NIC 2018 - RRES

Project Progress Report 1

Element 1

5th September 2018

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SGN©

Co-Authors:

ULC Robotics

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Contents

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1 Executive Summary

The purpose of this document is to report on the first six months of the NIC Robotic Roadworks and Excavation System (RRES) project and the key deliverable due by the next PPR. The report contains a summary of the progress made by SGN, with subsequent reports from ULC Robotic as the principle project partner.

RRES is an innovative and advanced robotic system which will be designed to improve existing methods of excavation, repair and maintenance operations performed daily at SGN and the other GDN's. The objective is to reduce the excavation size, costs, labour and equipment while making the work safer.

The key deliverable to date is the successful delivery of the robotic arm research and evaluation which will permit an appropriate vendor to be sourced. The content of this report and the identified project progress, aligns with the project plan conveyed in the submission.

Notable Achievements to date in the project are:

- Delivery of the System Spec Document is a living document that describes a high-level set of preliminary specifications which will guide the development of the system
- Delivery of the robotic arm specification Document which we define our approach in specifying and selecting the appropriate robotic arm for the RRES is described.
- Delivery of the excavation tooling specification document. The document demonstrates the development efforts that have been carried out at ULC robotics since the beginning of the project to design and build a safe and effective excavation system for the robotic roadworks system.
- Creation of webpage and email address to promote external dissemination

This report has been written in accordance with the NIC guidance document.

2 Background

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

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

The subsystems to be developed under Element 1 have been categorized into three main groups: deployment system, below ground sensing and excavation tooling.

2.1 Deployment System

The deployment system consists of the robotic arm, the mobile platform and the computing system that carries out all robotic operations. To properly identify, develop and specify different components for the system, and to design the most optimal deployment method, preliminary specifications and capabilities required to perform each of the operations have been defined. These specifications will be adjusted based on the new findings from site visits as well as the feedback from SGN.

2.2 Below Ground Sensing

Prior to starting excavation, and during the excavation process, the robot operation will utilize sensors to scan in "layers" to identify buried assets in its excavation path.
To better focus research and development efforts, the sensing operation is broken down into two main categories of sensors. (1) Pre-Excavation Sensing and (2) Post Excavation Sensing

Pre-Excavation Sensors will be used to scan the roadway above the excavation zone prior to cutting the road surface to identify utility lines and other obstructions in the first layer of the work path. Although not a focus, ULC will also review sensors that may be used with the system increase the accuracy of robotic operations in target location.

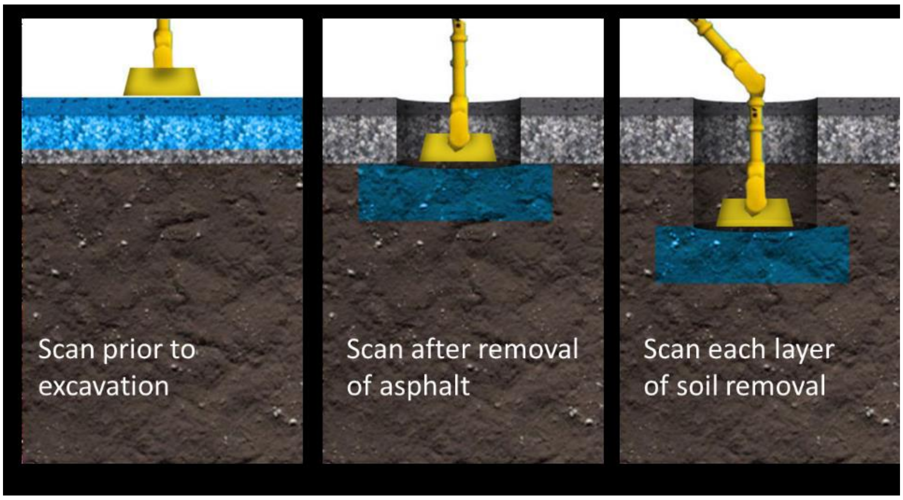


Figure 1 - Below-Ground sensing conducted in layers throughout the excavation process

Post-excavation sensing system can be used after every stage of excavation to create a point cloud and texture model of the bottom of the keyhole. A point cloud is a set of data points which represent points in 3D space and can be used for measurement, navigation and to generate accurate 3D models of environments. Point clouds are generally produced by 3D scanners, which measure a large number of points on the external surfaces of objects around them.

2.3 Excavation Tooling

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.

3 Project Managers Summary

In preparation for the project, key members of ULC's engineering staff were reassigned to support the project and new staff was hired to fill key roles in the project. Additional hiring will be performed throughout the project to support each Element of the work and as specialty equipment/components are identified (Example – Robotic Arm Specialist with experience with the specific arm which is selected). Figure 2 below demonstrates the current organizational chart for the project.

[redacted]

As Explained in section 2 of this report, the subsystems to be developed under Element 1 have been categorized into three main groups: below ground sensing, excavation tooling and deployment system. The following are the progress in each of these categories to date.

3.1 Below Ground Sensing

Below ground sensing will employ ground penetrating radar (GPR), metal detector, EM and acoustic sensor to detect any utilities buried in the shallow depth (1-2 ft). The purpose is to avoid any direct mechanical damage to the utility. To understand the capability and limitation of each technique, a controlled lab environment was needed to test each technique in detecting every single type of utility. Thus, a test box was designed and built in the lab to test the detection of different buried utilities.

After an in-depth literature review and consulting subject matter experts, typical and minimum diameters of different utility lines that the RRES could encounter at an excavation site were identified and listed in Table 1.

Pipe type	Typical diameter	Minimum diameter
Gas pipe (plastic)	75mm, 90mm	20mm
Gas pipe (metal)	4 inch	0.75 inch
Electrical cable	2 inch, no conduit	0.5 inch, 10mm
Telecomm cable/fiber optic	4 inch, w/ conduit	10mm
Water pipe (plastic)	90mm, 75mm Less common: 110mm, 125mm	25mm or 15mm
Water pipe (metal)	4 inch	0.5 inch

Table 1 - Typical and minimum diameters of different utility lines

Based on the utilities identified and listed in table 1 the following 7 different lines were chosen to be buried in the soil box for laboratory testing

1) 4 inch steel pipe (also represents metallic conduit)
2) 75 mm PE pipe (also represents nonmetallic conduit)
3) 1.5 inch electrical cable
4) 0.5 inch steel pipe
5) 15 mm PE pipe
6) 0.5 inch electrical cable/coax cable
7) 0.5 inch fiber optical cable (full dielectric)

The first three represents the typical diameters and the last four represents the minimum diameters of the utilities that the RRES could encounter at an excavation site.

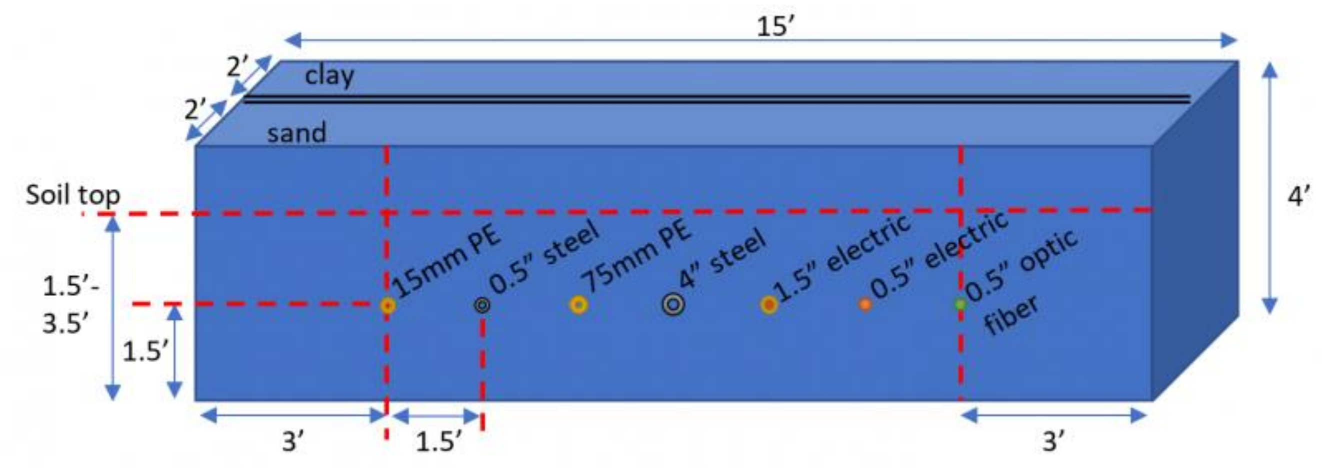


Figure 3 - The designed soil box for testing sensor technologies in the lab

The test box size is 15’x 4’x 4’ as shown in Figure 3. The test box was then further divided into two 15’x 2’x 4’ compartments. The two compartments were filled with construction sand and clay soil respectively. These two soil materials represent two extreme cases for below ground sensing sensor technologies to operate in. The utility lines in the sand and clay compartments were lined up to create a side-by-side comparison between the two soil materials. All the utility lines are 1.5’ above the bottom of the test box to avoid any possible interference from the bottom materials. Additionally, the 3-feet clearance is maintained at the two ends of the longest dimensions. This is to avoid any undesired reflection from the wall of the box when using GPR or acoustic sensors. The utility lines are 1.5’ apart to minimize mixture of signals from two adjacent lines as much as possible. Figure 4 shows the soil box as it was built at ULC robotics.

Figure 4 - The soil box built at ULC robotics for evaluation of sensor technologies

As mentioned earlier, one of the high potential sensor technologies for mapping the utility lines under the ground is Ground Penetrating Radar (GPR). [redacted] All the antennas used in this study are listed in Table 2.

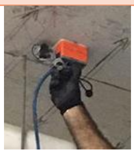
Antenna	Frequency	Depth range	Notes
	350 MHz Digital antenna	0-21 ft (0-7 m)	Tested
	900 MHz Shielded antenna	0-3 ft (0-1m)	Not Tested (cable not available at the time)
	1.6 GHz General purpose concrete antenna	0-18 in (0-50 cm)	Tested
	2.0 GHz Palm antenna	0-12 in (0-40 cm)	Tested
	2.6 GHz High resolution concrete antenna	0-12 in (0-40 cm)	Tested

Table 2 - GPR antennas used for evaluation on the soil box

Figure 5 demonstrates some of the B-Scan results collected from the soil box using the evaluated GPR antennas. In this figure, the buried utility lines show us as gray scale hyperbolas.

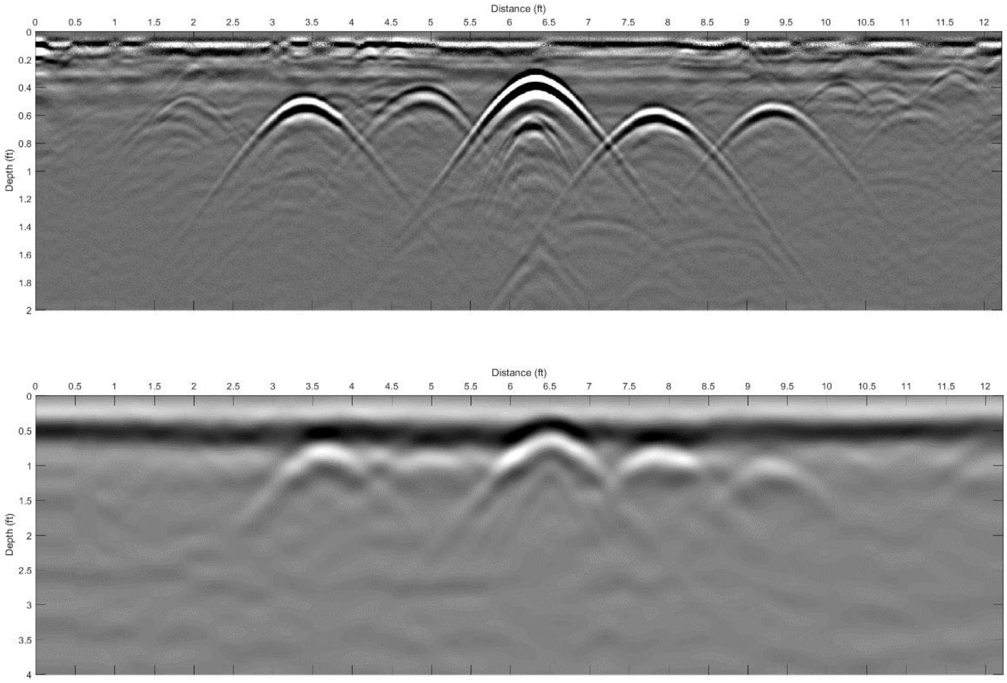


Figure 5 - Sample GPR data collected from the soil box, buried utilities in sand (Top Image), buried utilities in clay (Buttom Image)

[redacted]

[redacted]

3.2 Excavation Tooling

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.

Cutting the Road Surface

The RRES operation is intended to cut the road surface with minimum assistance from the operator. Deployment of the cutting tool using a robotic arm provides a high level of accuracy and precision to the operation. One of the operations on which robot arm specifications are highly dependent is the process of cutting the road surface. ULC robotics has started an in-depth investigation into different techniques that can cut the road surface fast and efficiently, given the specifications of each operation. Below is a list of the techniques considered for cutting the road surface.

1) **Core Drilling** - A core drill is a drill specifically designed to remove a cylinder of material, much like a hole saw. The material left inside the drill bit is referred to as the core. Core drills used for concrete are typically water cooled.
2) **Circular Saw** - A circular saw is a power-saw using a toothed or abrasive disc or blade to cut different materials using a rotary motion spinning around an arbor. Figure 2 demonstrates a circular saw for cutting the road surface.
3) **End Mill Cutting** - An end mill is a type of milling cutter, a cutting tool used in industrial milling applications. It is distinguished from the drill bit in its application, geometry, and manufacture. While a drill bit can only cut in the axial direction, a milling bit can generally cut in all directions. End mills can be used for cutting concrete and road surfaces with high precision and accuracy.
4) **Chain Saw Cutting** - A chainsaw is a portable, mechanical saw which cuts with a set of teeth attached to a rotating chain that runs along a guide bar. A concrete chainsaw is very similar to a regular chainsaw and is used for cutting into blocks of concrete. In a concrete chainsaw, the chain itself contains diamond grit to give it the strength and durability required to cut tough surfaces. The chain is also lubricated with water to overcome the high friction and to wash away the dust.

ULC Robotics has designed and is in the process of building a combination test platform and prototype roadway cutting system. The test platform is designed to accommodate multiple types of cutting heads, and is designed with the rigidity and mechanical capability to drive the cutting heads with adequate force and precision. The system is also designed to take data from the process as it is running, such that the exact requirements for cutting can be determined, and a final production unit can be designed around maximizing capabilities while minimizing weight, system size and cost. The design of this CNC test platform is shown in Figure 6.

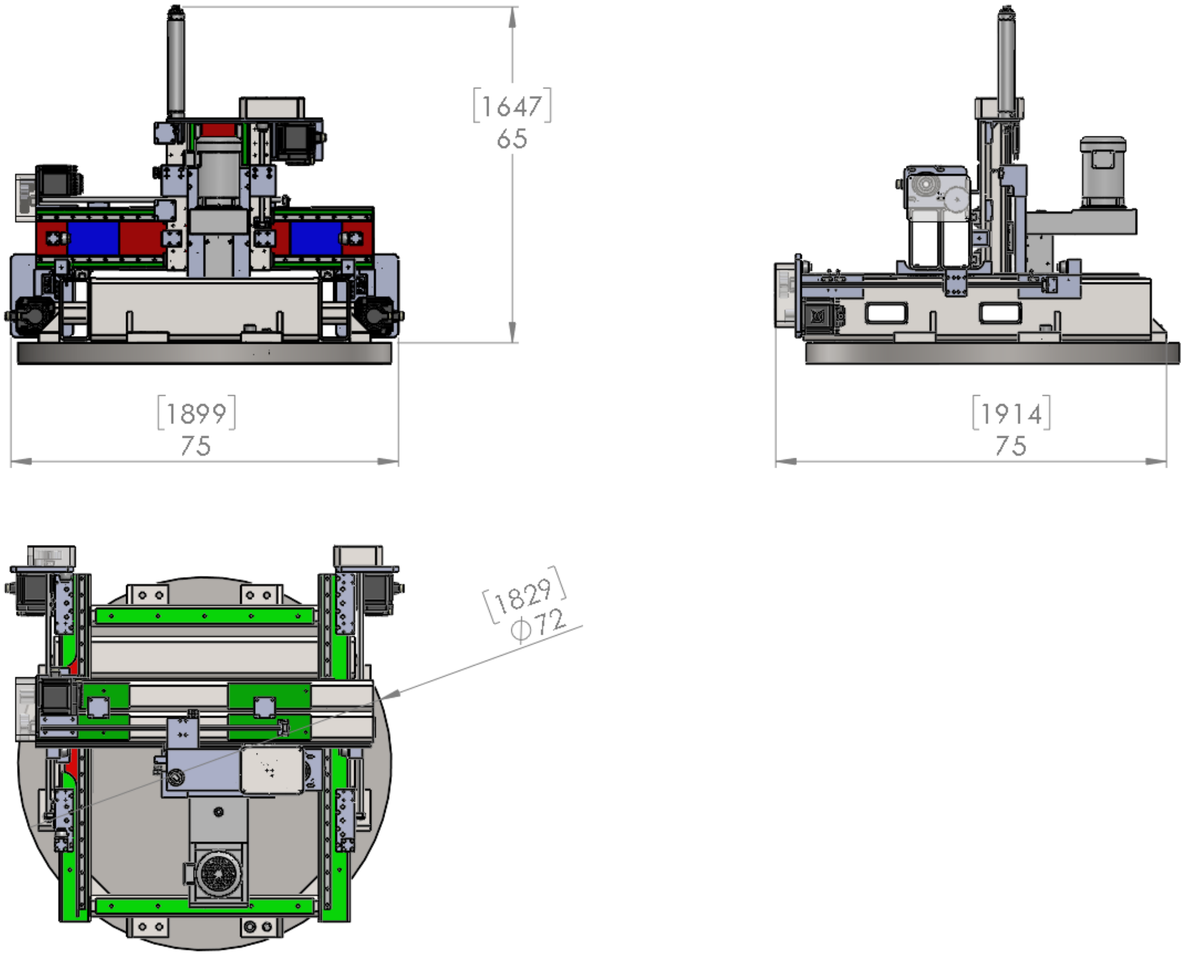


Figure 6 - Design of CNC machine for evaluating different road cutting techniques – Dimensions [mm] in

Design of the CNC equipment was based on the following requirements:

- Working envelope to cut at least a 24” diameter core
- Able to physically and mechanically accommodate any of several different cutting heads (spindle, chainsaw, etc)
- Able to precisely measure forces involved in moving the cutting head as well as the forces for cutting

[redacted]

Testing procedure:

This system will be used to test various cutters, cut methods and strategies for efficiency, productivity quality and safety. Based on the results obtained after thorough testing of many different methods, the system will be refined and incorporated into the RRES suite of tools. This system will likely be reduced in size to match the needs required for the ultimate solution, and mounted on a mobilization platform to position it for operation.

[redacted]

[redacted]

[redacted]

The ideal combination of variables will result in a core cut out that is time competitive with the existing core drilling methods, and contribute as far as improved setup, automation and flexibility.

Soft Touch:

One of the key focus and benefits of this project will be the ability to excavate the ground without causing any damage to the buried assets. 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. This tool, coupled with the ability to sense buried utilities and objects, will enable a redundant safety feature in the excavation operation.

During the second phase of the project, ULC developed and successfully tested a soft-touch technique for removing soil. This technology was developed after extensive research on existing excavation methods such as hydro-vacuum and air lance was conducted, as well as on applications for similar tooling outside of the utility industry, including agricultural soil agitation and paint blending. The findings from this phase of the project created a foundation for further improvements to the soft-touch system as well as the development of more efficient tools for excavation.

Prototype 1 – Proof of Concept

As mentioned earlier, before submission of the bid document, ULC had designed and built a prototype end effector incorporating the soft-touch concept. The goal of this design/prototype build was to develop an end effector which would enable testing of the mechanical function, efficiency, and robustness of the method. In this design, shown in figure 6, a vacuum tube created a path to lift the agitated soil from the excavator's head to a vac machine at the excavation site. A rotary auger, shown in figure 7, was also incorporated in the centre of the vacuum tube to break up the soil and raise it up inside the tube.

Figure 7 - Prototype 1, developed through the second phase of the project to prove the concept of soft-touch

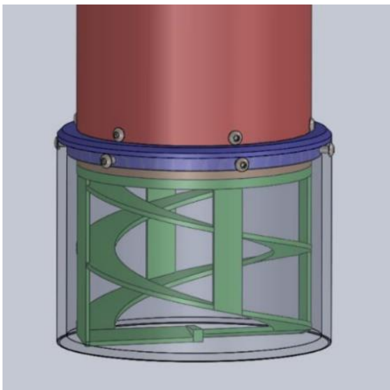


Figure 8 - Design of the rotary auger to break up and raise the soil

Achievements:

- Electromechanical soil lift prototype was designed and built
- Successful excavation without any damage to the buried utility

Lessons Learned:

- Due to the form factor and design of the auger, soil often clogged the auger
- The auger was found ineffective in lifting the agitated soil
- The rotary head was not adequate to break up the soil structure

Prototype 2 – Soil Agitation using Air Nozzles

In order to improve soil agitation during the excavation process, significant modifications were made to the prototype built in the previous phase of the project.

Replacing the auger with a rotary blade

During the tests done with excavation tool prototype-1 at occasions soil clogged up the auger due to the short clearance between the blades of the auger and the edge of the vacuum tube. Also, the spirals design of the auger in prototype-1 would prevent the rocks from getting into the vacuum tube. Since the auger design was not very useful in agitating the soil, ULC designed and built a new rotary blade to replace the auger inside the vacuum tube. This design can be seen in Figure 8.

[redacted]

[redacted]

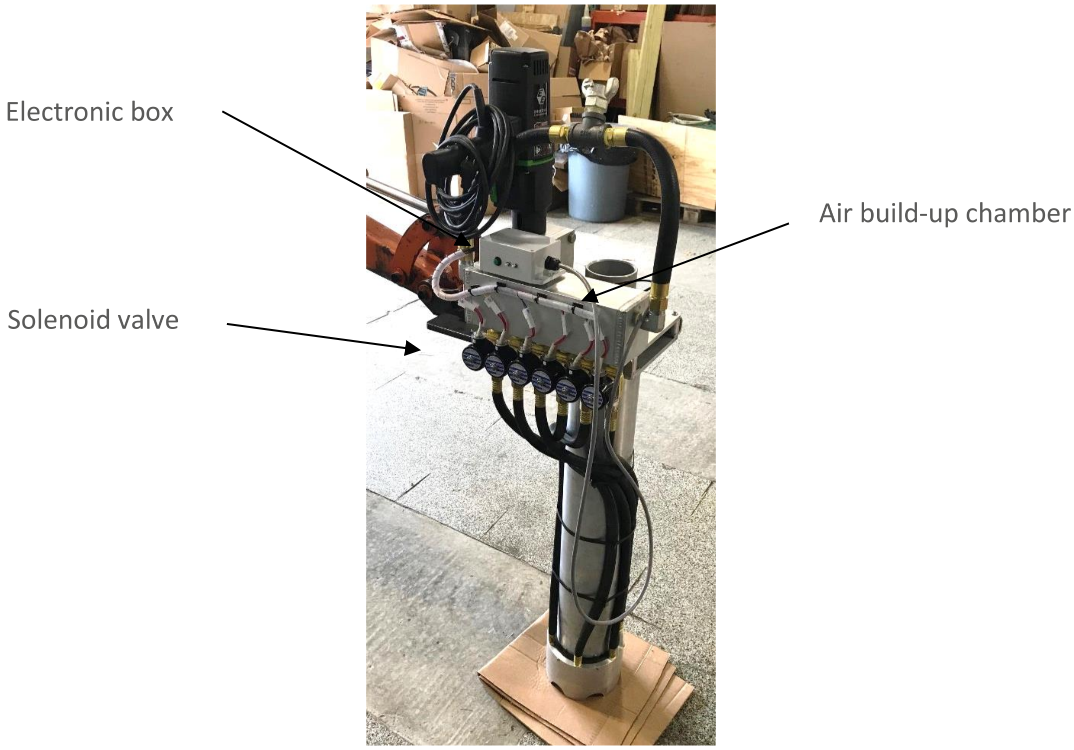


Figure 10 - Prototype 2, excavation tool with integrated air jet system

Achievements:

- The pulsing air jets were very effective in breaking up the soil.

Lessons Learned:

- The rotary blade was not nearly as useful as the air jets in agitating the soil.
- At times, the rotary blade blocked the passage of the rocks to the vacuum tube.
- The vacuum pressure was not strong enough to remove the soil as fast as it was being agitated.

[redacted]

[redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]

[redacted]

- [redacted]

Prototype 4 – Incorporation of Rotary Air Jets

Based on the test results using prototype 2 and 3, ULC decided to completely redesign the excavator. Below is a list of the new features that were considered in the new design:

1) Smaller and Lighter Design
2) Using a 4" diameter tuber from the end effector to the vac truck hose inlet
3) Internal rotary valve system to eliminate the spacious solenoid valves by using a pneumatic motor
4) Air jets facing different directions. By designing an interchangeable nozzle head variations of nozzle directions can be tested

The versatile design of this prototype allows for different excavation settings. Currently, various tests are being conducted using this prototype and the results will be provided in the future reports. Figure 11 demonstrate the design of this prototype.

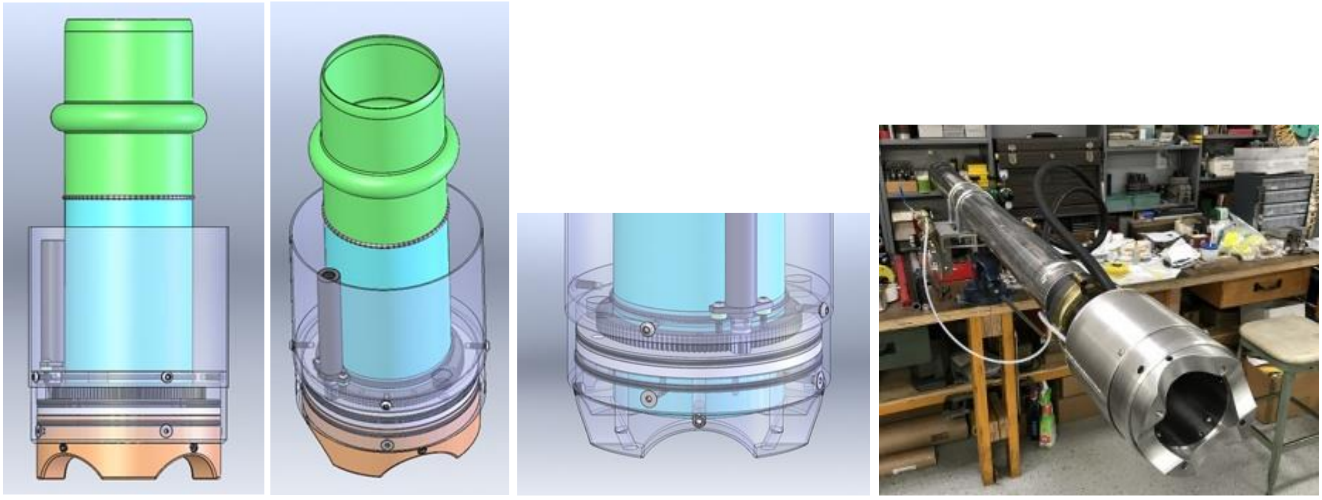


Figure 11 - Prototype 4, Rotary design for switching the air jets

3.3 Robotic Arm

One core element of the Robotic Roadworks and Excavation System (RRES) is the robotic arm which will conduct excavation and operations on buried piping with high precision, repeatability and accuracy. The robotic arm module is comprised of the robotic arm and associated motor drivers which enable the operation of end-effectors, grasping and excavation tooling. The on-board controller is used to distribute, process and translate the main controller commands into local commands in the robot coordinate system. Sensors on the robotic arm will provide data input for path planning and for collision avoidance capabilities.

Both the End-effector and Excavation modules are driven by the robotic arm controller to perform the operations assigned by the main controller (located in the operations vehicle). Various motor drivers will be used to control the various degrees-of-freedom, speeds, feeds, and the precision of the tool motion.

ULC robotics has begun to thoroughly research robotic arm manufacturers and high potential products which may support this project. ULC is currently developing key systems which will inform the final specification of the arm along with the mobile platform and support equipment.

Robotic Arm Operations

The robotic arm is expected to have provisions for interfacing with below-ground sensing equipment, excavation tooling and accessories, an automated tool changing system, and holders or mounting points for other accessories such as cables and tubes. The robotic arm will mount to the mobile platform, which will provide it with motion and stabilization.

The list below represents key items that will be performed by the robotic arm. ULC is currently researching, evaluating and developing end effector tooling and the process for the RRES. This work is being performed in parallel to a global search for robotic arm manufacturers whose technology may fit this project. Final specifications for each key operation will be defined prior to the down-selection and procurement of the robotic arm. Note: Although we have listed key operations below, additional considerations will be made to ensure that all operations required during the excavation process are accounted for during final specification development.

Sensor Deployment and Below Ground Sensing

Once the area to be excavated has been identified, operatives will carry out an above ground survey to detect below ground plant below the selected excavation location. The robot arm can be used to optimize the deployment of sensors at the excavation location to identify and locate the utility lines buried below the target location.

Currently, research and development are being conducted to identify sensing technologies. The final sensor selection, along with the optimal deployment requirements for each sensor (pre-excavation and post-excavation sensing), will define the final force, speed and motion requirements for the robotic arm.

Core Drilling/Cutting Road Surface and Core Removal

The street surface and substructure can be broken using traditional tools such as a keyhole coring saws. The accuracy and repeatability of robotic arms may be utilized to cut the road surface using non-conventional techniques such as end mills. The findings of this research and development effort will support the finalization of the load and torque rating specifications for the arm and the greater robotic operation.

Soil Excavation using the "Soft-Touch" system

ULC is currently developing the excavation tooling end effector for the robotic system. A soft-touch soil-lift excavator, combined with high-efficiency vacuuming, allows the robotic system to excavate rapidly with unprecedented precision and confidence to ensure that buried infrastructure will not be damaged. The results of this development effort will inform the load and torque rating specifications for the arm and the greater robotic operation.

Universal Access Fitting (UAF) Installation

Conventional inspection, maintenance and repair activities require operatives to enter the excavation, which can be confined and hazardous, to perform operations directly on the pipe. Precise motion control provided by a robotic arm may enable the RRES to conduct repair and maintenance activities with improved accuracy to the conventional repair procedures. The development of the UAF will be performed in the second half of the project but considerations relative to the installation method, process and tooling associated with the UAF are being considered at this stage to ensure that the robotic arm selection takes into account the UAF installation operation requirements.

Future Progress

The table below lists the key stages and deliverables for Element 1 until our next progress report:

Milestone	Description	Due Date
Progress Report 1 – robotic arm research and evaluation	Source vendor for robotic arm (PD2)	05/09/2018
Computing system specification document	Develop computing system specifications	30/10/2018
Summary of mobile platform research and evaluation	Source vendor for mobile platform (PD3)	14/11/2018
Progress Report 2 – Computing system specification document and documentation of system design.	Order commercially available and custom electronic components for RRES onboard computing and communication (PD4)	26/12/2018

Table 5 – Summarry of Future Progress until the next PPR

4 Business Case Update

Given the early stage of development of the project, it has not been necessary to make any updates to the business case.

5 Progress against Plan

The project has progressed as the plan completed as per our submission. The Gantt chart shown in figure 11 shows the project plan for Element 1.

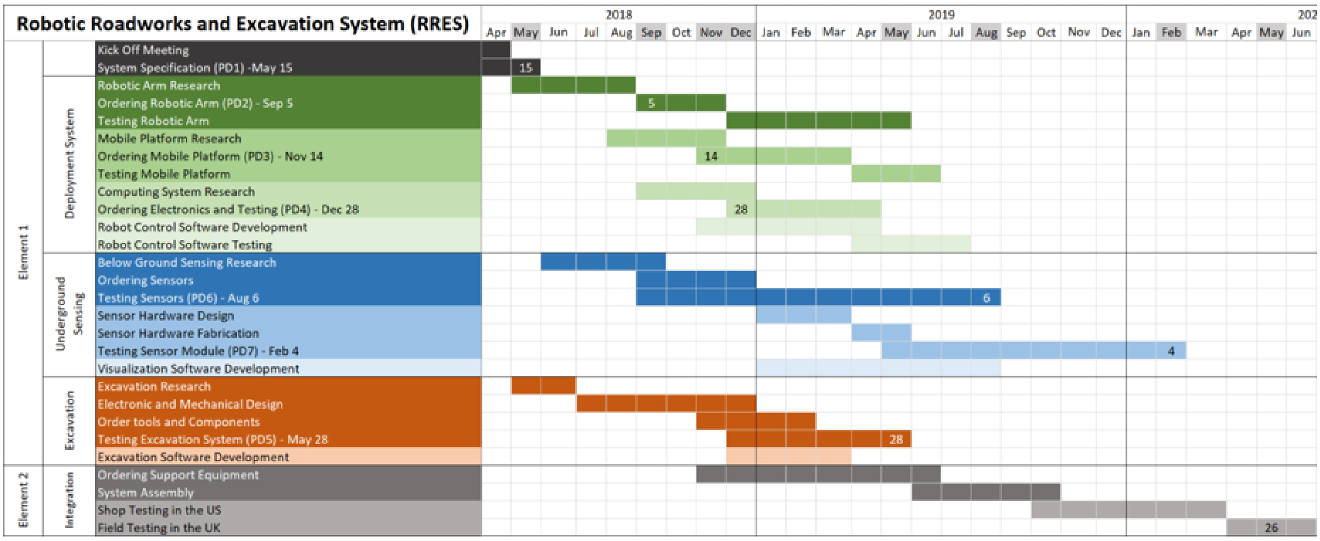


Figure 2 – Project Plan

The key milestones that have been completed and are planned to be delivered next progress report are highlighted below:

Milestone	Title	Description	Planned Date	Delivered Date
1	**Project Start**	Project kick off and mobilization	02/04/2018	02/04/2018
2	**System specification document**	Describes capabilities to be developed under the project	15/05/2018	15/05/2018
3	**Robotic arm specification document**	Documents the performance parameters for robotic arm and resultant implications for integrating arm with sensors and tooling.	12/06/2018	12/06/2018
4	**Excavation tooling specification document**	Documents the high-level set of preliminary specifications that will guide development of the excavation prototype.	26/06/2018	26/06/2018
5	**Progress Report 1 robotic arm research and evaluation**	Suitable vendor selected through a competitive procurement process and purchase order has been submitted	05/09/2018	05/09/2018
6	**Computing system specification document**	Order commercially available and custom electronic components for RRES onboard computing and communication	30/10/2018	*tbc*
7	**Summary of mobile platform research and evaluation**	Procure below-ground sensors and cameras for shop testing	14/11/2018	*tbc*
8	**Progress Report 2 Computing system**	Source and fabricate excavation tooling components	26/12/2018	

	specification document and documentation of system design.			*tbc*

Table 6 – Summary of key stages and deliverables for Element 1

6 Progress against Budget

As the project has progressed as planned and on budget, the total expenditure to date is £1,068,467 with a further £457,975 expected to be processed in the next few days following Milestone 5's approval.

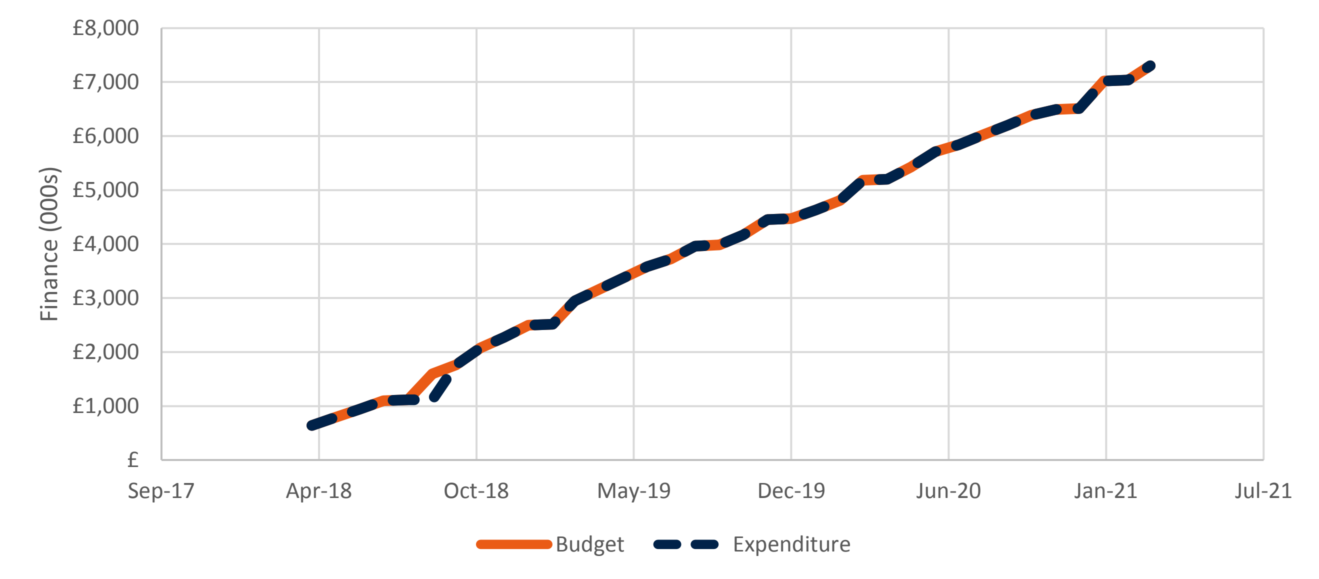


Figure 3 – Planned Budget Versus Actual Expenditure

The key project deliverables are attributed below:

Milestone	Description	Main Project Achievements	Amount	Cumulative	Status
1	**Project Start**	✓ Reallocation of Resources ✓ Hiring and onboarding of new staff ✓ Project kick off and mobilization ✓ System specification development and engineering analysis ✓ Initial review of sensors ✓ Initial review of excavation techniques and tools	619,978	619,978	Paid
2	**System specification document**	✓ Development of a prototype excavator ✓ Integration of air nozzles into the excavator head ✓ Design of a new rotary head for the excavator ✓ Sensor evaluation for below-ground sensing ✓ Sensor evaluation for above ground sensing	132,960	752,938	Paid
3	**Robotic arm specification document**	✓ Site visits in the UK ✓ Build and testing of the new excavator head with air nozzles ✓ Electronics design and fabrication of excavator controller ✓ Design of a test environment for below ground sensing ✓ Evaluation of below ground sensing technologies ✓ Development of a stereo vision technique for depth calculation ✓ Initial review of robotic arm manufacturers ✓ Simulation of robotic operation in Robot Studio	132,960	885,898	Paid

4	**Excavation tooling specification document**	✓ Testing soft-touch excavator head ✓ Review of Vice unit for the project ✓ Engagement with sensor manufacturers for evaluation of their products ✓ Shop testing below ground sensors on the created test environment ✓ Further development of the stereo vision system for distance measurement ✓ Initial investigation into rotary tools for cutting the road surface	132,960	1,018,858	Paid
5	**Progress Report 1 robotic arm research and evaluation**	Source vendor for mobile platform	457,975	1,476,833	In Progress
6	**Computing system specification document**	Order commercially available and custom electronic components for RRES onboard computing and communication	147,734	1,624,567	Planned
7	**Summary of mobile platform research and evaluation**	Procure below-ground sensors and cameras for shop testing	295,467	1,920,034	Planned
8	**Progress Report 2 Computing system specification document and documentation of system design.**	Source and fabricate excavation tooling components	177,280	2,097,314	Planned

Table 7 – Summarry of financial progress

7 Project Bank Account

The statements for the transactions of the bank accounts for the NIC funds over this reporting period can be found in Appendix B.

8 Project Deliverables

3 milestones have been met with one currently being reviewed. The subsequent reports have been submitted to SGN for approval.

Review system specifications Report: The purpose of this "living" document is to describe a high-level set of preliminary specifications which will guide the development of the system. Initially, these specifications will be used to guide and focus the research and preliminary design being performed under each phase of work. Throughout the project, as new learning is acquired regarding the environment, the technology and the system itself, and as SGN and ULC make critical decisions along the way, these specifications will be updated.

Develop robotic arm specifications Report: In this report, we define our approach in specifying and selecting the appropriate robotic arm for the RRES is described. The selection criteria are outlined that will be required for a successful robotic arm manufacturers and high potential products which may support this project.

Develop excavation tooling specifications Report: The purpose of this report is to demonstrate the development efforts that have been carried out at ULC robotics since the beginning of the project to design and build a safe and effective excavation system for the robotic roadworks system. This document also describes a high-level set of preliminary specifications that will guide development of different parts of the project.

9 Data access details

We have created an email box where interested parties can request consumption data gathered. Also, our webpage provides a platform for us to update our stakeholders. Email and webpage links can be seen below:

Email: rres@sgn.co.uk

Webpage: https://www.sgn.co.uk/Innovation/RRES/

10 Learning Outcomes

Substantial research was performed to generate the high-level specifications of the system that will guide the direction of the project.

The robotic arm specification which outlines the performance parameters required for RRES was produced. After the kinematics and dynamic assessment for the robotic arm, we have a greater understanding of the capabilities required of the robotic arm in order for RRES to perform safely and efficienlty.

With the construction of the soil box that wil be used for testing, the performance of the GPR aantennas with varying frequencies were analysed and evaluated with different soil types. This learning is vital as RRES wll require use the soft touch excavation technology on the various environments of the gas network.

11 IPR

Due to the early development stage of the project, no IPR has currently been registered during the reporting period. Concepts and technology which are being developed may create IPR in the future. All relevant IPR will be registered under the project.

12 Risk Management

The updated risk register can be found in Appendix C. Since the start of the projects some of the risks have been reduced or retired. Significant changes in the risks from the submission are explained below:

Risk	Comment/Update
1	Risk Project Team resource requirements – The project commenced with appropriate staff in place. We continue to appoint designated resources to target specific areas of the project. This risk is now retired.
3	Limited below ground detection capability – with research and development being conducted in this area, confidence has grown in the technology to detect all buried objects required as part of the scope. We are still in an early stage however testing has been constructive in detecting the material. Risk score reduced.
6	A commercially available robotic arm cannot meet project specification – market research has been carried out which shows there are a selection of appropriate robotic arms that could be used for RRES that are commercially available. Risk score remains pending further development.

11	Communication between project team – regular progress update meetings and formal reports to document milestones have worked well with communication between partners. Face to face meetings with the ULC project team members is ongoing and periodic. Risk score reduced.

Table 8 – Risk Register

13 Accuracy Assurance Statement

The commercial and technical deliverables associated with this project are progressing on time and within budget. We confirm that we are following relevant SGN process and procedures in order to ensure that the information provided within this report are accurate and complete at the time of writing.

14 Material Change Information

No material change has occurred.

Appendix A - Additional Reports

Milestone reports and presentations are available on request:

- System Specification Document
- Robotic Arm Specification Document
- Excavation Tooling Specification Document

Appendix B - Bank Statements

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Appendix C - Risk Register

Risk Owner	Reference
SGN	SGN
ULC Robotics	ULC
SGN appointed technical Service Provider	TSP

Definition	Explanation	Probability	Score
Almost certain	event is expected to occur in most circumstances	>90%	5
Likely	event will probably occur in most circumstances	50-90%	4
Possible	event should occur at some time	30-50%	3
Unlikely	event could occur at some time	10-30%	2
Rare	event may occur only in exceptional circumstances	<10%	1

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 (DD/MM/YYYY)	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. *SGN have decreased the risk of resources by hiring a designated officer to the project.*	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. C - SGN and ULC to survey potential sites to determine suitability well in advance of the trials B - 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
6	**A Commercially available Robotic Arm Cannot Meet project Specification** ULC will identify and purchase an commercially 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
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	SGN, ULC	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	**Poor RRES Market Uptake** 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	1	4	4	A – Distribute customer and stakeholder questionnaires to ensure that customer needs are being addressed B – Design of soft-touch excavation tooling and below ground sensing systems will be evaluated for use without the use of robotics so as to enable operation and commercialisation without the use of a robotic arm C – Disseminate Interface Control Drawing (ICD) for open-source tooling to enable maximum market size potential through alternative application development D – Continue to seek out project partners in the utilities and industrial sectors	SGN, ULC	TBD	1	3	3
16	**Low RRES Utilisation** 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	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	SGN, ULC	TBD	1	3	3
17	**Project Delivery** There is a risk that the project scope cannot be delivered within the allocated budget and schedule.	Time / Financial	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 - Pursuefunding from alternative sources such as customers in industrial markets or venture capital firms	SGN, ULC	TBD	1	3	3