For decades, pipeline integrity managers have used a set of evolving tools to improve the solutions that are available for integrity challenges. While great progress has been made on mainline piping systems, which are conventionally piggable, a key difficulty facing pipeline integrity personnel has been the ability to inspect and gather data on pipelines that are unpiggable or hard to navigate. Inspection tools must navigate these lines and accurately measure the size and specific location of all defects.

This article will outline what is required in the next series of inline inspection (ILI) technologies in order to overcome unpiggable or difficult to inspect pipeline integrity verification. Although finding the phenomenon known as a ‘pit within a pit’, detecting and sizing small anomalies, and reducing false digs would be beneficial, a key question still remains: how do we get there?

Next generation inline inspection technologies need to go beyond navigation to consider accuracy of detection, measurement and location of flaws, Robert De Lorenzo, Quest Integrity, USA, explains.
ILI development history
ILI tools were first introduced in 1965. Early tools used sleds carrying magnetic flux technology and could only identify metal loss in the bottom quarter of the pipe for distances of up to 30 miles. By 1970, ILI tools could detect metal loss around the entire pipe circumference. Over the next decade, dramatic improvements led to the first ultrasonic (UT) tools. These could directly measure and quantify metal loss, resulting in more accurate inspection results.

Advances in ILI technology continued into the 1990s and 2000s. The accuracy of detecting and sizing metal loss anomalies improved as new and more sensors were added to pigs, which allowed for higher resolution imaging. While first generation ILI tools were limited to metal loss detection, these newer tools could address a variety of damage mechanisms, such as internal and external corrosion, dents and cracks.

Combination sensors were later introduced on commercial pigs. Sensors using different technologies and with different capabilities can now be sent simultaneously through pipelines. This gives engineers a more robust view of the pipeline along with a greater ability to detect and characterise anomalies.

Being more refined and sophisticated, present day tools have reached a level of sensitivity and accuracy that allows inspection data to be used for advanced fitness for purpose calculations and integrity assessments. However, despite these technological developments, ILI still has many limitations.

The navigation hurdle
Now that major inspection techniques — MFL and ultrasound — are well-established, recent and ongoing developments have had a different focus. Over the last decade, ILI research and development projects have been geared towards solutions for unpiggable pipelines, which cannot be inspected using standard intelligent pigs.

There is a myriad of scenarios that make a line unpiggable. According to Dr. Keith Leewis, in ‘An Introduction to Unpiggable Pipelines’, the simplest explanation includes the obvious barriers to pigging a single pipeline:

- Access – a free swimming tool cannot be introduced or removed.
- Low pressure and flow – there is insufficient flow to overcome friction and drive a pig.
- Multi diameter – problems with loss of sensor coverage and/or high velocity excursions.
- Physical barriers – the tool cannot navigate past internal obstacles or barriers.
- Inconvenience – customers cannot tolerate any reduced product flow and access is curtailed.

While many piping systems have historically been deemed unpiggable, advances in smart pigging and other inspection technologies now allow for inspection of these lines. Industry leaders in ILI navigation capabilities have shown that many of these unpiggable aspects are now manageable. In fact, the Pipeline Research Council International (PRCI) now discourages use of the word ‘unpiggable’. With sufficient planning and budget, any line can be pigged if the integrity benefits of the ILI data justify the difficulty and expense that is necessary to guarantee the tool passage.

For example, Figure 1 shows a 4 in. unpiggable pipe that contains back to back S, mitred and 1D bends. The fabricated test loop shown is routinely navigated by Quest Integrity’s ILI InVista™ tool, which can navigate other unpiggable features, such as dual and tri diameters, bore restrictions and low flow.

The challenge
Recent high profile pipeline failures have encouraged increased regulatory scrutiny over pipeline integrity assessment and
management. The consequences of potential failures mean that operators cannot selectively manage different parts of their pipeline systems with variable attention. While regulatory compliance may be achieved by hydrotesting some lines, this testing will not provide a complete picture of the condition of a pipeline. ILI now allows operators to gather a large amount of inspection data about systems that they were previously able to obtain very little or incomplete information.

As well as collecting information about a wider range of pipeline systems, the quality and resolution of data is also enhancing. While many high resolution inspection technologies can accurately size the length and depth of a flaw, it is now possible to go beyond basic flaw dimensions. High resolution wall thickness data allows for Level 2 (effective area) assessments on areas of metal loss, while high resolution geometry data allows engineers to calculate stress concentration factors and build finite element models of individual dents to demonstrate fitness for service.

Competing inspection technologies can be evaluated not only by comparing the cost of inspection, site preparation and mechanical setup, but also by examining what can be done with the data after the inspection. Discussions about ILI often focus on data quality, precision of measurement and statistics about flaws of a variety of depths. While these are important and easily quantifiable, for a pipeline operator the most crucial decisions come down to the ability to safely operate the pipeline and to spend maintenance budgets efficiently.

Gathering a high quality data set from an inspection allows for enhanced planning and management of a pipeline system.

The growing challenge

By inspecting hundreds of lines that were previously termed ‘unpiggable’, and with significant strides being made to develop solutions for the unpiggable over the last decade, a new challenge has arisen. It is no longer enough to be able to navigate extreme pipeline geometries alone.

Across the pipeline industry, operators’ demands have led to a focus on the ability to not just locate, but also accurately identify and size small diameter defects that are classified as pitting or pinhole corrosion. Thus, operators are challenging ILI service providers to both navigate pipelines and acquire data that is detailed and accurate.

The POF chart shown in Figure 2 is a common reference for standardising and categorising the capabilities of ILI vendors’ tools. It is not enough to merely identify small diameter defects. Operators require accurate information to allow for a prioritised repair plan. Accurate depth measurements allow dig programmes to be more cost-effective, with corrosion growth analysis and engineering assessments being enhanced.

A pit within a pit requires ever-increasing resolution to identify and quantify accurately. With reference to the POF chart, while the larger anomaly may be classified as pitting or general corrosion, the critical part of this defect is well within the pinhole range.

While the POF classification chart is a useful first cut at classifying pipeline anomaly types, its general definitions are tied to older methods of MFL flaw boxing and identification. As illustrated in Figure 3, the orientation of anomalies in a pipeline is key when analysing or processing the data from an MFL inspection. Other technologies, such as ultrasonics, are not nearly as sensitive to flaw orientation. Detection and sizing capabilities are a function of the total size of the anomaly, as well as tool sampling frequency.

However, when it comes to sizing and characterising anomalies appropriately, all ILI technologies are sensitive to the size of the deepest part of the anomaly.

Figure 4 shows a large area of general metal loss that is easily detectable by all modern ILI tools. In order to correctly characterise and prioritise such an anomaly, the ILI tool must be able to resolve the deepest area of corrosion. In this case, the deepest area is a pit within a pit that is less than 0.04 in. dia.

Correct identification and sizing of deep small diameter areas drives ILI technology development.
As illustrated in Figure 5, the coverage resolution of an ILI tool is defined by its inspection grid or the density of data measurements acquired in both the axial direction (along the pipe axis) and circumferential direction (around the circular pipe axis). This inspection grid is one of the primary components in determining how small of a flaw can be detected with a particular ILI tool. The finer the grid spacing, the smaller the minimum detectable flaw size.

Grid size is the primary driver of an ILI tool’s probability of detection capabilities. To achieve measurement success on a flaw that is 0.2 x 0.2 in. (the reference size for a pinhole defect in the POF specification), a minimum grid resolution would need to be on the order of 0.08 x 0.08 in. or greater.

Looking ahead
For all intents and purposes, an ILI tool is very much like a camera taking pictures along the inside of the pipeline. Thus, for illustrative purposes, let us use a digital camera analogy. ILI tools follow a similar path to digital cameras with regards to increased resolution.

When cameras first became commercially available, their resolution was subpar to film media. However, as digital technology progressed, pixel resolutions increased to rival – and eventually surpass – that of standard film. Increased resolution brought crisper, more detailed images.

ILI tools of yesterday struggled to collect data on the bottom 30% of a pipe’s surface and to navigate. Similar to cameras, today’s ILI tools are moving forward in resolution, accuracy and repeatability. Higher resolution ILI tools are becoming more commercially available and offer enhanced quantifiable images and measurements, as illustrated in Figure 6.

For piggable pipelines, ILI tools offer sizing of anomalies just 0.4 in. across and identification of anomalies with diameters of as small as 0.25 in. However, achieving this type of resolution requires multiple sensor carriers on long, heavy tools. This tool design means that trade-offs are required, such as sacrificing the tool’s ease of use and navigability.

Most desirable would be a short tool consisting of one or two modules, containing hundreds of MFL or UT sensors and that was still lightweight and flexible enough to be hand carried in the field, while also able to navigate tight bends, multiple pipe radii, taps, tees, valves and other restrictions that are characteristic of unpiggable and challenging pipelines.

The industry would also want a tool that requires minimal onsite setup time that is easy to launch and receive.

Flow conditions in challenging pipelines can be hard to control. A next generation tool would need to be able to navigate and gather a complete dataset along with a range of flow velocities, often during one inspection run. As well as providing operation security and confidence, a bidirectional pipeline camera would allow for inspection of lines that end in a tee or pipe vault.

However, each of these ease of use or navigation considerations still require a camera to take high resolution images of the pipeline. It was not until small digital cameras began to take pictures on par with bulkier film cameras that they became truly ubiquitous.

The inspection data collected from an ILI run is key to a pipeline operator. The data helps to enhance operator confidence, drive repair plans and prevent a loss of containment. In lines where small diameter pitting and pinhole type defects are a concern, quality and resolution of the ILI inspection data is essential. The anomaly shown in Figure 2 is an example of where we need a high resolution digital zoom to take a truly useful and clear picture of the pipeline.

Conclusion
Since the pipeline industry now has ILI tools that can navigate the most difficult of pipelines, there is a new focus on ensuring that these tools return with as high a quality of picture as possible to highlight the condition of each pipeline that is inspected. While ILI tools must be able to navigate past back to back mitre bends and buckles, they must also be able to detect and size small diameter pitting that lies between the mitres.

As designers of ILI tools that enter some of the most difficult pipelines, solving this challenge is what pipeline operators require and demand. In today’s environment of increasing regulatory scrutiny, the industry must strive towards obtaining the best pipeline pictures in even the most challenging environments. The demand for ever improving data, ease of use and navigational ability is a challenge that was introduced by the formerly unpiggable pipelines.