NIC 2018 - RRES

Project Progress Report 5

26th November 2019

Oliver Machan – NIC RRES Project Manager

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Contents

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1 Executive Summary

The purpose of this document is to report on the progress the project has made since the last submission on the 6th August 2019. The report contains a summary of the progress made from SGN, with subsequent reports from ULC Robotics as the principle project partner. Also, the planned progress and the key milestones to be delivered over the next PPR period is included.

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.

Since the last PPR, we have progressed with the development of RRES' sensing and excavation technology. Below is a list of the major achievements by the development team during this period of the project.

- Building a test site for evaluation of the excavator head
- Design and build of the mock roadway for testing the sensors
- Installation of the robotic arm and development of control algorithms
- Design of the electrical components and power management system for the robot

The content of this report and the identified project progress aligns with the project plan conveyed in the submission although some of the above developments will appear in the preceding PPR following engineering document approval.

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: Excavation, Sensing and Deployment System.

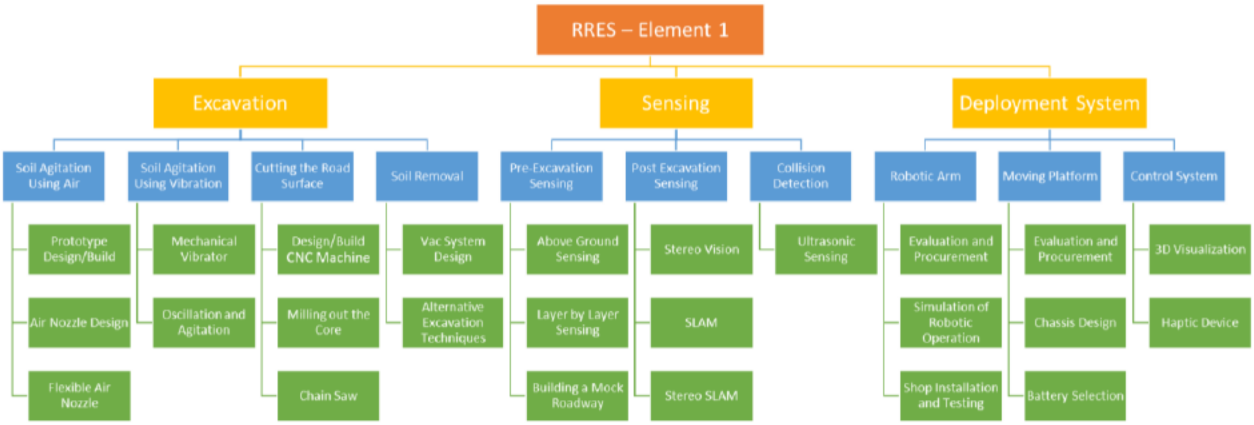

Figure 1 – Element 1 Overview

Excavation

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.

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.

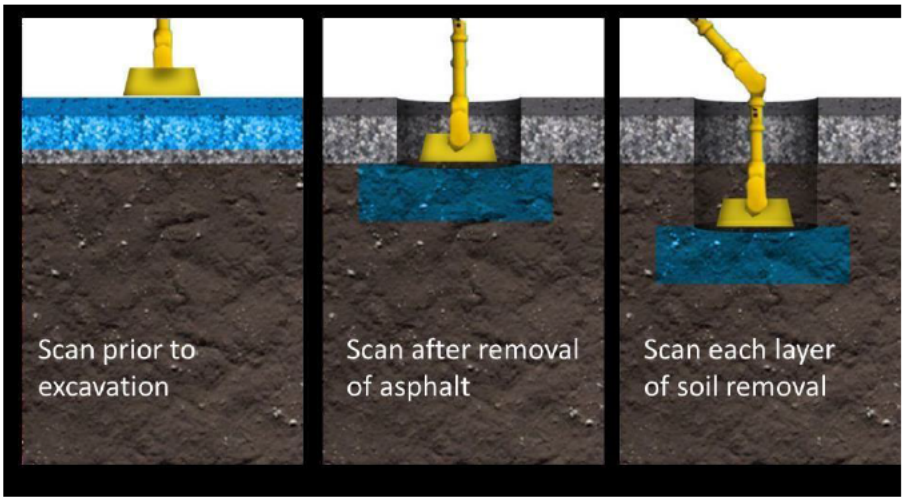

Figure 2 – Below Ground Sensing

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 many points on the external surfaces of objects around them.

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.

3 Project Managers Summary

The project has entered an exciting time where the theory and research conducted during the first stages of the project are being put through extensive testing. The results of these tests are being fed back into the ultimate design. There has been substantial development in the excavation and sensing subsystems along with the electronics and control system systems required to manage them.

3.1 Sensor packages

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. To find the most suitable sensors for the operation high potential sensor technologies were identified, and different products manufactured by different vendors were researched and evaluated by ULC. A detailed report on the findings from this research was submitted on January 8, 2019 “Document on Sensor and Camera Research”. Based on the assessment presented in this report, ULC selected some of the high potential sensors for further testing and evaluation which is now nearing final integration and testing.

3.2 Mock Roadway Recap

To test and evaluate the performance of ground penetrating radar (GPR) and electromagnetic (EM) sensor, two test sites, called “Mock Roadway” from here on, have been built to simulate different underground conditions. Factors taken into consideration include soil type (sand or clay), utility depth, utility size, utility material, and utility orientation.

Mock Roadway 1

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Mock Roadway 2

After a series of tests on Mock Roadway 1 using different underground sensing technologies, ULC had a better understanding of the performance of different technologies. Mock Roadway 2 was then designed and built to further assess the capabilities of the sensors in the detection of buried assets.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

3.3 GPR Sensing – Testing and Results

Sensors will be used to scan the roadway above the excavation zone before cutting the road surface with the goal to identify utility lines and other obstructions in the first layer of the work path. As proposed in the bid document, the excavation will be carried out in layers. After removing each layer of soil, a combination of one or more sensors will be used to gain more accurate information about the presence of obstacles in the path of excavation.

Ground Penetrating Radar Survey Cart

[redacted]

[redacted]

Test Procedure

To scan the entire site, taking Mock Roadway #1 as an example, the GPR cart is pushed in a straight line from one edge of the test site to the opposite one, as shown in Figure 7. This is called a line scan. [redacted]

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3.4 EM Sensing – Testing and Results

As the construction of Mock Roadway 2 has just been completed, the EM tests have only so far been conducted on Mock Roadway #1.

Electromagnetic Sensor Cart with 2D Lidar Positioning

The EM sensor cart is shown in Figure 6(a). The commercial off-the-shelf EM sensor is designed as a handheld device. It only has limited data transfer capability and no automatic control capability. For the stock product, the data acquisition must be done through a series of push-button operations. To eliminate the difficulties of data acquisition, a custom Bluetooth and a servo module was designed and built by ULC and is added to the device to remotely "push" the button using a control laptop. Additionally, the fashion of data acquisition using the EM sensor is the point-by-point measurement.

Obtaining an accurate location of each measurement point is difficult. To solve this problem, a 2D Lidar is mounted on the top of the EM sensor cart. It continuously scans the surroundings and looks for the 4 datum poles at the corners of the site, as shown in Figure 6(b). By calculating the distance from the Lidar to the 4 poles, the location of the cart is determined. The locations of the 4 poles are selected such that the edges of the quadrangle are all different. The four poles are 6-inch PVC pipes. The control laptop communicates with both Lidar and EM sensor and merges their readings into one file such that each EM sensor reading is appended by the coordinates.

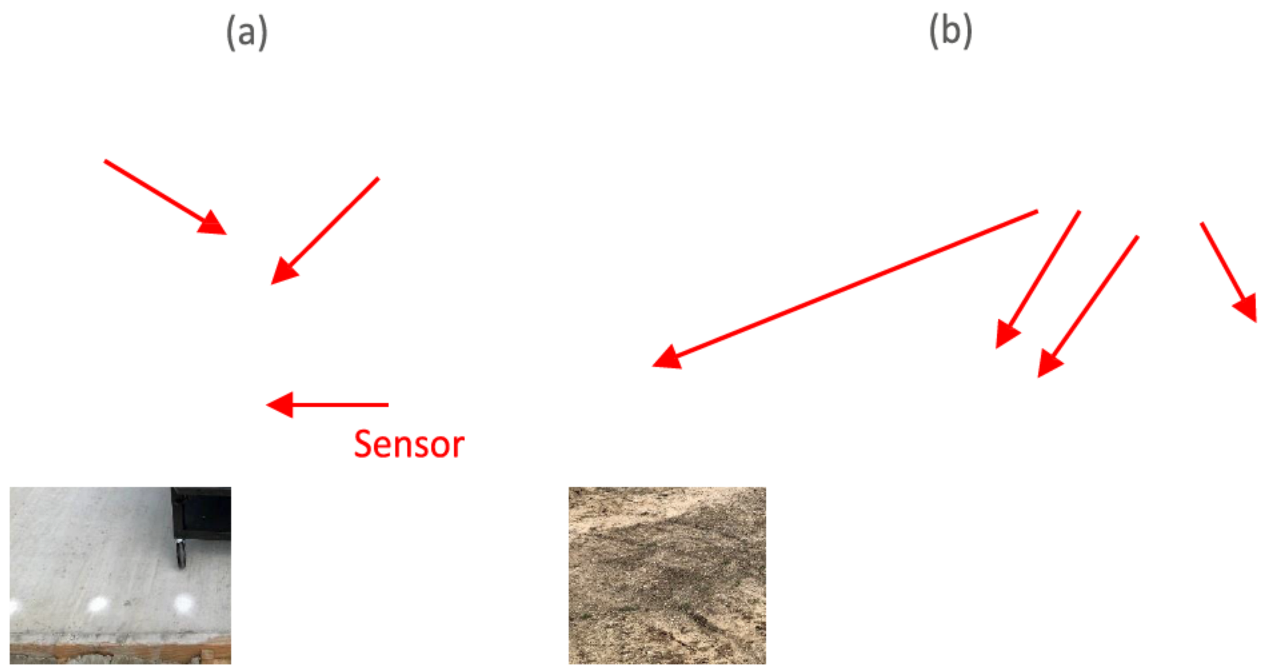

Figure 6. (a) Electromagnetic sensor cart with a 2D Lidar and (b) datum poles for Lidar location

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3.5 Excavation with the Robotic Arm

ULC is conducting research and evaluation into the feasibility of three modes of operation: Manually, Autonomously and Semi-Autonomously. The main goal of the project is to enable the operators to conduct the operation manually first and throughout different development stages increase the autonomy of the operation in the areas that would make sense. At the end of the project, ULC will provide its recommendations on the most suitable ways to conduct the excavation operation. The following is a summary of each of these control modes and the advantages and disadvantages of each.

Since the last update on the design of the electrical and power system for RRES in Jun 2019, ULC has been working on developing the detailed design of the components that the electrical system is composed of. Below is a list of the tasks that were conducted on the electrical and power system:

- Testing and evaluation of battery system performance.
- Testing and evaluation of AC power system performance.
- [redacted]

Testing and Performance of Battery System

The battery system performance testing is underway. The battery system has logged approximately 250 hours of use to date and has undergone many recharge cycles. The testing has consisted of operating the entire robotic system, mobile platform, robot arm, and chainsaw entirely from the system's battery pack. The performance was monitored on the system's power monitor display. The load on the batteries has been variable from minimal load, [redacted]

It was found that the battery system is performing to expectations and has been operating [redacted]

AC Power Systems Testing and Performance

[redacted]

The AC power systems performance was monitored while powering various components of the system, for approximately 250 hours to date, during normal use [redacted] Testing will be performed under higher loads to prove that during further operation cycles that the robot will undergo.

The AC power system has a mains pass-through feature that allows the system to operate from mains voltage while charging the batteries. During charging, and while the mains pass-through system is in use, battery charging current is automatically adjusted to give priority to providing power to the load when limited mains current is available [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]D that was added to the system can output 30kW which is more than adequate to power the chainsaw motor.

Teardown and Rebuild of System

Based on the learning from the evaluation, use, and testing of the current robotic system, enhancements and improvements are being made to the system to prepare it for a reliable and independent deployment to operation sites. To accommodate the desired changes, various parts of the system are being torn down and rebuilt.

[redacted]

[redacted]

Addition of ground-fault circuit interrupters

Ground-fault circuit interrupters (GFCI) were added to the system to improve the safety of the personnel operating the system. A ground-fault circuit interrupter detects leakage of current that does not take the proper return path to the power supply and disconnects the power should such leakage occur. An example of a ground-fault would be if a person were to come in contact with an exposed live electric wire resulting in a path for current to flow through the person to earth. Since current would be flowing to earth, the GFCI would detect that not all of the power is being returned to the power supply and it would immediately disconnect the power to prevent the person from becoming electrocuted. Ground faults can also be created by live electric wires or equipment becoming wet and creating a path for the current through the water.

The GFCIs used in the RRES consists of ground-fault sensors and circuit breakers that are designed so they can function as a typical circuit breaker for overcurrent protection as well as being able to trip, electronically, by a ground-fault sensor to disconnect power should a ground-fault be detected. The use of the combination of the ground-fault sensor and circuit breaker will bring the equipment into compliance with standards UL 1053 for ground fault sensing, for the United States, as well as BS EN 61008, Specification for Residual Current- Operated Circuit Breakers, for the UK and Europe. It also serves as a UL 489 and BS EN 60947-2 circuit breaker for overcurrent protection.

[redacted]

[redacted]

Repackaging of Electronics

The system electronics and power system components are being re-packaged to improve access, robustness, and serviceability.[redacted]

[redacted]

[redacted]

Other Enhancements

Other enhancements that will be included during the reassembly of the system are as follows:

- Re-routing wiring to improve wiring integrity.
- Improvements to cable management and protection of wiring.
- Relocation of operator controls to improve environmental protection of them and to improve ergonomics.
- Continuation of firmware development to add new features and to improve ease of operation based upon operator feedback during testing.

4 Future Progress

The table below lists the key milestones that are planned to be delivered over the next progress period:

Milestone	Description	Due Date
Automated tool changing specification document	Develop specifications for tool changing method and system	26/11/2019
UAF and UAF tooling specification documents	Develop specifications for UAF tooling	07/01/2020
Test plan/report for below-ground sensor module	Complete shop testing of below-ground sensing capability (PD7)	04/02/2020
Design documentation for automated tool changing system	Source components and raw material for automated tool changing system	18/03/2020
Progress Report 6 – Test plan/report for shop testing of prototype RRES	Complete shop testing of prototype RRES	31/03/2020

Table 4 – Planned Milestones over next PPR period

5 Business Case Update

No modifications have been required to the business case which remains valid in its current form.

6 Progress against Plan

The project has progressed as planned. The Gantt chart shown in figure 16 shows the project plan for Element 1 and 2.

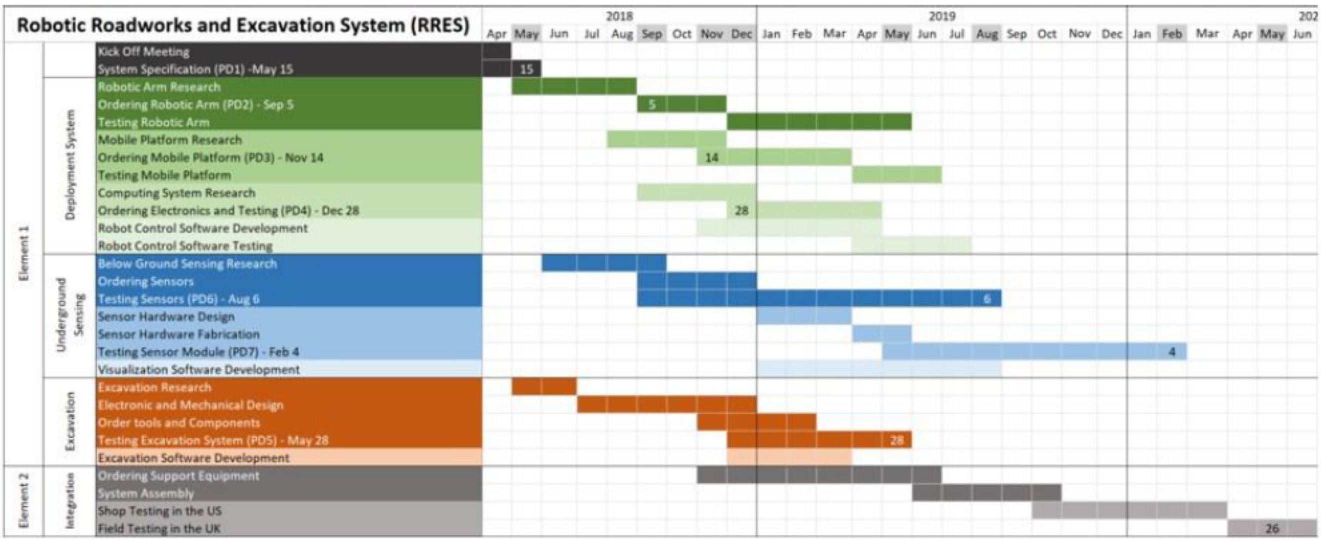


Figure 16 – Project Plan

Below are the milestones that were delivered on time as per this PPR period. Also, the planned millstones over the next progress period have been included:

Milestone	Title	Description	Planned Date	Delivered Date
16	**Progress Report 4** Test plan/report for individual sensor/camera technologies	Complete shop testing of sensors and vision systems	06/08/2019	Approved
17	Documentation of assembly progress	Complete shop testing of prototype excavation tooling	15/10/2019	Approved
18	Mobile operations specification document	Perform mobile platform design modifications and testing	12/11/2019	Awaiting Approval
19	**Progress Report 5** Automated tool changing specification document	Documentation of design and build progress	26/11/2019	Awaiting Approval
20	UAF and UAF tooling specification documents	Develop specifications for UAF tooling	07/01/2020	On Target
21	Test plan/report for below-ground sensor module	Complete shop testing of below-ground sensing capability (PD7)	04/02/2020	On Target
22	Design documentation for automated tool changing system	Source components and raw material for automated tool changing system	18/03/2020	On Target
23	**Progress Report 6** – Test plan/report for shop testing of prototype RRES	Complete shop testing of prototype RRES	31/03/2020	On Target

Table 5 –Delivered Key Milestones

7 Progress against Budget

As the project has progressed as planned, the total expenditure to date is £3,759,572 with a further £262,230 set to be released by the 26/12. The deliverables for the 19th milestone will be reviewed, and payment will be processed once approved.

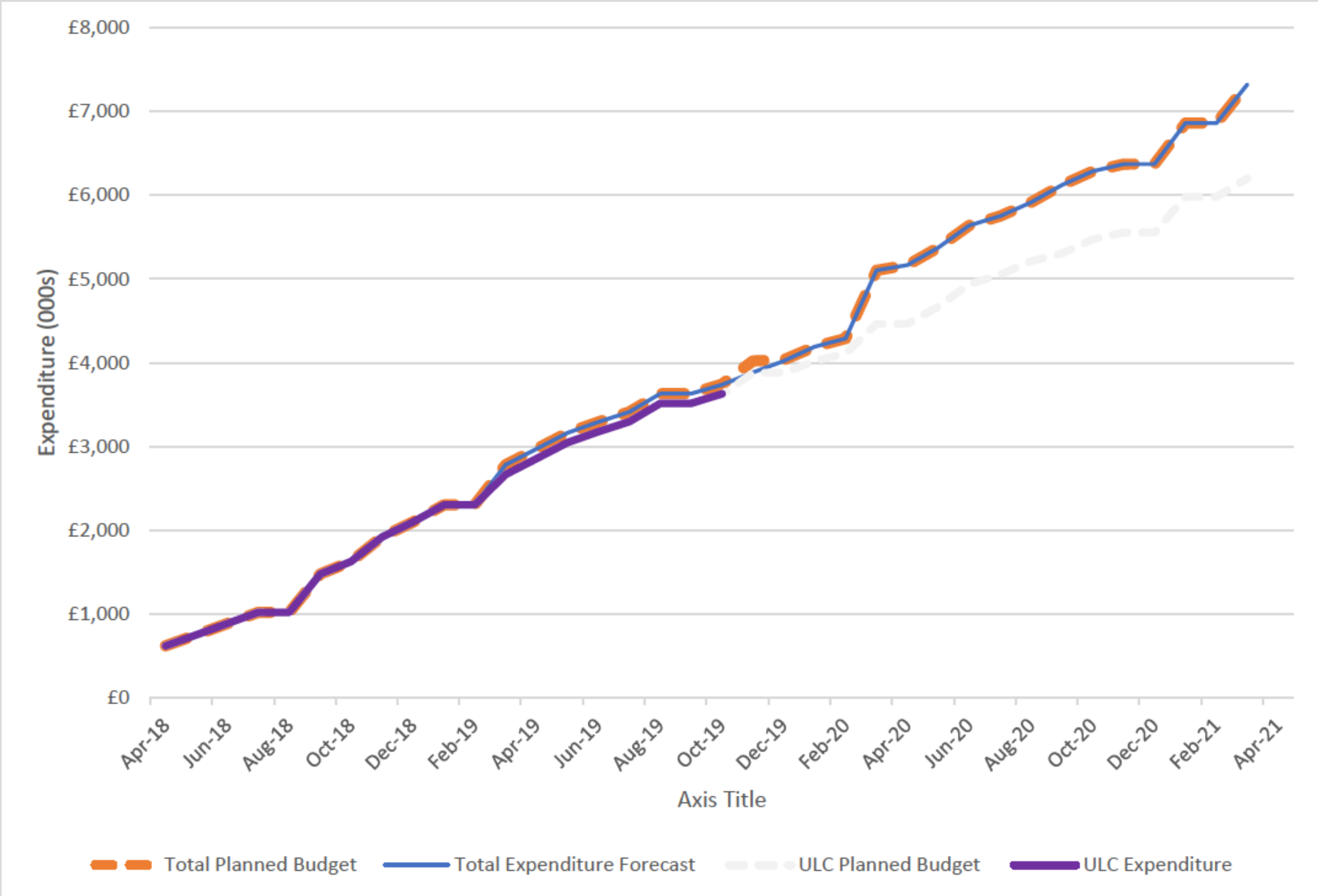


Figure 31 –Financial Overview

The key project deliverables are attributed below:

Milestone	Title	Main Project Achievements	Amount	Project Total	Status
16	Test plan/report for individual sensor/camera technologies	Complete shop testing of sensors and vision systems Installation of the chainsaw on the robotic arm Building the new mock roadway Testing the GPR antennas in the Clay environment Modifications to the excavation operation using the robotic arm	£218,793	£3,516,038	Awaiting approval

		Development of noise filtration techniques to eliminate 3D point cloud noise Engaging MTC in development of cutting bits for the chainsaw			
17	Documentation of assembly progress	Assemble prototype RRES system	£103,827	£3,619,863	On Target
18	Mobile operations specification document	Develop specifications for mobile platform motion planning and control	£111,120	£3,730,983	On Target
PPR5	**Progress Report 5**				
19	Automated tool changing specification document	Develop specifications for tool changing method and system	£151,110	£3,882,093	On Target

Table 6 – Planned Key Project Deliverables

8 Project Bank Account

The statements for the transactions of the bank accounts for the NIC funds over this reporting period are available in appendix B.

9 Project Deliverables

In addition to the milestones completed as per the previous project progress reports, there have been a further 3 milestones delivered. The subsequent reports have been submitted to SGN and are available on request.

Test plan/report for Sensor Technology:

The purpose of this report is to provide an update on the test results that has conducted using the sensors procured for the RRES project.

Documentation of assembly progress:

The purpose of this report is to demonstrate the development efforts that have been carried out to properly design all the components, mechanical and electrical, that the mobile platform consists of as well as the latest update on the fabrication and assembly work.

10 Learning Outcomes

The main outputs of this project are the technical and engineering knowledge gained whilst researching new methods to assess and remediate the existing gas distribution network. Therefore, it is essential that learning opportunities generated by this project are successfully disseminated for GB GDN's, the wider gas community, national and international standard bodies, academia, local authorities and other key stakeholders. Learning will be disseminated so that the technology can be incorporated by all GB GDNs upon successful completion of the project.

At present a large proportion of the design work and specification can't be shared with external parties due to the IPR conditions concerning the design. Dissemination of this information prior to patent approval could jeopardise the commercial aspects of the system, and impact on the financial return to the GB gas consumer and SGN. This has been factored in to the Stakeholder engagement plan, with most key events planned after the expected approval date of the patents. An update on the IPR conditions of the project can be found in section 12 of this report.

We look to engage with external stakeholders and have organised a keynote speaker slot in the upcoming Utility Week Live event that will be held in May 2020. Here Ollie Machan, will present the progress of RRES and as SGN will have a stand there, we will be able to disseminate the learning the project has produced.

Key Learning Outcomes
Cutting the road surface -Our testing has creating substantial learning in determining the performance criteria that impacts cement road surfaces.
Excavator Head - The most effective approach to agitate and excavate the soil was determined.
Pre-Excavation Sensing - Proper rotation of the GPR antenna can improve the detectability of the buried utilities.
Internal Dissemination
RRES update as part of innovation update within our executive monthly report
Steering Group Meeting was held in June with representatives from across the business including; legal, operations, Safety and Policy.
External Dissemination
At Utility Week Live, SGN and ULC had stands where RRES project information was disseminated to the utility industry. Also, RRES was presented as part of the keynote and innovation session.
An update of the progress made by the RRES team was presented at the IGEM AGM for the London Section.
Article in May's Gas International magazine which articulated the collaborative effort behind RRES.
RRES promotional video created by ULC and shared on YouTube

Table 7 – Summary of learning outcomes

11 IPR

In accordance with the Gas network Innovation Competition Governance Document, ULC Robotics will report on intellectual property rights (IPR) being pursued on the project. There is one application outstanding, however as the project progresses, additional filings will be pursued as several key parts of the system are finalised.

Application Type	Description	Application No.	Receipt Date.
US Provisional Patent	GROUND PENETRATING RADAR SYSTEM AND METHOD	62821107	20/03/19

Table 8 – Summary of patents

12 Risk Management

The live risk register that identifies risks and scores them appropriately is attached in appendix C. Notable updates to risk register are shown below:

Challenges with cutting the road surface

There is a risk that the designed chainsaw tool for cutting the road surface cannot cut the core in a timely manner. However, rigorous testing has commenced to understand the criteria that affects the cutting performance. This learning has been integral in the design iterations that have shown vast improvements when we come to retesting. Our plan is to further develop the subsystem with the aid of MTC, and carry out further testing in different environments, before we can retire this risk.

Limited Below Ground Detection Capability

There is a risk that the sensor suite is unable to detect all buried objects. However, our testing has proved the importance to have the antenna's polarity aligned correctly with the utility lines to improve the sensitivity as well as increasing the level of confidence is correct detection. By using a robotic arm, scans with different angles can be conducted very accurately and fast. The probability to miss utility lines is minimized. The sensitivity to lines with arbitrary angle will be increased. The level of confidence in correctly detecting each buried asset is also improved since each line is detected multiple times under different polarizations. More realistic testing is planned to ensure this risk is mitigated.

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

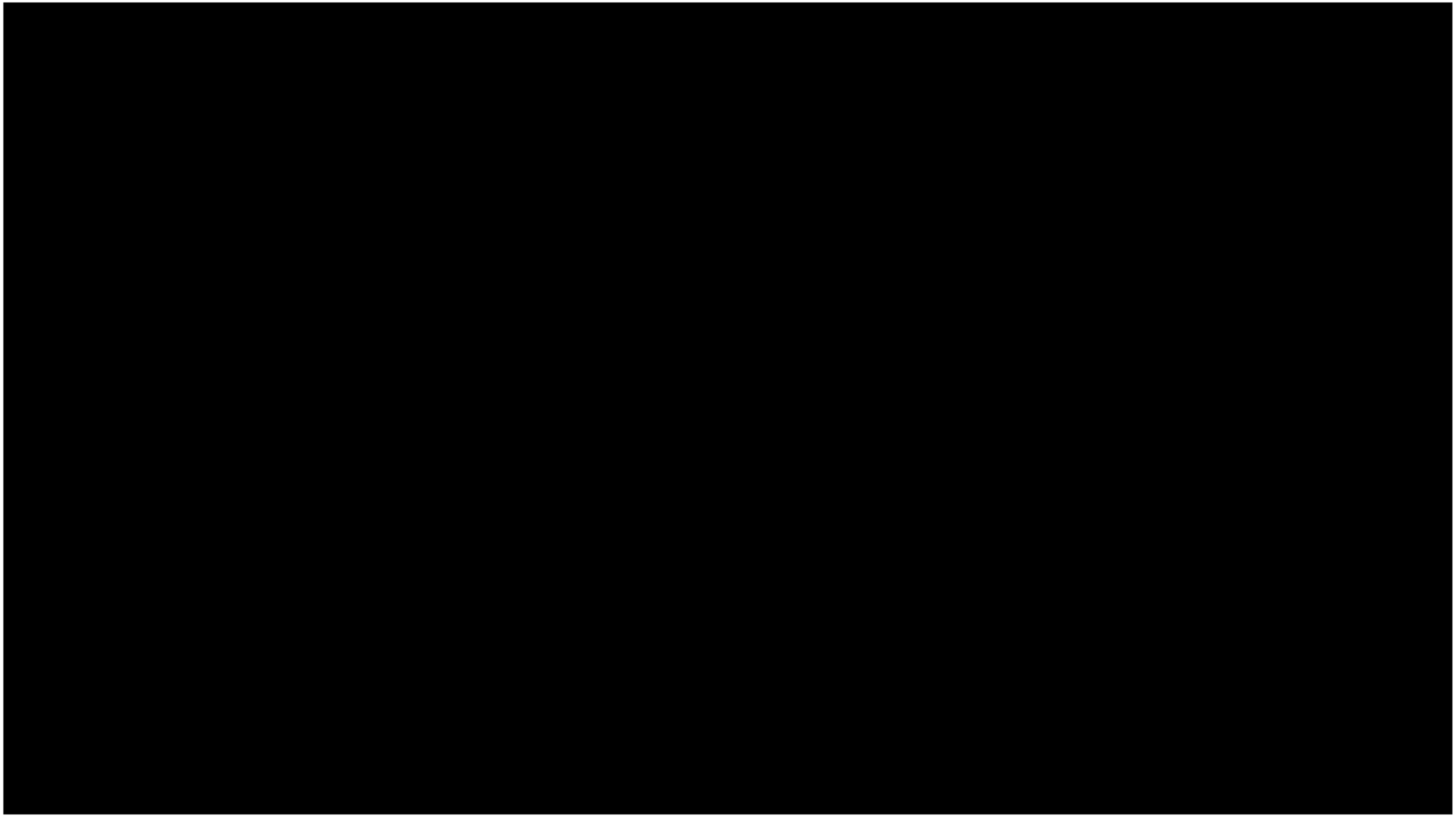
Below are the milestone reports that are available on request:

Report
Test plan/report for individual sensor/camera technologies
Documentation of assembly progress
Mobile operations specification document

Table 9 –Milestone Reports across PPR5

Appendix B - Bank Statements

[redacted]



Appendix C - Risk Register

Ref	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. MTC resource has been aquired for the cutting the core package.*	Time / Financial	1	3	3	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	2	5	10	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 requirements. 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. E - Use a combination of different sensors to increase the level of confidence in accurately detecting the targets	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 separate out support equipment into multiple small vehicles instead of one larger one. E - Decrease the overall weight of the system through design and build optimizations	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 relevant 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	**Suitability 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 infrastructure will not be approved.	Technical	3	4	12	A - The relevant 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 relevant 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 components 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 collaborative 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 center 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 necessary approvals for access to trial sites and impact wider industry acceptance of the technique.	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 facilitates will be identified to allow final preperations works to take place in the geographical 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 - Pursue funding from alternative sources such as customers in industrial markets or venture capital firms	SGN, ULC	TBD	1	3	3
18	**Challenges with cutting the road surface** There is a risk that the designed chainsaw tool for cutting the road surface cannot cut the core in a timely manner. *Rigorous testing has commenced to understand the criteria that affects the cutting performance.*	Time / Financial	2	3	6	A – Design alternative solutions for setting the core such as endmill or a traditional core drill B - Conduct tests in different surface environments with a variety of depths of cut C - Development of different chains and cutting teeth for the chainsaw for operation in different environments D - Engage with tool manufacturers to develop custom made tools for the designed chainsaw	ULC	28/05/2019	1	3	3

Table 10 – Risk Register