performance indicators or Outcome Delivery Incentives (ODI's) to monitor United Utilities delivery of these objectives. Many of the ODI's have revenue implications associated with them, meaning additional revenue can be received for overperformance and provided back to customers for underperformance. ODI's for the wastewater network include numbers of internal and external flooding events, the number of pollution incidents and the occurrences of both blockages and collapses. ODI targets are agreed upon as part of the five-year business planning cycle and will look to balance the cost, risk and performance in a manner that best meets the needs of customers. Given the undesirable nature of the wastewater event ODI, there is an understandable desire by customers to reduce their occurrence.

United Utilities's business plan determination from OFWAT for the period between 2020 and 2025 contained the following performance commitments, based on 2017/18 actual performance levels:

- 11% reduction in sewer blockages by 2024-25.
- 22% reduction in external sewer flooding incidents by 2024-25
- 20% reduction in pollution incidents by 2024-25
- 73% reduction in internal sewer flooding incidents by 2024-25

The challenge for United Utilities to deliver these performance targets is further complicated by several headwinds including climate change, sewer misuse and the need to keep customer bills affordable through ongoing efficiencies.

3. INNOVATION LAB

United Utilities recognises that if you do today, what you did yesterday, then the outcome will likely be the same. Therefore, innovation has been a core value at United Utilities for many years with the objective to make services better, safer, faster, and cheaper for customers. The company's Innovation Strategy (Utiliites, n.d.) is multifaceted and one element is a process to engage with early-stage innovation start-ups. Establishing the water industry's first 'Innovation Lab' provided the mechanism for the United Utilities to present customer challenges and allows for the submission of ideas from across the world. The lab process enables the selection of the most promising ideas which provides the successful suppliers with live operational environments to learn and develop, plus access to a diverse network of external mentors to provide practical guidance. Each Lab typically lasts for a period of 10 weeks and afterwards United Utilities can further develop the most promising ideas by establishing supply agreements.

The first Innovation Lab commenced in 2017 and the second Lab in 2019 received 82 applications to tackle five challenges that included; 'Right Information, Right Place Right Time'; 'Empowered and Knowledgeable Colleagues'; 'Connected Customer'; and the catch-all 'future of water'. Eight organisations were successful and selected to join the Lab at Innovation Centre in Warrington. One of the successful organisations was VAPAR, which was founded in 2018 by two Australian engineers. The idea for VAPAR came about when one of the engineers was required to watch and code pipe inspection CCTV footage as part of her job. The reciting of this sometimes 'painful' experience to her longtime robotics engineering friend led to the realisation that Artificial Intelligence (AI) technology now existed to automate the manual coding process. VAPAR was formed with the intention of using AI to speed up the repairs of pipes by automating the fault detection from inspection footage.

4. CONCEPT

The concept of AI is not new and is based on levering computers and machines to mimic the problem-solving and decision-making capabilities of humans. The process uses Neural Networks or Deep Learning algorithms that take the form of inputs and outputs, with multiple layers of decision-making between the two. This process is described in Figure 1 below (IBM, 2020). There are multiple applications of Deep Learning ranging from speech recognition (E.g. Siri) to recommendation engines (e.g. e-commerce checkout recommendations). This application is based on Computer Vision technology that enables computers to derive meaningful information from digital images and then use the information to take action. Recently the market has been valued at £48.6 billion and examples of its application include Autonomous Vehicles, Healthcare, Agriculture and Manufacturing (Marr, 2019).

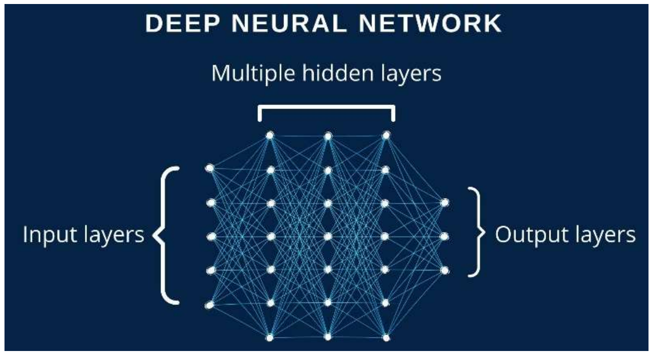

Figure 1. Neural Networks or Deep Learning algorithms take the form of inputs and outputs, with multiple layers of decision-making between the two.

VAPAR application of Deep Learning and Computer Vision to automate the processing of pipe inspection footage is based on the following patent-pending (Wipo IP Portal, 2021) approach:

1. Labelling: The process starts with the creation of a labelled dataset that is used to train and test the AI. The labelling design is critical to ensure the accuracy of the AI and allow the outputs to align with different pipe inspection standards used across the world.

2. AI Training: The labelled dataset is used to train the AI and this is predominantly an automated process that relies on the quality of the input data. However, the training is a complex process given the need to predict over 700 possible defects to ensure alignment with the pipe inspection standards.

3. AI Deployment: The trained AI model is deployed using the latest cloud technology and allows the user to upload just the inspection footage and receive back a coded report from the AI that identifies the asset from the information included on the footage title screen.

4. Human Review: The AI outputs still require review by a human due to the complexity of pipe inspections making it impossible to identify 100% of the pipe characteristics accurately, 100% of the time. This 'Collaborative Intelligence' (Wilson, 2018) approach is known to deliver significant performance improvement and, in this case, leads to an accurately coded report being generated with one to five minutes of human input. A large proportion of VAPAR's development resources are focused on optimizing the 'Collaborative Intelligence' model to minimise the level of human input and ensuring the outputs are trusted for investment decision-making purposes.

4. EVOLVING CAPABILITY

VAPAR successfully completed the Innovation Lab in December 2019 and the experience generated the following insights associated with using AI for pipe inspection fault detection:

1. Size of the market opportunity: over 200 people within United Utilities were using the CCTV footage as part of their day-to-day work.

2. Standards alignment: Any solution would need to align with the local standard for CCTV pipe inspection and in this case, that is WRc's Manual of Sewer Condition Classification and Sewer Risk Manual.

3. Need an accurate output: The outputs need to be accurate for operational purposes due to false-negative results leading to preventable internal flooding or pollution event.

4. AI Computer Vision technology can be used to detect faults and other characteristics within storm and wastewater pipes.

The success of the Innovation Lab led to a supply agreement being established to allow further testing and evolutions of VAPAR's service offering. The first pilot was completed in 2021 and focused on evolving the accuracy of the AI capability. Additional data was made available by United Utilities and VAPAR's Australian clients to increase both the volume and complexity of the training and testing dataset. An agile development process was utilised where the AI training process was completed each month and the feedback from the training process was used to modify the labelling. The accuracy of the AI model was measured against a benchmark data set generated by United Utilities Engineers and was considered 100% accurate. The assessment considered two metrics:

- Paired: The AI-identified defects are within 1m of the benchmark identified defects.
- Matched: The type of AI-identified defect matched the benchmark-identified defect within 1m.

Figure 2 shows the results from the analysis of how the accuracy increased with each cycle of the AI training process. This is an ongoing activity within VAPAR as efforts are made to close the gap between the AI outputs and the final outputs generated after the human review. Reducing this gap will develop further efficiencies and decrease the time to process the surveys. The analysis was extended to include the contractor-identified defects, and this indicates both approaches are comparable when compared to the benchmark. The inaccuracy associated with the human results is not surprising given the nature of the work (e.g. repetitive and subjective) and VAPAR observing this level of accuracy within other organisations. However, the 'Collaborative Intelligence' (Wilson, 2018) model incorporated within the VAPAR approach looks to combine AI and Human inputs to increase the accuracy of the outputs.

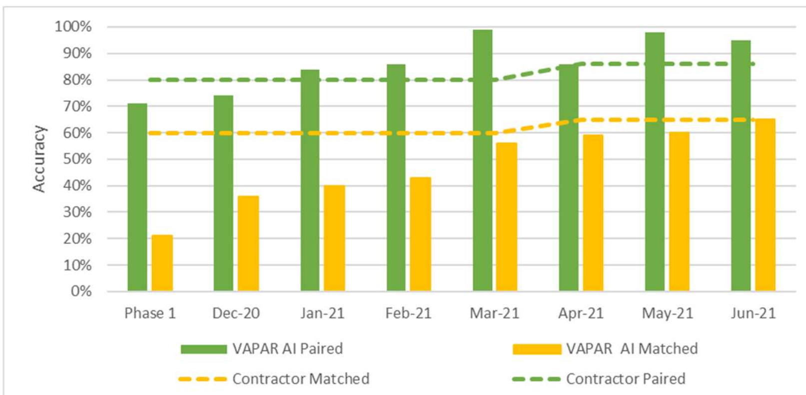

Figure 2. United Utilities and VAPAR successfully increased the accuracy with each cycle of the AI training process, which is now an ongoing process within VAPAR's business.

The second pilot ran between February and May 2022 and deployed the VAPAR technology as part of the United Utilities Routine Maintenance Inspection programme. The annual programme involves periodically inspecting over 1000km of sewers to identify the need for maintenance (e.g. cleaning, root cutting and or capital works) prior to flooding or pollution events occurring. The inspection programme developed over many years and starts with a Fastpass CCTV survey to understand the need for further maintenance based on the surveyor assessment. This is then followed by post-maintenance fully coded structural CCTV surveys where maintenance needs were identified.

VAPAR was used to process both the Fastpass and fully coded structural CCTV surveys for a third of the programme over a four-month period and the following insights were identified:

1. VAPAR produced fully coded pipe inspection outputs from Fastpass footage. This provides the opportunity for financial efficiencies: removes the need for fully coded CCTV surveys and the associated higher costs.

2. Allows for faster decision-making with survey processing times reduced from weeks to days. Further time savings were generated by removing the need to code in the field. These time savings created a secondary benefit by removing the need for the contractor to over programme activities to ensure the outputs where delivered.

3. Off-site coding provides the opportunity to deliver an accurate and consistent human coding input to the process. This allowed the field crews to focus on the survey quality and reduced the training costs.

4. Provides the opportunity for automatic scheme development through the platforms Repair Recommendation functionality, which was only possible by having increased confidence in the CCTV survey outputs. This does not remove the need for engineering input, but it does help to ensure a more consistent approach to the resolution of customer service failures.

5. The additional data generated by the AI application and its storage centrally allowed contract management insights to be generated for both the client and contractor. Furthermore, near real-time data was openly available to communicate the performance AI and guide the development of the AI capability. Figure 3 shows one of the dashboards developed during the trial to identify contact management and AI accuracy insights.

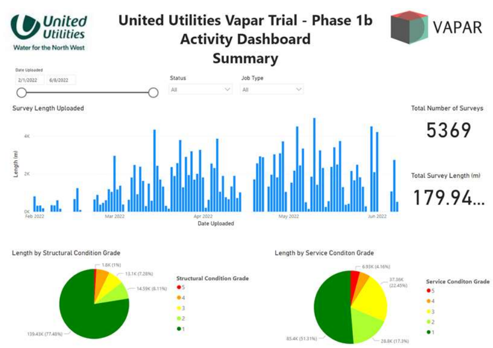

Figure 3. The VAPAR-enabled dashboards provided contact management and AI accuracy insights.

A core element to the success of this latest trail was the collaborative environment between United Utilities, Sapphire Utility Solutions & IPSUM (United Utilities survey contractors) and VAPAR. The team shared a common purpose to identify and understand how the technology could be used to deliver efficiency and performance improvements to United Utilities Customers.

5. NEXT STEPS

The scales of the efficiency opportunities identified from the Routine Maintenance Inspection programme is leading to a wider rollout of the VAPAR technology across the ensure programme. The rollout includes the integration of the VAPAR outputs within United Utilities Dynamic Network Monitoring (DNM) platform (Stone, 2021). The platform contains feeds from thousands of monitors, plus other datasets that allow the business to take a proactive approach to how it manages its network.

Another element of the wider rollout is the use of VAPAR for processing reactive surveys, which are complete after a blockage or flooding events. These surveys are not typically coded and the interpretations is based on the field engineers perspective, This can be subjective and variable, and ultimately lead to inconsistent investment decision making. Another trial has recently been completed to test the use of VAPAR for reactive maintenance decision making and this included the processing of 19,000 historic surveys, which was processed in a 12-day period. This data is now being used to inform United Utilities 2025 to 2030 business case to OFWAT with regards asset health.

As identified during the Innovation Lab, United Utilities use CCTV's survey data across multiple areas of the business from Strategic Investment Planning to the adoption surveys associated with new development. A programme of works now exists to explore if VAPAR's capabilities can be used to generate further efficiencies within United Utilities and further grow the collaborative relationship between the two organisations.

6. CONCLUSION

No product or service meets all its customer's needs when first released and the guidance from some serial entrepreneurs is that you should be embarrassed by your first product (Masters of Scale). The development of a service that meets a customer's needs is an iterative process. This has been the case with the development of VAPAR's AI pipe inspection capability, which started with the Innovation Lab and United Utilities' need to adopt new technologies to meet its regulatory performance challenges. The collaborative relationship has successfully demonstrated AI technology can be used to automate fault detection processes in pipe inspections and create efficiencies. Furthermore, it has shown that the best results are achieved where humans and machines work together to complement each other's strengths.

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2. PAGE NUMBERS

Each paper will be assigned a number in the electronic conference proceedings. To facilitate printing and further referencing, local page numbering is used in each paper, starting from page 1. The page number should appear centered as a footer.

Sample: Paper Ref# - 1 # is the paper number that will be assigned to you in an automated email and “1” is the first page

3. EQUATIONS, FORMULAS, SYMBOLS AND UNITS

Center all equations and formulas and number them consecutively. Refer to equations in the body of text by these numbers (e.g. “Eq.1” or “Equation 1 shows…”). Use imperial or metric units and Arabic numerals. Use of units must be consistent throughout the paper.

$$\sigma = \frac{P}{A} \quad [1]$$

4. ILLUSTRATIONS

Number illustrations (whether drawings or photographs) consecutively in the order of appearance and refer to them as Figure 1, Figure 2 to 4, etc. Avoid placing illustrations sideways on a page; however, if this is not possible, no other text should appear on that page (Najafi, 2003). Photographs should be of good quality contrast. Figure lettering should be approximately the same size as the text with a minimum of 10 point font. Make sure that illustrations borrowed or adapted from another source are properly acknowledged.

Captions should be placed immediately below the illustration.

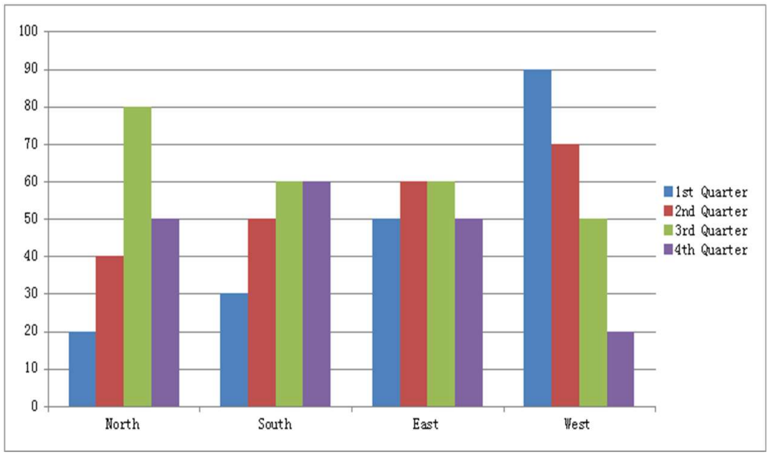

Figure 1. Guidelines for No-Dig Show 2010: sample figure and positioning of the legend

5. TABLES

Number tables consecutively in order of appearance and place them as close as possible to where they are first referenced in the text. Refer to tables as Table 1, or Tables 1 and 2, in the body of text. Avoid abbreviations in column headings (other than units). Indicate units in the line immediately below the heading. Type the caption above the table to the same width as the table and leave one line space between the table caption and the table.

Table 1. Sample table for the as explained in the requirements for papers

Title	Sub-title (units)	Sub-title (units)
Line 1	1234	4321
Line 2	1321	8765

6. REFERENCES (in alphabetical order)

Gokhale, S., and Ariaratnam, S. (2002). Life Cycle Modeling of Sewer Infrastructure, *Journal of No-Dig Engineering*, Volume 3, No. 2, pp. 33-42.

Najafi, M. (2003). Educational needs in Trenchless Technology. *Proceedings of 2003 No-Dig Show*, Las Vegas, Nevada, March 31-April 2, 2003.

Please note that paper should be submitted in PDF format, not exceeding 10 megabyte