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Innovation in Non Destructive Testing and Inspection Technologies

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Abstract

Why is it so difficult to implement new technology. Intuitively one would say that one should use a new technology when it is better than the old technology. Adaptation of a radical new technology however will have a big impact on the way the business processes around the technology are organized. This may result in the optimal time of adaptation being either earlier or later.

In Non Destructive Testing (NDT) every new technology has to be qualified, and even then it takes many years for the market to see a technology as proven and accepted. A common way to approach replacement is to demand equal or better performance of the new technology being employed. Performance however is often assessed by a mix of parameters.

The questions central to this article are:

1. What is the relative performance of the new and old technology?
2. What are the changes and consequences of adopting the new technology?
3. When (in which circumstances and what time) to replace the old technology?

In this paper some theoretical notions on these questions are introduced. Than the questions are studied in the context of a practical NDT case, replacement of visual inspection by guided waves piping inspection for the detection of corrosion under insulation in piping of process plants. It is concluded that on all performance parameters defined, the new technology is superior to the old one. The case and theory are used to identify six factors that delay the implementation of new NDT technology.

The research presented in the paper is conducted by Applus RTD and Delft University of Technology and aims to better understand the innovation process in NDT and other areas where new technology and safety interact. The research is motivated by Applus RTD trying to improve facility in employing new technologies. The intent is to understand how to maximize the value created for customers while retaining high quality and consistently providing customer confidence.

1 Introduction

Implementing a radical new technology can have serious consequences for the business process of an organization. A radical technology offers improvements in performance of five times or greater, an entirely new set of performance or a 30 percent reduction in cost compared to contemporary technologies[1]. Radical technologies include MRI scanners (improved performance), memory metal (new type of performance) and the transistor (reduction in costs). Adoption of these technologies means that they have to be implemented in existing business processes. A business process includes both the primary process and the secondary and sustaining processes of an organization[2].

The basic idea of this article is that implementation of a radical technology may require considerable changes in the business process of an organization. The required changes in this primary process, in turn, may have an effect on the optimal timing of replacing the old technology. We will illustrate this point using the case of a radically new technology, Guided Waves Piping Inspection, for the detection of corrosion under insulation in process plants. This technology can substitute the traditional approach of stripping the insulation and doing visual inspection.

Implementing radically new technologies and substituting contemporary technologies is a topic that has been researched by several scientists. Sahal[3] and Geels[4] for example describes how internal combustion engines have substituted sails in seagoing cargo ships. After the first implementation of an internal combustion engine, completion of this process of substitution lasted about a century. One of the reasons for this long period is that, at first, the performance of the internal combustion engine lagged behind the performance of sails. The case of Guided Waves Piping Inspection will shows that, even in the case of superior performance of the new technology, immediate substitution of an old technology is unlikely.

Corrosion detection in industrial installations is invaluable. The effect of a broken pipeline in a chemical plant can be tremendous both for the entire plant and its immediate surroundings. This detection should minimize the occurrence of such potential disasters. However, as we will show, this detection is also just a secondary process that should minimize the interference with the ongoing primary process of the industrial installation, and it should be very cost-effective.

An important issue to consider before implementing a radically new technology is its relative performance vis-à-vis the contemporary technologies. Several issues have to be considered before a decision about the implementation of the new technology can be taken:

1. What is the relative performance of the new and old technology?
2. What are the changes and consequences of adopting the new technology?
3. When (in which circumstances and what time) to replace the old technology?

In section 3, we will discuss the relative performance of technologies and the effect of this relative performance on the decision to implement a new technology. We will illustrate the construction of a performance measure for the case of the ultrasound technology and will show that, on the basis of this measure, implementation is immediately possible. In section 4. factors will be described that may delay the implementation of the new technology. In the last section are the conclusions and managerial implications of our findings.

2 Relative performance of technologies and when to implement a new technology

In theory, the relative performance of two technologies, a traditional and a radically new one, can be assessed using a common performance measure. Performance of a technology tends to evolve in an S-shaped curve over time[(5)(6)]. Using a common performance measure, the evolving performances of both technologies can be shown (See Figure 1). At first sight, it seems logic to consider the implementation of a radically new technology once its performance has exceeded the performance of the contemporary technology (at T3 in Figure 1).

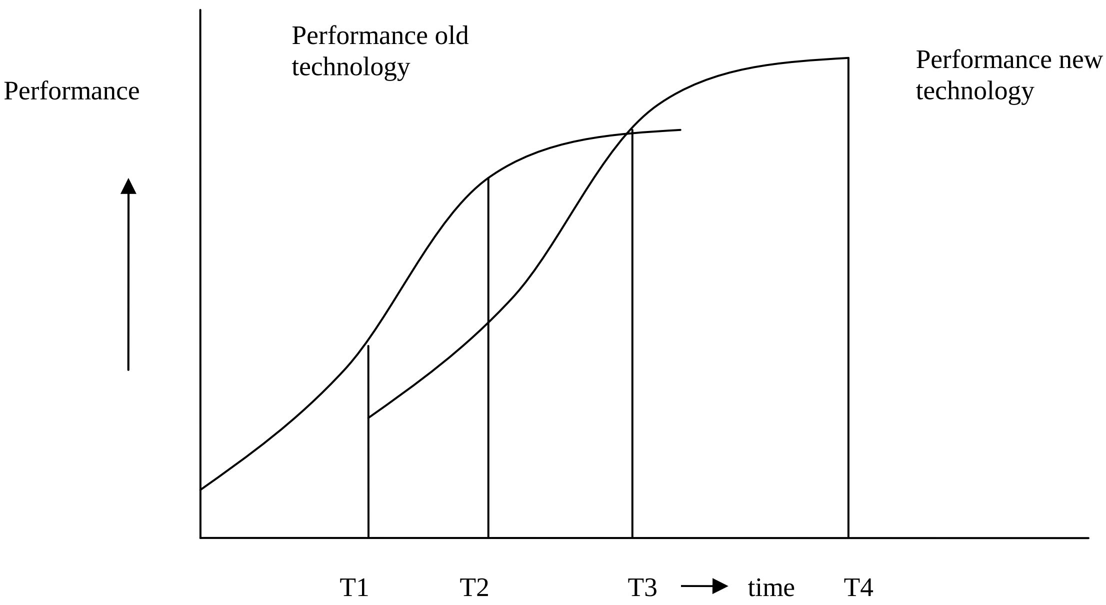

Figure 1. The relative performance of an old and a new technology in the course of time

In practice, assessing the relative performance of competing technologies over time and deciding when to implement the new technology, can be difficult for various reasons:

1. Even with a complete performance pattern for both technologies, it is not straightforward when implementation should be planned.
2. It may be difficult to find a common performance measure.
3. At a certain point in time, the performance curves are only partly known.

Ad 1. Even with a complete performance pattern for both technologies, it is not straightforward when implementation should be planned.

Figure 1 shows the relative performance of a new and an old technology depicted over time. Suppose that the performance of the new technology is first assessed at T1. At that time it seems unreasonable to substitute the old technology because both the performance and the increase in performance of the new technology is lower. At T2, the increase of performance of the new technology for the first time exceeds the old technology. Although the performance itself is lower is becomes likely that the performance of the new technology will exceed the performance of the old one in due course. At T3 the new technology has both higher performance and a higher increase in performance. The decisions when to start using the new technology is highly dependent on the time that is required to develop and implement the technology. It makes sense to start working on the new technology once the increase in performance of the new technology is higher and the performance of this new technology approaches that of the old one, that is somewhere between T2 and T3. However, many companies will simply wait until T3 has occurred and wait further until the new technology is about to become the dominant approach in the industry. Christensen et al. show that the survival rate of companies in an industry depends on the time they adopt a radically new technology and enter the industry. The survival rate of the companies that enter the industry just before the technology becomes the dominant approach is higher then those that enter earlier or later[7]. In terms of Figure 1, a technology usually becomes dominant in an industry much later than T3, for example at T4. The exact timing of T4 depends on the diffusion rather than the performance pattern.

Ad 2. It may be difficult to find a common performance measure.
Figure 1 implies that a common performance measure for both technologies can be found. In practice, the performance of technologies can be assessed using multiple measures. Overall performance would then require some kind of index that is a combination of separate performance measures. The transistor, for example, is a radically new technology that can replace the vacuum tube. Performance of these amplifiers can be measured in many ways like the quality of the amplified signal (does the amplifier not distort the characteristics of the signal) and the reliability and cost of maintaining the technology (what is the chance of breaking for each type of amplifier). Apparently, vacuum tubes showed the best performance on the first aspect whereas the transistor did so for the second aspect. Combining the performance aspects in one kind of overall performance index is not straightforward because the relative importance of both aspects depends on the application. For long range telephony, for example, the reliability is more important than the quality of the amplified signal. However, for audio equipment this is the other way around.

In general, the difficulty of assessing a common performance measure is further complicated when the performance of each technology is composed of many separate measures. New and old technologies might also enable different kinds of performances thereby almost preventing the possibility of constructing a common performance index.

Ad 3. At a certain point in time, the performance curves are only partly known
Suppose that a common performance indicator for the radically new and the old technology can be found. In that case the performance of both technologies can be compared. In practice however, these measurements over time only show a limited part of Figure 1. In practice, at time T2, the data may look like in Figure 2. This figure shows that the performance of the new technology is not certain, as is indicated by the band around the performance. It most cases it is very difficult to get good data about the performance of a radically new technology at the start of its life cycle. It also shows that

at time T2, only a very limited part of the information in figure 1 is available. Multiple scenarios are possible then, like the scenario that the performance of the new technology will never exceed the performance of the old technology or the scenario that the performance of the new technology will quickly exceed the old one.

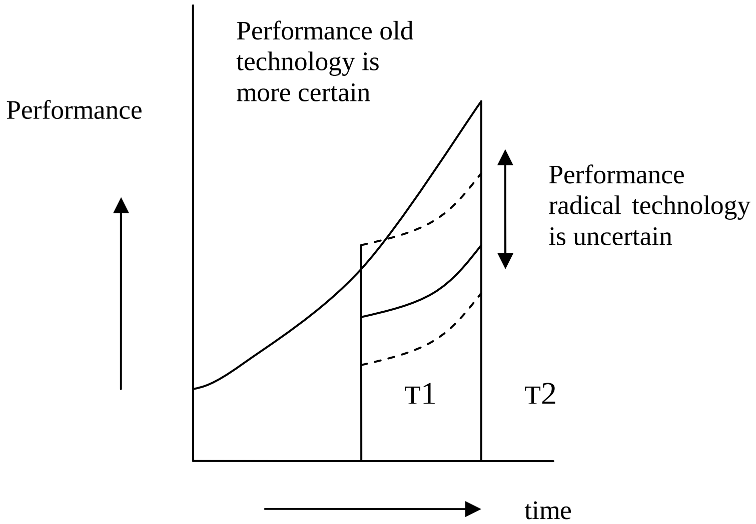

Figure 2: Performance data at the start of the life cycle of a radically new technology

3 Relative performance of Guided Waves Piping Inspection and Visual Inspection

The main comparison is this article is between two approaches for inspecting insulated piping in refineries, chemical plants and other process plants. The “old” method is Visual Inspection, the “new” one Guided Waves Piping Inspection. Both technologies need an introduction as the name does not necessarily bring the right association to mind.

In this section the approaches will be compared on several levels. The reason for comparing at several levels is, that this will give rise to a number of performance measures for the technologies. First of all the physical measurements principle is compared by looking at the minimum defect size that can be detected. Secondly the technologies are assessed at procedure level according to Probability of Detection (POD). A third technical performance measure is related to how well the actual problem in the piping is addressed. The measure used here will be the cost incurred to achieve a desired level of safety. The three levels are depicted in Figure 3.

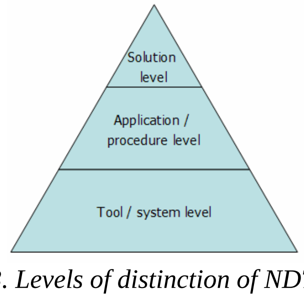

Figure 3. Levels of distinction of NDT services

3.1 Visual inspection (VI)

Visual Inspection (VI) is usually a walk-through type of inspection of the work area to detect incomplete work, damage or inadequate clean up of a worksite, in this case a process plant. In practice this can mean many things. The inspector is usually someone who is trained in the various aspects of the processes, design and safety of his plant, and thus can detect problems more readily. The inspector often has aids in his work, like check lists to aim his attention at predictable or high risk issues, camera's to record his findings and a computer system to store the piping information.

In this article, the inspection of insulated piping for Corrosion under Insulation (CUI) is the main subject. Under normal circumstances visual inspection would only be capable of detecting issues that are visible on the outside of the insulation. In cases where a Risk Based Inspection methodology is followed, it is also often required to strip of the insulation and do a 100% investigation of the surface of the piping, every so many years.

3.2 Guided Waves Piping Inspection (GWPI)

A relatively new NDT technologies in the market is Guided Waves Piping Inspection (GWPI). GWPI was developed by Guided Ultrasonics ltd. based of research of Imperial College[8]. The principle of GWPI is based on an ultrasonic pulse being sent through the pipe around the whole circumference. Because of the excitation around the whole circumference, there is no geometric spreading of the wave and thus low attenuation of the sound traveling along the pipe. In this way inspection ranges can be achieved of 5 - 100 meters along the pipe from a single probe position, in both directions. The practical range is usually around 20 meters, in both directions.

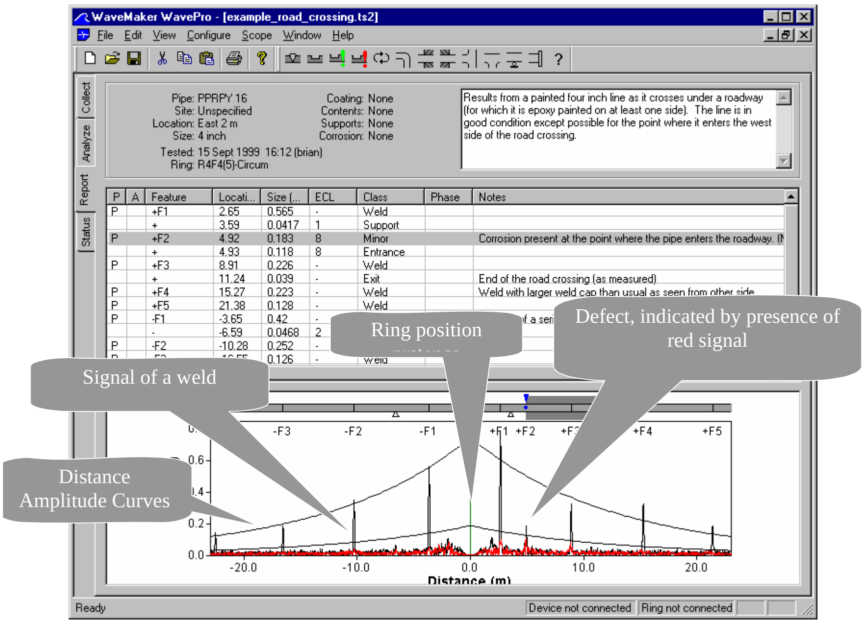

Figure 4. Typical result of a Guided Waves Piping Inspection

The tool is operated by placing a probe ring around the pipe at a location where it is clean and accessible. This probe ring, linked to electronics and a computer, will excite the pipe with a low frequency ultrasonic guided wave. The presence of the pipe features like welds and welded attachments makes it easy to overlay separate measurements, because defects can always be reported relative to a specific geometric feature. In Figure 4. welds can be seen every 6 meters as big regular signals. There is also an irregular signal at 5 meter that indicates a defect.

3.3 Comparison at the tool level: detection capability

The first thing a scientist or equipment designer will focus on is what he can see with his equipment. In the case of VI we can refer to our own human experience of what we can see and what we can't. At this level of comparison we can all testify that someone with good eyesight can see details down to 0.1mm.

For GWPI technology we can refer to many publications and research reports[(9)(10)]. Although a lot can be said about this, for the purpose of this article we will stick with the commercial information spread by our equipment supplier Guided Ultrasonics Ltd[(11)]. On their website they claim to be able to detect damage of 5% cross sectional area. Without going into detail about what it all means, on a 6" schedule 40 pipe (actual diameter 168.3mm and wall thickness 7.11mm) this would be a defect of 50% wall thickness reduction over 10% of the circumference of the pipe (about 3.5mm deep and 50mm across).

Just from the difference in description, one from experience and the other a complicated calculation, it is obvious that comparing is not simple. At tool level, it is clear that you can see much more with your eyes than with GWPI. However, GWPI is able to see in areas where the eyes can't go, in this case under the insulation. Also for visual inspection, again from everyday experience we know that people miss seeing things altogether, and that an automated system has a longer attention span. To really say something about the comparison we have to incorporate aspects like: the specifics of the object under investigation, the ability of the operator and the procedure of the inspection.

The level of detail of a measurement is an important factor however. The plant engineers will need an accurate wall thickness reading to determine the corrosion rate, to calculate remaining lifetime and make fitness for purpose calculations. For both GWPI and VI additional testing and evaluation methods will be needed to collect all relevant information.

3.4 Comparison at procedure level

At procedure level it is much harder to get hard figures for comparing performance. Some research has been done into the Probability of Detection (POD) of visual inspection [(12)(13)(14)]. In general it was found that poor detection rates of about 50% are achieved, mainly due to the human factor. With GWPI equipment a much higher level of POD is being claimed. The minimum size defect mentioned in the previous paragraph was found with 90% POD.

There are many complications with using POD as a performance measure. First of all, there is no such thing as a tool POD. POD is almost always defined as the probability to detect a flaw of a certain size. All relevant parameters impacting the detectability should be incorporated in the probability model(15). In maintenance situations in a process plant, these factors are so many that it is not practically possible to even determine them. At one of Applus RTD's major clients another approach was chosen. A sample of a few tens of pipelines in their process plant was inspected using two inspection approaches (both for every line):

Approach 1: Guided Waves	**Approach 2: Visual inspection**
Accessibility of piping by cherry picker	Accessibility of piping by scaffolding and removal of insulation
Guided Waves measurement while insulation was in place	Visual inspection of all piping
Follow-up of indications with ultrasonic wall thickness reading	Follow-up of indications with ultrasonic wall thickness reading

The aim of the exercise was to demonstrate that GWPI would at least detect all critical defects, assuming that Visual Inspection would. The result was, that GWPI performed significantly better than Visual Inspection. Although Visual Inspection found more defects in total, Guided Waves picked up some critical ones, that Visual Inspection had missed.

Now knowing that the detection capability of Guided Waves was better than Visual Inspection on a procedure level, this put the client in the position to have to evaluate how well the solutions offered covered the problem of Corrosion under Insulation on piping.

3.5 Comparison on Solution level

The broad problem of the maintenance of high risk pipework requires a solution that will not only look for one defect mechanism e.g. CUI. Referring to API 581 (16), one has to start with the inventory of degradation mechanisms. The degree to which NDT will help establish the extend to which these mechanisms are actually present will determine an inspection interval. In most cases plant owners will compare the total cost over a particular period to establish the financial performance of inspection technologies.

For our two technologies, several scenarios for the total cost of inspection over the lifetime of the plant were investigated. The inspection intervals achieved with visual inspection was about 20 years, mainly due to the fact that lines would be repainted, which will extend the required inspection interval. The main cost in this scenario was the building of scaffolding around the pipe, and the removal and installation of the insulation material. The inspection interval for GWPI was about 10 years. The main cost in this scenario was the GWPI.

Over the economic lifetime of the installation, the GWPI achieved a 40% cost reduction on the total cost of inspection.

Note: GWPI works particularly well on relatively undamaged and well kept piping. On old or badly kept piping, other scenario's will probably perform better. Additionally there are other limitations to the applicability of GWPI[17]. Similar remarks could be made for Visual Inspection however.

3.6 Performance comparison: Conclusion

When comparing Guided Waves and Visual Inspection across all three levels, one has to conclude that GWPI is a radical new technology. It adds functionality (looking at inaccessible places), outperforms it's alternatives on the procedure level, and achieves a 40% cost reduction. Why then is it not implemented on a larger scale.

4 The factors that delay the implementation of a radically new technology

Given that GWPI was shown to outperform visual inspection we used the case and theoretical information to determine what might cause delay in implementation. Six factors where determined.

1. The actual performance of a radically new technology is uncertain
Being able to compare the relative (price)performance of a new technology with its contemporary alternatives is a prerequisite for the decision to adopt this technology. However, data about this performance is often not available, incomplete or highly uncertain.

This uncertainty in combination with the severe consequences of a failing technology will lead to a conservative and late adoption behaviour in the industry. In general the development and implementation of radically new technologies is paved with accidents and subsequent efforts to improve the technology until the real benefits of the technology become available [18]. In general, the risk of failure can be characterized as the chance that a failure happens times the anticipated effect of this failure. Industrial installations face a small chance of failure but a very large effect once the failure occurs. The chance of failure is difficult to assess yet crucial for estimating the risk. Adopting a new testing methodology like pipeline inspection at first has an unknown effect on the probability of failure and therefore potential customers will tend to wait until the technology is proven.

Moreover, in the case of GWPI the rules for comparing the technologies came from considerations outside the direct technical environment of the test. Risk assessment is a complete science in its own right that needs to be involved in order to make the right assessment.

2. Acceptance of the new technology requires inclusion in regulatory frameworks

Broad adoption of a new NDT technology requires that this technology be described in a standard. These standards are written by groups of engineers out of the user community of current technologies. These people will have to compare old, well know technology with new unknown technology. In most cases the new technology will have to be demonstrated many times before it will get the benefit of the doubt. No one wants to be the one that has to testify in court why they used this unproven new thing instead of using the old reliable one.

Another factor in getting radical new technology regulated is that there are many regulators, company ones, states ones and federal ones, that each will want to develop their own investigation and justification.

3. Radical technology requires a change to the business model

Changing the inspection technology is not just a question of changing technology, it requires a change in the business model of both inspection entity and client. When viewing innovation in the context of a value engineering tool like the value chain of Porter(2) it is interesting to note that inspection technology, although a typical supporting activity, can have a serious impact on the primary process of the client. If a plant has to be offline for measurements this will seriously impact the value generated in the primary process.

In most cases new technologies will improve the situation. However, it will also be required for the support activities to convince the primary process that a change is needed, and that they need to reorganize because a support activity is going to change. In the case of GWPI this means handing over data on the equipment earlier and to different people, and maybe rerouting or changing some of the production. It is obvious that such a change will carry a cost of it's own and may not be welcomed by the production people, who are often assessed by the amount of downtime of their process.

4. Adoption of the radically new technology requires more rather than less monitoring

Guided Waves Piping Inspection requires more frequent monitoring during the life cycle of an industrial installation. This increased monitoring work is shown to lead to reduced overall costs of maintenance for the installation over its life cycle. However, if the cost of monitoring is not related to this decrease of overall maintenance costs and the decrease in probability of failure then the increased effort in monitoring is just seen as an increase in monitoring budgets or costs. In that case adoption will be postponed or cancelled.

5. Implementation requires considerable investments

Implementation of new technologies that are related to safety and are meant to reduce risks inevitably have to be tested and norms have to be established how to use the technology. In the case of a radically new technology the lack of norms may require that the technology is applied in parallel to the old technology for some period of time. That means that at first, the cost of monitoring will increase considerably. Thomke(19) noticed a similar phenomenon in the case of car crash simulation programs. At first, these programs were used in addition to the traditional way of (actual) crashing. Later on, when the simulation was well developed it turned out to be possible to substitute some of the expensive and time-consuming crashes by simulations. Simulations enabled a huge increase of tests in a shorter period of time and thereby considerably increased the safety of car designs.

6. The timescale in the oil, gas and chemical industry is long
One of the observation on the implementation of new technology is, that it is often linked to the economic life time of the most import asset to which it applies. In the case of the process plant, its economic lifetime is usually 30 to 40 years. Following this line of thought it should be expected that adaptation of a new testing method will also take this kind of time. In other NDT related cases this was indeed observed(20). The factors impacting this timescale are things like the material used in the main structure and the penetration of new rules and regulations for the building of the main asset. GWPI being first introduced in the mid 90s should now be halfway towards acceptance.

5 Conclusions

One of the important criteria to decide whether and when to implement a radically new technology is the relative performance of this technology. In the article it is described that comparing the performance of an old and a new technology can be difficult for various reasons: a common performance measure may be difficult to find, the knowledge about how the performance of technologies develops over time is usually incomplete and uncertain and, finally, even if the performance curves are completely known it may be difficult to decide when to implement the new technology.

In the article we describe the case of Guided Waves Piping Inspection. This technology undoubtedly is radically new: it increases the performance considerably and it decreases the costs with more than 1/3 compared to visual inspection. It is also a rare case because pipeline inspection using ultrasound has an improved performance on all relevant performance indicators when compared to visual inspection. It is a rare example of a technology that seems to call for immediate implementation.

It is shown that in practice, even for superior technologies like pipeline inspection using ultrasound, considerable delays before implementation can be expected. This article describes six reasons for this delay:

1. The actual performance of a radically new technology is uncertain
2. Acceptance of the new technology requires inclusion in regulatory frameworks
3. Radical technology requires a change to the business model
4. Adoption of the radically new technology requires more rather than less monitoring
5. Implementation requires considerable investments
6. The timescale in the oil, gas and chemical industry is long

When comparing the several factors that make up the hurdles to adaptation, the change to the total value make-up of both inspection entity and client is apparent. More research into to value added and destroyed on both implementation and final stable use will have to be done.

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