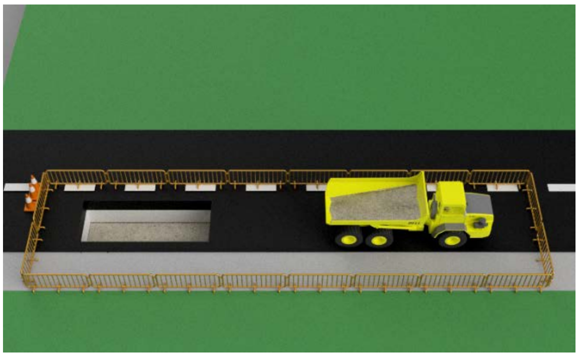
RRES

F.2.4 - Case (a): Robotic automation of conventional and core-and-vac systems for excavation and reinstatement (Urban)

Operation: **Backfilling**

Description:
In the conventional process, new backfill material is brought in to reinstate the carriageway after the works have been completed. Additional plant, such as a dumper or boom truck is needed to drop material into the excavation. On busy urban roads, this increases the overall footprint of the site and the disruption caused by the works.

The RRES will attempt to reuse the same soil that was vacuum excavated prior to completion of works. This reduces the resource requirements, carbon footprint and the duration of the operation.

Traditional	RRES
	

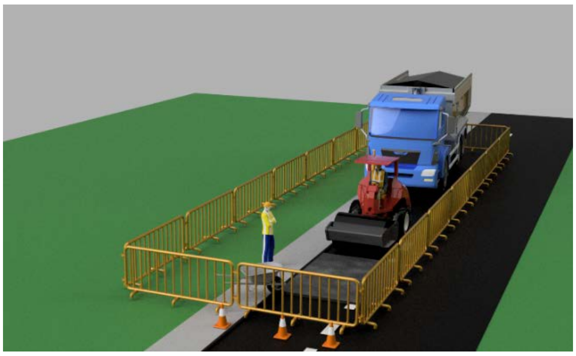
F.2.5 - Case (a): Robotic automation of conventional and core-and-vac systems for excavation and reinstatement (Urban)

Operation: **Reinstatement**

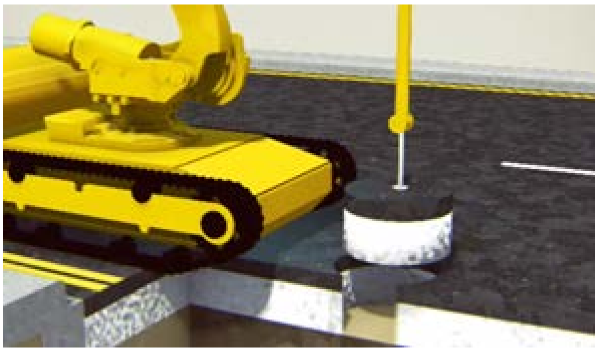
Description:
In a conventional reinstatement process, a new road surface is laid on top of the backfilled material manually. Multiple vehicles are required, as are virgin or recycled materials processed away from site. Once the new surface has been laid, a significant amount of time needs to be left for the tarmac to set before it can take traffic loading. This is often perceived by our customers as a period of nothing happening, with no visible operational work taking place or people on site. Once the new surface material has set, a team will return to site to remove the traffic management and barriers and reopen the carriageway.

In contrast, the RRES can replace the same surface core that was removed at the start of the process. This process is much quicker, allows the carriageway to be reopened quickly and reduces the amount of resources required to carry out the operation. Replacing a core which matches the surrounding surface material exactly also reduces the possibility of any subsidence over time as a result of constant loading from traffic, resulting in ‘potholes’ or uneven road surfaces.

Traditional



RRES



F.3. Comparison of RRES with Core & Vac Roadworks

F.3.1 - Case (a): Robotic automation of conventional and core-and-vac systems for excavation and reinstatement (Urban)

Operation: **Breaking of Surface**

Description:
Core-and-vac technology requires two men to complete the core removal operations, which include manual placement of a heavy cutting drum over the excavation site, and manual cutting and removal of the core. The RRES operations, by contrast does not require any operators to perform manual operations. The work can be completed faster with no risk to the operative as a result of automation of key processes.

Core & Vac

RRES

F.3.2 - Case (b): Robotic 'soft-touch' capability to allow wider application of core-and-vac technology (Urban)

Operation: **Soil Excavation**

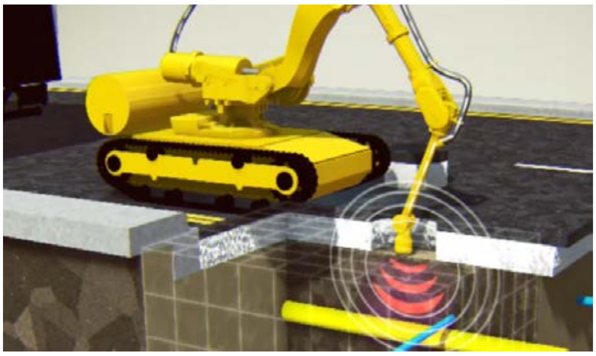
Description:
Once the core has been removed in a core-and-vac process, the ground below it is broken out using an air lance and vacuum hose. Two operators are required to loosen

the soil using an air lance and remove the soil using the vacuum excavator. This process is less labour intensive than conventional excavation techniques, but still requires two operatives to lean over the core and use of tooling.

The RRES soft-touch excavation tool breaks the soil and vacuums it in one operation. It also enables the application of core-and-vac excavation to previously prohibited sites, such as sidewalks.

Core & Vac

RRES



F.3.3 - Case (c): Robotic automation of routine inspection / maintenance / repair work activities (Urban)

Operation: **Inspection, Maintenance and Repair**

Description:

Core-and-vac repair work is completed using long-handled tooling to perform various key tasks required to complete a fitting. Tool heads are interchange above ground and then lowered to the main by an operative standing over a core. Due to length of the long-handed tool and remoteness of the operative from the actual operation this requires a high degree of precision in challenging environments. This becomes more challenging as excavations get deeper or the diameter of the main being worked on increases. The RRES facilitates easier installation and repair work by providing a longer reach and better precision when compared with manned operations.

Core & Vac

RRES

F.3.4 - Case (a): Robotic automation of conventional and core-and-vac systems for excavation and reinstatement (Urban)

Operation: **Backfilling**

Description:
Both current Core & Vac techniques and the RRES make use of the same soil that was vacuum excavated prior to completion of works. In the core-and-vac process, tamping is performed manually, while the RRES automates tamping and validation at intervals throughout backfilling.

Core & Vac

RRES

F.3.5 - Case (a): Robotic automation of conventional and core-and-vac systems for excavation and reinstatement (Urban)

Operation: **Reinstatement**

Description:
In both processes, the core removed at the beginning of the process is replaced. The RRES automates this operation, removing the requirement for manual intervention to position the core.

Core & Vac

RRES

F.4. Comparison of RRES with Traditional Transmission Excavation

SGN carry out circa 100 excavations on high pressure pipelines per year to carry out inspection, maintenance, new connections, diversions or replacement. Unlike distribution infrastructure, transmission pipelines are inspected regularly both internally using intelligent line inspection systems. Any defects identified or areas where the results of the inspection prove inconclusive need to be inspected directly, often requiring multiple excavations.

We have around 600km of unpiggable pipelines for which inspection and maintenance requirements through excavation will increase in the next price control, due to assets exceeding their design life. Note this increase has not yet been forecast and is not included in the CBA.

All available mapping and pipeline records are reviewed to establish the depth of cover and any fittings or attachments on the pipeline. Hazard zones; areas where mechanical excavation is not permitted for use in the immediate area around the pipeline are set to mitigate the risk of damage. The following diagram illustrates the inner and outer hazard zones and the danger zone in relation to a high pressure gas pipeline.

Figure 1: Hazard Zones

Prior to any mechanical excavation works taking place trial holes are excavated by hand to expose the pipeline and confirm its route. Depending on the depth, diameter and environment the pipeline is in, the excavations can be very significant, see photos and require shoring and structural support to allow safe excavation using hand tools. This process can take between a week and a month for particularly deep pipelines. A mechanical excavator cannot be used to excavate or provide mechanical assistance in the danger zone or within 1.5m of any ancillary item such as standpipes or fittings to avoid accidental damage and only then with a permit, which are rarely issued.

Figure 2: A 5½ meter deep £78k trial hole

Once the pipeline has been exposed and it's route confirmed, mechanical excavation is then used to remove material outside of the prescribed danger zone. Even though these controls are in place, damages to high pressure plant still occur with serious consequences to the operatives in the immediate area, risk to supplies and significant loss of gas and repair costs.

F.4.1 - Case (e): Robotic automation of the excavation and reinstatement process for LTS pipelines

Operation: **Trial Holes**

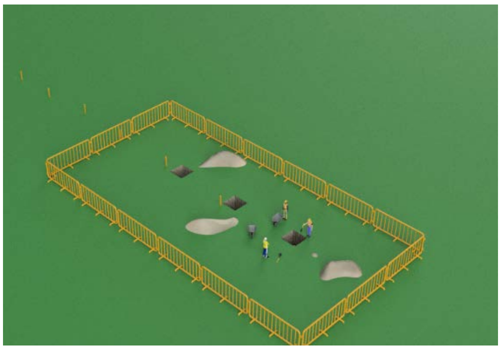
Description:

When excavations are required on high pressure transmission pipelines, detailed working practices are put in place to mitigate the risk of damage. In the conventional process, all available mapping and pipeline records are reviewed to establish the depth of cover and any fittings or attachments on the pipeline. Hazard zones; areas where mechanical excavation is not permitted for use are set until the exact route and depth has been confirmed. The immediate area around the pipeline is classed as the 'Danger Zone', covering a 1.5m area around the pipeline where no mechanical excavation is permitted at any time.

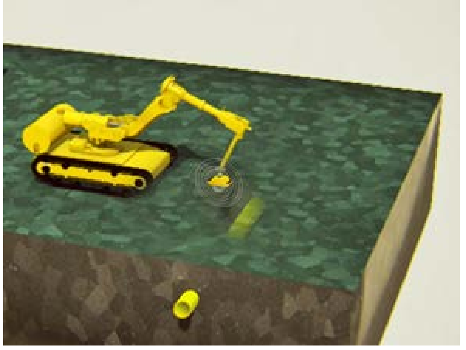
Large trial holes are then dug by hand at several locations along its route to verify the location of the buried asset. Due to the location of these assets normally being in rural areas and the potential impact if damage occurs, they are laid much deeper than distribution mains in urban areas. Depending on the depth of the asset and the type of ground it is in, trench support is often required to protect the operatives carrying out the works as they manually excavate to expose the pipe.

The RRES will automate the excavation of trial holes, utilizing soft touch technology to avoid any potential damage to the plant. This will greatly reduce the time it takes to carry out the operation compared to manual excavation. It is envisage that in time (and with evidential data gathered through continued operation) the case can be made for the RRES to eliminate the need to trial holes all together.

Traditional



RRES



F.4.2- Case (e): Robotic automation of the excavation and reinstatement process for LTS pipelines

Operation: **Excavation of Full Pipe**

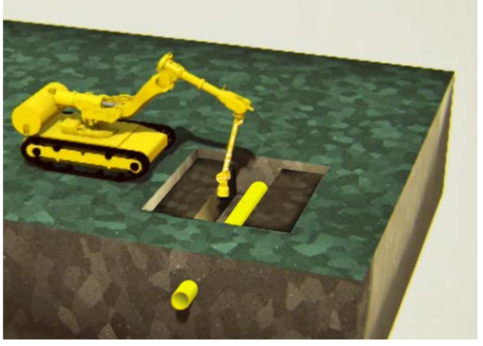
Description:

In the conventional process, the area around the pipe is dug back, allowing access to the pipe for the remaining danger zone to be excavated. The danger zone is then excavated by hand, typically requiring three or four operatives.

The RRES will utilize 'soft-touch' technology and below-ground sensing to automate the excavation of the danger zone. Larger mechanical equipment will then clear the remaining area around the pipe.

Traditional

RRES



F.5 – HAVS Elimination Case

The term HAVS (hand-arm vibration syndrome) is the collective name for a range of injuries caused by hand transmitted vibration. HAVS is caused by regular and prolonged exposure to high levels of vibration resulting in damage to the tissues of the hands and arms.

Symptoms can include:

- Circulatory disorders - blanching of the fingers
- Numbness and tingling in the fingers
- Reduced sense of touch and temperature
- Reduced grip and dexterity
- Joint pain and stiffness in the hand and arm

The Control of Vibration at Work Regulations 2005 requires employers to protect employees from vibration at work. We seek to achieve this by eliminating or controlling the exposure of workers to vibration. Our aim is to prevent any new cases or deterioration of existing cases and currently this is controlled by managed Exposure Action Values and Exposure Limit Values for operatives (see table below). If successful, the RRES system would not only eliminate exposure to HAVS for our operatives, but it will also remove significant downtime due to operative switchover for vibration exposure.

Exposure Action Value (EAV) 100 points - This is the level of daily exposure to vibration for an employee above which we are required to take specific action

Exposure Limit Value (ELV) 400 points - The ELV must not be exceeded by any employee during any given day. If exposure occurs above the ELV, the SGN operational manager must:

Appendix G: Stakeholder Engagement Examples

Appendix H: Letters of Support

We have received letters of support from a broad range organisations who are excited about this potential development and the benefits it will bring to their industries.

Organisation	Industry/Body	Signatory
SP Energy Network	Electricity Distribution	James Yu Future Network Manager
National Grid UK	Gas Transmission	Tamsin Kashap Innovation Manager
Cadent	Gas Distribution	Martin Lord Operations Portfolio Manger
Balfour Beatty	Utility & Civil Contractor	Andrew Edwards Gas & Water Innovation Manager
GISG	Gas Industry Safety Group	Chris Bielby Chairman
NJUG	National Joint Utilities Group	Bob Gallienne Chief Executive
EUA	Energy & Utilities Alliance	Mike Foster CEO
MTC	Manufacturing Technology Centre	Steve Statham Associate Director – Emerging Markets

ofgem

Appendix I: Risk Register and Mitigation Plans

RIIO NIC NETWORK INNOVATION COMPETITION

Definition	Explanation	Probability	Score
Almost Certain	Event is expected to occur	>90%	5
Likely	Event will probably occur	>50-90%	4
Possible	event should occur	>30-50%	3
Unlikely	Event could occur	10-30%	2
Rare	Event may occur	<10%	1

Risk Owner	Reference
SGN	SGN
ULC Robotics	ULC
Technical Service Provider	TSP

Scoring Key		
16-25	10-15	1-9

Ref No	Risk	Business Risk	Inherent Risk Likelihood	Inherent Risk Impact	Inherent Risk Score	Controls & Mitigation	Owner	Anticipated Date for Retiring Risk	Residual Risk Likelihood	Residual Risk Impact	Residual Risk Score
1	**Project Team Resource Requirements** There is a risk that ULC Robotics and SGN will not be able to hire personnel in time for the project start date.	Time Financial	3	3	9	A - Generate requisitions and start hiring as soon as bid is approved. B - A 6-month lag between project award announcement and project start date to allow time for the required resource to be found and appointed before the project starts. C - ULC has a the option of moving resource from other projects or utilise additional resource available at the MTC.	ULC SGN	01/04/2018	1	3	3
2	**Challenges with Single Arm-to-Toolhead Interface** If a single robot arm-to-toolhead interface design cannot accommodate all end effectors due to variations in toolhead size, weight, power, and technical complexity, it may result in increased operational complexity.	Time Financial Technical	3	3	9	A - Development of the preliminary arm-to-toolhead interface specification has been scheduled to accommodate estimated toolhead specifications. B - Design, development, and testing of tools to be reviewed by robotic arm expert for feedback and modification of the design.	ULC TSP	28/05/2019	1	3	3
3	**Limited Below Ground Detection Capability** The sensor suite is unable to detect all buried objects due to varying object types and sizes, sensor capabilities, and depth of excavation additional process may need to be added to the operation of the RRES which could increase the time and cost of the operation.	Technical	3	5	15	A - Soft touch excavation tooling will provide additional safety redundancy to support risk mitigation. B -Initial research has been carried out in early concept phases of the project to identify the sensor types available which meet the current requirments. C - Build a test environment that simulates the variations in the relevant ground conditions and buried infrastructure. D - Consult with sensor vendor and develop additional sensor data processing techniques to improve buried object visualization.	ULC SGN TSP	02/02/2021	1	3	3
4	**Truck Size Exceeds Maximum Size Limit** All of the necessary tools, sensors, mobile drive platform with arm, operator control station, support equipment and other accessories need to be transported to site in a vehicle which maintains a minimal site footprint and comply with UK highway vehicle regulations.	Time Financial Technical	2	5	10	A - Create 3D model of truck with sensors, tools and mobile platform. Develop layout and operator control workstation volume mark out. Determine estimate of size requirements. B - Design modifications to truck to increase storage volume and develop alternate mounting concepts. C - Evaluate low utilization tools, sensors and support equipment and consider transporting them to site only on-demand. D - Review vehicle specification requirements for the target areas of operation and the potential to seperate out support equipment into multiple small vehicles instead of one larger one.	ULC SGN TSP	16/03/2021	1	4	4
5	**Field Trial Location Challenges** Suitable field trial locations for initial controlled testing, urban and rural sites cannot be found.	Time	2	2	4	A - SGN to carry out a review of criteria and identify multiple site locations which could be used for the trial. B - SGN and ULC to survey potential sites to determine suitability well in advance of the trials C - Engagement sessions with local authorities will be carried out in advance of the trial to ensure relevent stakeholders are supportive of the project and trial requirements.	ULC SGN	02/08/2021	1	2	2

Definition	Explanation	Probablility	Score
Almost Certain	Event is expected to occur	>90%	5
Likely	Event will probably occur	>50-90%	4
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Rare	Event may occur	<10%	1

Risk Owner	Reference
SGN	SGN
ULC Robotics	ULC
Technical Service Provider	TSP

Scoring Key		
16-25	10-15	1-9

Ref No	Risk	Business Risk	Inherent Risk			Controls & Mitigation	Owner	Anticipated Date for Retiring Risk	Residual Risk		
			Likelihood	Impact	Score				Likelihood	Impact	Score
6	**A Commercially available Robotic Arm Cannot Meet project Specification** ULC will identify and purchase an commerically available robotic arm to perform the excavation, pipe preparation, and installation of the UAF. If there isn't an arm that can complete all operations for the budgeted value there is a risk to the project budget and scope.	Time Financial	3	4	12	A - Develop the operational strategy, tool specifications and end effector specification early when developing robot arm requirements. B - Consider options for increasing the capabilities by using other strategies such as multiple arms, end-effectors with increased degrees-of-freedom, robot arm support mechanisms to withstand larger loads etc.	ULC	12/05/2020	2	4	8
7	**Sutability of UAF for live gas installation** If the UAF design and installation procedure doesn't meet the required industry standards or performance criteria there is a risk it's use on live gas infastructure will not be approved.	Technical	3	4	12	A - The relevent design and performance specification and designs will be identified and influence the UAF design. B - A test criteria will be agreed and extensive shop testing will be performed using field pipe of various conditions. C - An independent review of the fitting will be carried out and the process for the application of relevent industry approvals will have begun.	ULC SGN TSP	27/10/2020	2	3	6
8	**Use of the RRES does not meet SGN's Safety Management Framework Requirements (SMF)** If SGN does not provide approval for the RRES to operate in a field test due to inability to meet SMF requirements, the RRES design or operation may have to be modified, resulting in increased cost and time.	Financial Technical	3	3	9	A - The SGN Project Steering Group will contain leads from the Engineering Policy, Safety Health & Environment and operations to influence the development process and ensure the design meets all safety requirements. B - Engage with SGN Policy and Safety leads and consult with industry bodies including Ofgem and HSE to ensure all requirements are met. C - SGN will appoint an independent Technical Service Provider with a detailed understanding of industry requirements to review the development process.	ULC SGN TSP	27/04/2021	1	3	3
9	**RRES Usage is Limited Due to Component Compatibility with Hazard Area Requirements** Once the system has been conceptually designed a review will be carried out to assess its suitability for key componets use in all of the target environments. If the specification does not meet the requirements of the review or control measures are required it could cause a delay to the project and additional cost.	Financial Technical	3	5	15	A - Incorporate a safety review process into the design of each component. Develop a checklist for collobarative design reviews with the project team. B - Incorporate a safety risk management program that identifies, assesses and mitigates safety risks. C - An independent review will be carried out by the technical Service Provider at key stages of the project to identify risk as they become apparent.	ULC SGN TSP	11/05/2021	1	5	5
10	**Scope Creep** If agreed system requirements or the agreed project scope changes late in the project the cost and time needed to complete the project could increase.	Financial Technical	2	3	6	A - ULC and SGN collaborate and finalise the specifications. B - SGN will create a Project Steering Group with leads from key areas of the business. The key component specification will be agreed with all members before being finalised to ensure all requirements have been met to mitigate the risk of any changes to the specification being requested later in the development process.	ULC SGN TSP	30/10/2018	1	3	3
11	**Communication between Project Team** Communication channels between the project team who are spread across the UK and USA at different time zones cannot be maintained.	Time Financial	2	4	8	A - Face-to-face meetings for key stage gate deliverables B - Use of virtual meeting centre and secure file share C - Regular interface meetings with the project team	ULC SGN TSP	27/10/2020	1	4	4
12	**Vendor Supply** Sub-contractor manufacturers and supplier delays could affect the overall schedule.	Time Financial	3	4	12	A - Review project plan if required for sourcing sub-contracted vendors B - Engage a number of different suppliers to ensure continuity of supply where possible.	ULC	15/04/2021	2	4	8

Definition	Explanation	Probability	Score
Almost Certain	Event is expected to occur	>90%	5
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Scoring Key		
16-25	10-15	1-9

Ref No	Risk	Business Risk	Inherent Risk			Controls & Mitigation	Owner	Anticipated Date for Retiring Risk	Residual Risk		
			Likelihood	Impact	Score				Likelihood	Impact	Score
13	**Stakeholder Opposition** A negative customer and wider industries perception of the project could cause issues with obtaining the neccssary approvals for access to trial sites and impact wider industry acceptance of the tehcnique.	Reputation	1	4	4	A - Implement and maintain a stakeholder management plan. B - Input from the SGN Regulation and Corporate Communications Officer to ensure high level of engagement with customers as early as possible. C - Presentations at industry events	ULC SGN	02/03/2021	1	4	4
14	**Logistical Challenges** There is a risk that customs and shipping difficulties could delay deployment of the system to the UK from the US.	Time Financial	2	3	6	A - Additional shipping time has been including in the project schedule for shipping and customs. B - Controlled testing faciliates will be identified to allow final preperations works to take place in the geograhical area of SGN's network, allowing the system to be shipped ahead of the live field trial with limited impact on the test schedule.	ULC	15/04/2021	1	3	3
15	**RRES Usage is Limited** If the RRES market uptake is poor, the full value of the RRES as described in the cost-benefit analysis may not be realised.	Financial Reputation	1	4	4	A – Distribute customer and stakeholder questionnaires to ensure that customer needs are being addressed; B – Design robotic tooling, including soft-touch excavation tooling and Universal Access Fitting (UAF) installation tooling, so as to enable operation and commercialisation without the use of a robotic arm; C – Disseminate Interface Control Drawing (ICD) for open-source tooling; D – Continue to seek out project partners in the utilities and industrial sectors	ULC SGN	TBD	1	3	3
16	**RRES Usage is Inefficient** If the RRES utilisation is low, the cost per excavation will continue to increase and the full value of the RRES outlined in the cost-benefit analysis may not be realised.	Financial Reputation	2	4	8	A – Design control algorithms for mobile platform and toolpath generation such that the size and shape of excavations that can be performed is maximised; B – Disseminate Interface Control Drawing (ICD) for open-source tooling so as to maximise the number repair and inspection operations which can be performed on excavated infrastructure;	ULC SGN	TBD	1	3	3
17	**Project Delivery** There is a risk that the project scope cannot be delivered within the allocated budget and schedule	Financial Reputation	2	3	6	A – Use a phased approach to project planning with go/no-go milestones such that the project can be reevaluated upon completion of key milestones and terminated if needed; B – Maintain a prioritised list of potential scope reductions that can be exercised if needed (e.g. elimination of automated tool changing, UAF installation tooling, etc.); C – Pursue funding from alternate sources such as customers in industrial markets or venture capital firms	ULC SGN	TBD	1	3	3

Appendix J: Technical Descriptions and Diagrams

J.1. Descriptions of Primary RRES Technologies

[redacted]

The diagram above illustrates several of the core technologies that will be employed by the RRES. Together, they comprise an advanced robotics system that uses closed-loop feedback control to transform inputs from sensors and cameras into actions performed by end effectors. Below, we provide descriptions of the fundamental principles behind each of these technologies and their specific application to the RRES project.

J.1.1 - Localization and Mapping Sensors

Localization and mapping capability will enable the RRES to visualize its surroundings in 3D space. [redacted]

[redacted]

J.1.2 - Below-Ground Sensors

Four categories of below-ground sensors have been investigated. The categories are based on the technological principle being used to detect below-ground objects. More than one of these technologies are anticipated to be used on the RRES. The final sensor selection will be performed during the course of the project.

[redacted]

A comparison of the technologies is shown below. Since no single technology can detect all buried utilities, a combination of technologies will be used by the RRES and the data from all the sensors will be used to increase the probability and accuracy of locating buried objects during excavation.

Technology	Detection Method	Advantage	Disadvantage
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

J.1.3 - Artificial Intelligence Engine

In the context of the RRES project, artificial intelligence refers to advanced computer algorithms that are utilized to accept various data streams and inputs and determine the actions performed by the robotic arm and associated tooling. These algorithms are collectively entitle the artificial intelligence engine. The diagram below illustrates a notional process for how ULC engineers will perform object detection and environment mapping using inputs from sensors and cameras. Once these operations have been performed, additional algorithms will be employed to articulate the robotic arm, attach, remove and transport end effectors, and to command the movements of the mobile platform. These outputs will be adjusted in real time based on sensor and camera inputs, thus constituting a closed-loop feedback control system.

[redacted]

J.1.5 - Soft-Touch Excavation Tooling

As discussed in the bid key focus and benefit of this project will be the ability to excavate without impacting buried assets. ULC has developed and tested a soft-touch technology in support of the project in order to demonstrate its feasibility. [redacted] This proven architecture will be revisited and optimized under the project.

J.2. Functional Block Diagrams

J.2.1 – Preliminary Electronics Block Diagram

[redacted]

J.2.2 – Preliminary Electronics Block Diagram Description

This diagram has been used as a basis for estimating the time and budget for the project. The diagram and architecture will be refined during requirements generation and conceptual design. [redacted] Below-ground sensing is shown to be comprised of various sensors that will operate in conjunction or sequentially to sense buried utilities. The figure shows a redundant set of sensors that could be used to increase system reliability and increase system accuracy.

[redacted]

The robotic arm module is comprised of the robotic arm and associated motor drivers to enable the operation of end-effectors and grasping and operation of tools. [redacted]

[redacted]

The mobile platform will be remotely operated by the operator in the vehicle. [redacted]

J.2.3 – Preliminary Software Block Diagram

[redacted]

J.2.4 – Preliminary Software Block Diagram Description

This diagram has been used as a basis for estimating the time and budget for the project. The diagram has been laid out as a set of functional tasks that need to be performed by the RRES. During the project requirements and conceptual design phases, the software architecture will be refined to identify the software components and interfaces.

A below-ground sensor software suite will ingest the data from multiple sensors, perform data filtering, data pre-processing and then fuse data from multiple sensors. The fused sensor data provides increased accuracy, resolution and detection probability of obstacles when compared to a single sensor. [redacted]

[redacted]

The Robotic Excavation System is comprised of decision and control software for performing the excavation operations. [redacted] Execution of the tool path is performed.

[redacted]

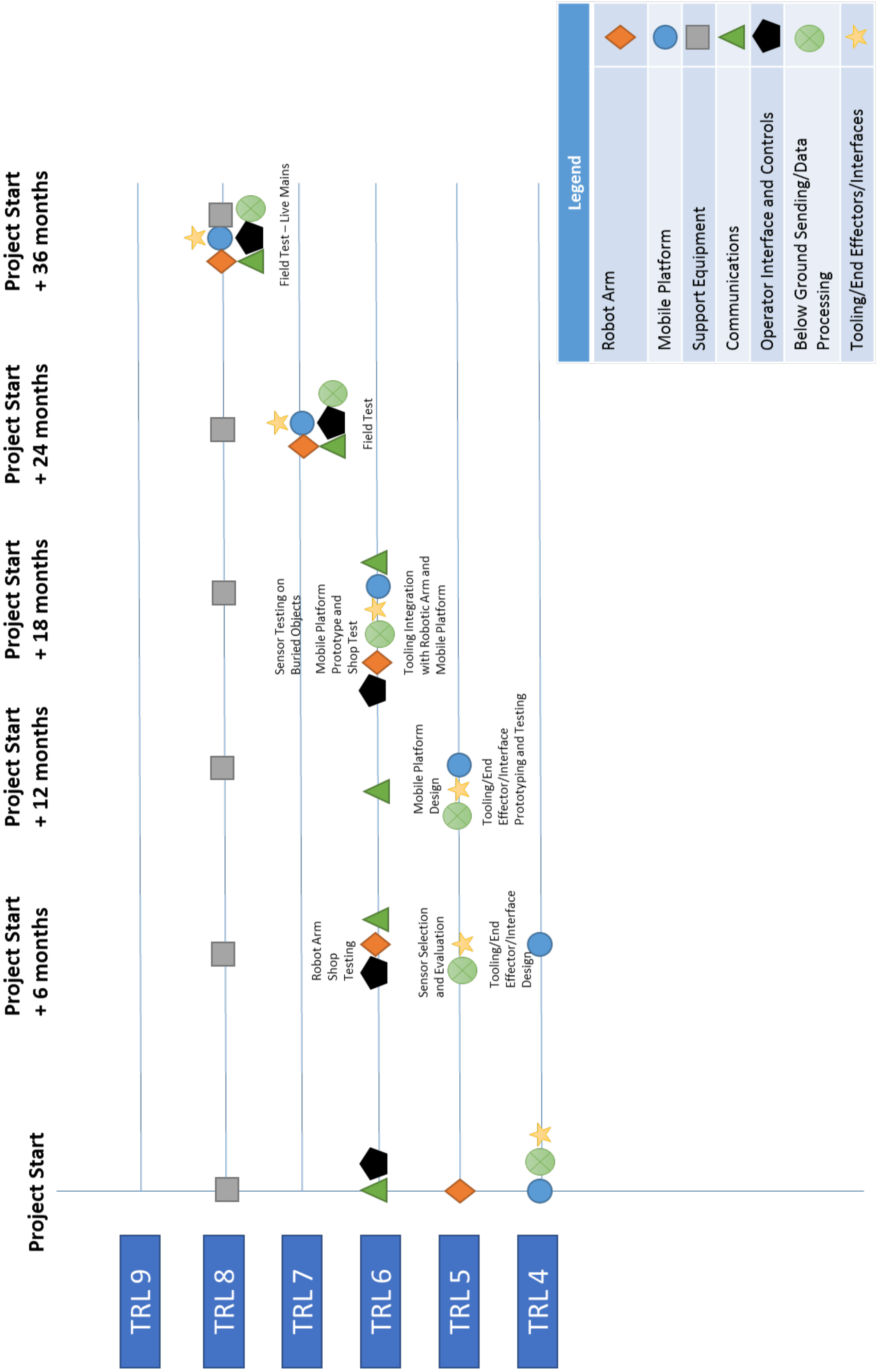
J.2.5 – Preliminary Mechanical Block Diagram

[redacted]

J.2.6 – Preliminary Mechanical Block Diagram Description

This diagram identifies the components needed for RRES operations. The diagram will be revised and updated at the start of the project. [redacted]

Appendix K: TRL Maturation Plan



Appendix L: Knowledge Dissemination Plan

L.1. External Dissemination

Who	What	How	When
Ofgem	- Project Data - Test Results - Project Progress	- Progress reports - Publish information on Ofgem portal - Update meetings - NIC conference - SGN Website	- Progress report every 4-6 months - Comprehensive learning report following project completion - Regular Ofgem portal updates - NIC conference dates tbc
HSE	- Project Data - Sensor Technology - Fit for Purpose Potential	- Progress reports - Update meetings - Offer technical visits	- Engagement with HSE at critical points in the project and as part of regular engagement
Gas Transporters	- Interested in all aspects of the project learning	- NIC Conference - SGN Website - Technical visits - Free demos (TBD)	- Regular updates on SGN website - NIC conference dates tbc - Technical visits tbc
IGEM	- Interested in all aspects of the project learning	- NIC Conference - SGN Website - Journal Paper - Paper evening presentation - Magazine articles - Technical visits	- Presentation at IGEM conference in 2019 - Project results published in IGEM and Network magazine - Technical visit hosted by MTC for IGEM Young persons in 2020
NJUG	- Learning related to transmission and distribution	- NIC conference - SGN Website	- Regular updates on SGN website - NIC conference dates tbc
Local Customers	- Project Progress - Outcome of Project	- Twitter - Facebook - YouTube - Leaflets	- Regular progress updates on Twitter and Facebook - System animation uploaded to SGN YouTube channel - Explanation leaflets used as required to inform customers
Local and National Press	- Project success (if successful)	- Press release	- Upon any successful outcome - System animation uploaded to SGN YouTube channel

L.2. Internal Dissemination

Who (SGN)	What	How	When
Board of Directors	- Project outline - Project results	- Board Presentations - SGN annual report	- Presentation at start & end of project - Project outline in 2018 annual report
Executive	- Project outline - Project progress - Project results	- Executive Presentations - SGN annual report - Progress reports - Site visits	- Presentation at the start, middle & end of the project - Project outline in 2018 annual report - Progress update to be given monthly by Project Director - Site visits to be offered thought Project
Investment Committee	- Project proposal, financial tracking and reporting	- Agenda item	- Monthly update
Innovation Board	- Project results - Change to operating procedures	- Bi-monthly progress - Briefing notes - Presentations	- Briefing notes issued before testing commencement - Presentations throughout the project
Operations Managers	- Project results - Change to operating procedures	- Briefing notes - Presentation at Ops committee	- Briefing notes issued before testing commencement - Presentations at the start and on completion of the project
All employees	- Project outline - Project results - Change to operating procedures	- TeamTalk - Briefing notes - Engineering bulletins - SGN Mail (magazine) - SGNnet (intranet)	- TeamTalks at key stages of the Project - Briefing notes & engineering bulletins to be issued when deemed necessary - Regular updates to SGNnet

ofgem RIIO NIC NETWORK INNOVATION COMPETITION

Appendix M: Payment Milestones

ULC Robotics will receive an up-front payment equal to approximately 10% of the total project budget to cover mobilization costs. ULC Robotics will additionally contribute £200,000 of its own funds at the start of the project. This up-front payment will be applied toward the cost of supplementing existing staff by hiring new staff, building out test environments, acquiring any needed tools and software, and purchasing raw materials and commercial equipment.

During this initial mobilization period, having funds available up-front to apply toward labour costs will allow ULC Robotics to hire additional staff and begin the project in the most effective manner. After the initial start-up of the project, the regular milestone payments proposed should provide steady cash flow to fund the project.

A portion of the material costs has been included up-front so that there will be no delay in purchasing some of the more expensive items required for this project. Some robot components will be highly specialized and may require longer lead times. By having a portion of the material costs available up-front, ULC Robotics will be able to purchase these items without significant delays or cash flow impacts.

	Date	Milestone	Deliverables	Value	Cumulative
1	02/04/2018	Project Start	N/A	£619,978	£619,978
2	15/05/2018	Review system specifications (PD1)	System specification document	£132,960	£752,938
3	12/06/2018	Develop robotic arm specifications	Robotic arm specification document	£132,960	£885,899
4	26/06/2018	Develop excavation tooling specifications	Excavation tooling specification document	£132,960	£1,018,859
5	05/09/2018	Source vendor for robotic arm (PD2)	***Progress Report 1*** – robotic arm research and evaluation	£457,975	£1,476,834
6	30/10/2018	Develop computing system specifications	Computing system specification document	£147,734	£1,624,567
7	14/11/2018	Source vendor for mobile platform (PD3)	Summary of mobile platform research and evaluation	£295,467	£1,920,035
8	26/12/2018	Order commercially available and custom electronic components for RRES onboard computing and communication (PD4)	***Progress Report 2*** – Computing system specification document and documentation of system design	£177,280	£2,097,315
9	08/01/2019	Procure below-ground sensors and cameras for shop testing	Documentation of sensor/camera research	£204,349	£2,301,665
10	05/03/2019	Source and fabricate excavation tooling components	Documentation of excavation tooling mechanical and electrical design	£181,289	£2,482,953
11	25/03/2019	Develop software for excavation tooling	Documentation of software development for excavation tooling	£182,610	£2,665,563

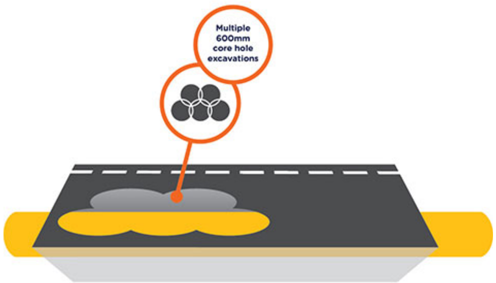
12	02/04/2019	Complete mechanical and electrical design of sensor module	***Progress Report 3*** – Sensor module design documentation	£190,398	£2,855,962
13	28/05/2019	Complete shop testing of prototype excavation tooling (PD5)	Test plan/report on prototype excavation tooling	£190,932	£3,046,894
14	25/06/2019	Perform mobile platform design modifications and testing	Test plan/report on mobile platform	£129,566	£3,176,460
15	09/07/2019	Design and fabricate interfacing hardware and electronics for prototype RRES	Documentation of design and build progress	£120,785	£3,297,245
16	06/08/2019	Complete shop testing of sensors and vision systems (PD6)	***Progress Report 4*** – Test plan/report for individual sensor/camera technologies	£218,793	£3,516,038
17	15/10/2019	Assemble prototype RRES system	Documentation of assembly progress	£103,827	£3,619,866
18	12/11/2019	Develop specifications for mobile platform motion planning and control	Mobile operations specification document	£111,120	£3,730,986
19	26/11/2019	Develop specifications for tool changing method and system	***Progress Report 5*** – Automated tool changing specification document	£151,110	£3,882,095
20	07/01/2020	Develop specifications for UAF tooling	UAF and UAF tooling specification documents	£137,839	£4,019,934
21	04/02/2020	Complete shop testing of below-ground sensing capability (PD7)	Test plan/report for below-ground sensor module	£92,337	£4,112,271
22	18/03/2020	Source components and raw material for automated tool changing system	Design documentation for automated tool changing system	£201,947	£4,314,218
23	31/03/2020	Complete shop testing of prototype RRES	***Progress Report 6*** – Test plan/report for shop testing of prototype RRES	£151,891	£4,466,108
24	26/05/2020	Perform field testing on prototype RRES (PD8)	Test plan/report for interim field testing	£205,289	£4,671,398
25	04/06/2020	Source RRES tether and support vehicle	Design documentation for tether and support vehicle	£267,347	£4,938,744
26	21/07/2020	Design and fabricate reel cart	Design and build documentation for reel cart	£111,646	£5,050,390
27	18/08/2020	Fabricate and test universal access fitting (PD9)	***Progress Report 7*** – Test plan/report for UAF	£162,403	£5,212,793
28	15/09/2020	Design and fabricate operator consoles	Design and build documentation for operator consoles	£91,992	£5,304,785

29	13/10/2020	Assemble full RRES	Documentation of RRES assembly	£167,139	£5,471,925
30	10/11/2020	Complete shop testing of UAF tooling	***Progress Report 8*** – Test plan/report for UAF tooling	£83,375	£5,555,299
31	12/01/2021	Design and fabricate interfaces between vehicle, support equipment and RRES	Design and build documentation for system interfaces	£264,661	£5,819,960
32	29/01/2021	Complete shop testing of full RRES	Test plan/report for shop testing of full RRES	£160,145	£5,980,105
33	26/03/2021	Perform field test of full RRES system (PD10)	***Progress Report 9*** – Test plan/report for final field testing	£219,674	£6,199,779

Appendix N: Relevant Innovation Projects

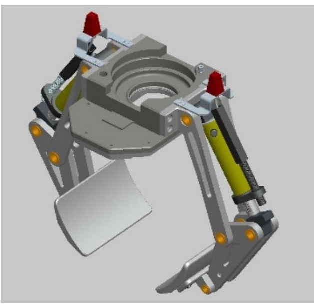
N.1. Olympic Rings

The scope of this project is the testing and development of a potential solution to enable multiple coring within highways to reduce the requirement for conventional excavation, allowing existing equipment to be used within core and vac excavations.



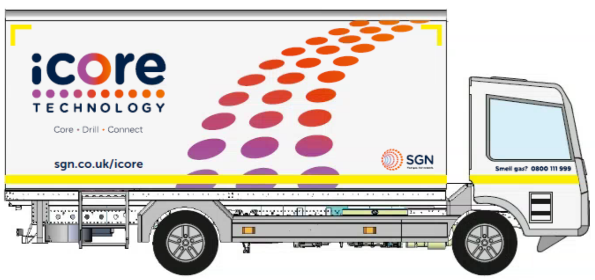
N.2. Core Drilling and Flow Stop

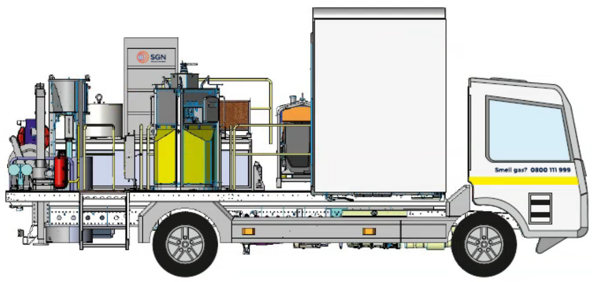
The scope of this project is to support development of equipment to undertake under pressure drilling, tapping and sealing through a 600mm diameter core excavation on 4-12" mains operating up to 2 barg. The second phase of the project will support development of flow stop equipment designed to operate in a 600mm diameter core excavation allowing flow stopping and bypassing of affected mains from 4" to 8 " and operating up to 100mbar.



N.3. iCore

iCore is one of several projects which aim to deliver an end to end keyhole solution for current operational activities such as flowstopping, mains and service replacement and connection works. iCore will provide a one stop keyhole solution, for mains and service replacement activities.





Appendix O: Project Image for Publication Use

Supplied as a separate file for electronic use:

NIC2017_SGN_GN_04_ProjectImageForPublicationUse.png

Appendix P: Full Submission Spreadsheet

Supplied as a separate file for electronic use:

NIC2017_SGN_GN_04_FullSubmissionSpreadsheet_v1

Supplied as an in insert at the back of the hard copy version.