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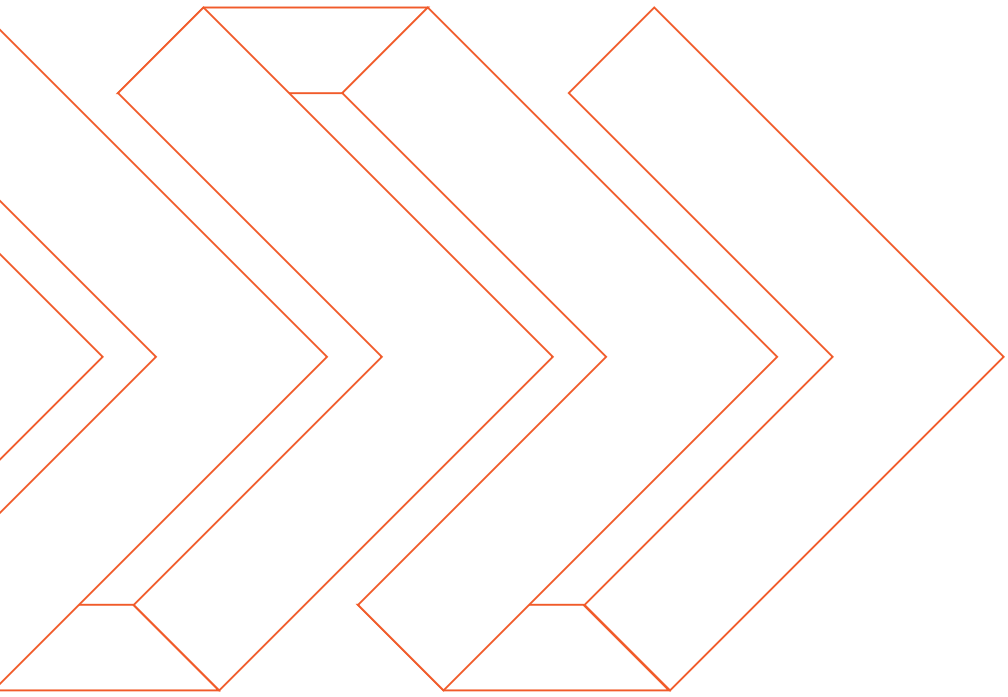
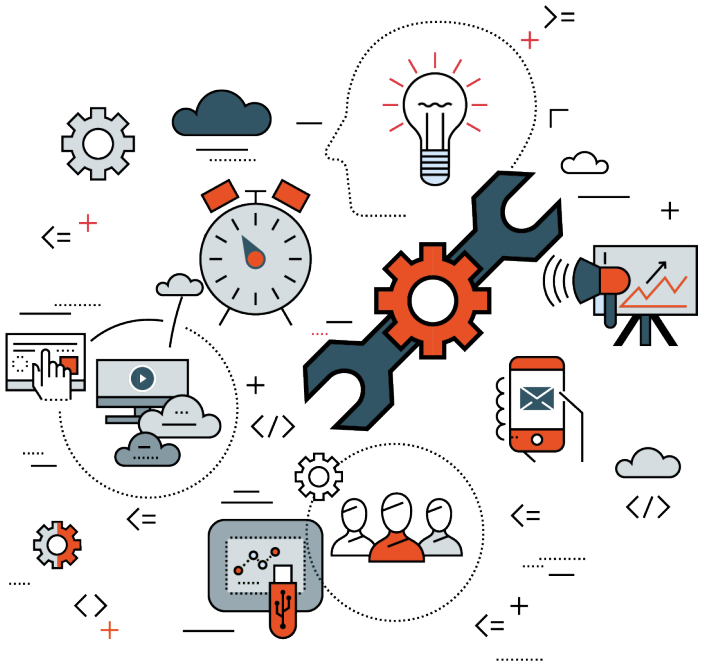
WHITE PAPER

Realizing the Opportunity in Predictive Maintenance Analytics

By Ed Maguire, Luca Mazzei, Alberto Cresto and others





Executive Summary

In response to questions from our corporate clients, we recognized substantial opportunity in and demand for Predictive Maintenance analytics solutions. We set out to develop our own opportunity thesis, and over the past 6 months landscaped a universe of over 40 companies, meeting with a number of them. What we found was a fragmented market with many small players, little industry adoption, and a strong need for cost-effective solutions that solve key pain points using new technologies. This report presents our findings.

Content

Introduction

Over time, all industrial assets age, see efficiency decline and potentially fail. The efficiency of industrial production processes is also subject to numerous external variables – the price of energy, product demand and pricing, maintenance schedules and unexpected outages caused by anything from weather disruptions to labor shortages. These challenges represent a significant cost to the manufacturing industry. A 2006 survey of auto industry executives revealed that each hour of downtime costs manufacturers on average $1.3 million. The costs, in turn, drive demand for a large industrial maintenance market, accounting for over 14 percent of the entire industrial services market.

Today industrial maintenance is mostly "preventive" in nature, aiming to minimize efficiency losses and the risk of unexpected failure. In recent years, maintenance practices have been augmented with increased equipment condition monitoring, with the goal of further extending the intervals between repair and maintenance. In 2015, industrial firms spent over $1.9 billion on machine condition monitoring, a number expected to grow to $3 billion by 2022.

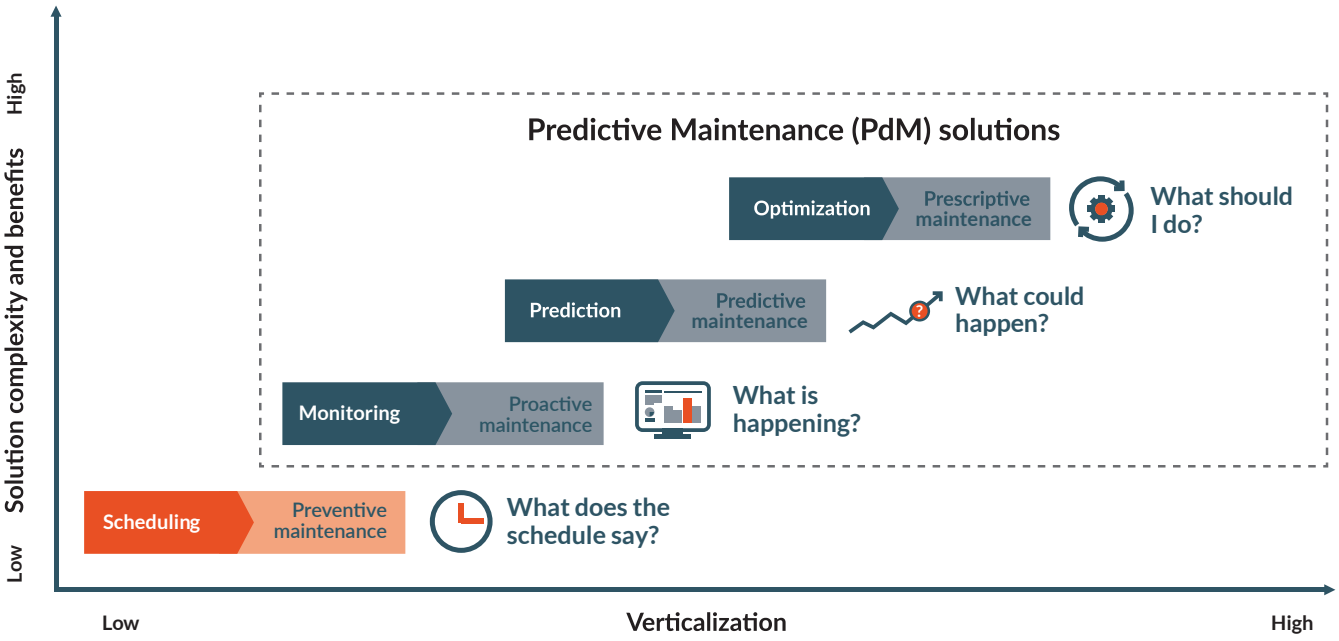


Figure 1: A taxonomy for predictive maintenance anylstics

Oddly enough, general production processes have not changed much since the Industrial Revolution. Companies buy industrial assets, place them into service based on pre-set schedules, adjust schedules based on seasonal cycles, repair assets when they fail, and replace them when they reach a certain age.

This centuries-old approach is on the cusp of disruption driven by three converging trends – industrial assets are getting connected, performance and organizational data is becoming widely available, and advances in computing and storage power enable unprecedented scale at declining cost. As these trends take hold, the factory floor no longer resembles a static group of assets, but rather becomes a dynamic, complex system that can be managed as such – similar to how data networks have been managed since their inception.

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The increasing availability of data and computing allows operators to **evolve beyond condition monitoring to anticipating problems before they happen, making predictive maintenance a lucrative, and potentially game-changing possibility.** Eventually industrial firms will be able to predict the performance of entire production processes under varying conditions – and thus modify not just individual assets and their maintenance cycles, but entire factory floors, wind farms, and other types of interconnected groups of assets.

It will be possible not only to know what may fail when, but to recommend what the operator should do about it ("prescriptive" maintenance).

This entire class of predictive maintenance (PdM) analytics solutions is expected to grow to be a $24 billion market by 2019 with the more advanced segments of the market – predictive and prescriptive maintenance – likely to grow the most. These categories will account for the majority (over 60 percent) of the maintenance analytics market by 2019 increasing from only 23 percent in 2014.

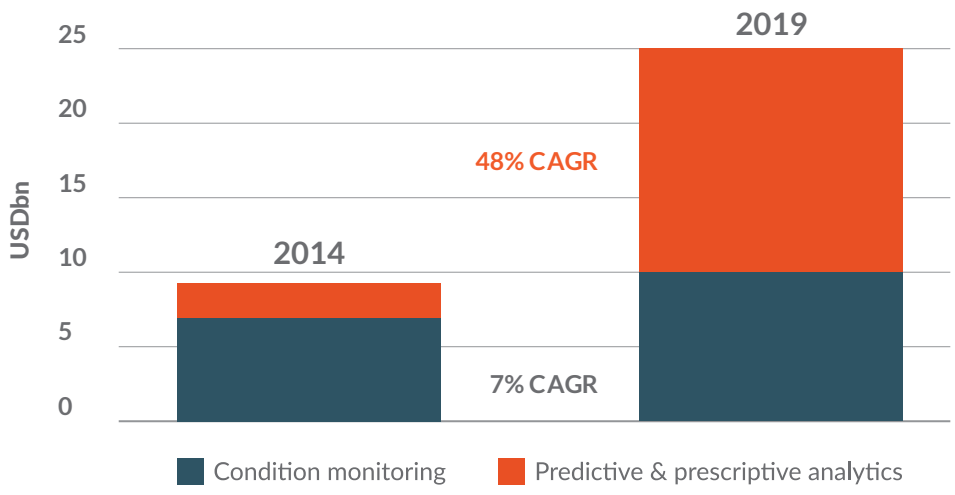

Figure 2: Maintenance analytics market size and growth (Source: ABI Research)

The transition offers tremendous opportunity for enterprises to move from incrementally improving their delivery of products and services to using real-time data to make positive changes on the fly - for individual assets and overall processes. The trends also present a massive opportunity for investors.

What is the opportunity?

While the transition will be significant as PdM becomes a reality, the ideas are not new. Indeed, precursors to today's PdM solutions started to evolve in the late 1990s / early 2000s (*see section The origins of predictive maintenance analytics*). However, the combination of high sensor cost, limited data, and the need to apply specialized algorithms to niche applications limited scalability and, in turn, adoption.

With dramatic advances in machine learning, declining cost of sensors, and improvement in their accuracy, **an emerging class of artificial intelligence (AI)-driven prognostics promises more compelling benefits to a wider range of users at significantly lower cost.** At Momenta Partners, we believe an inflection is at hand within the next 12-18 months.

One part of the opportunity is well-known and largely centered around the economic benefits from cost reduction (*see sidebar The economic impact of PdM analytics*). While there is limited data on the impact of optimization solutions given their recent emergence, there is every reason to believe that process optimization will deliver further economic benefits to industrial players across the value chain.

The broader opportunity, however, rests in the potential for PdM to disrupt those value chains and to resize its profit pools, essentially changing how much of the economic value accrues to different players. By providing greater transparency throughout the supply chain, PdM analytics will particularly empower the machine manufacturer and its owner/operator – to the detriment of everyone else in between.

This is not the first time such a transition has happened. In the 1990s, US manufacturers had already started to move their business focus downstream, from simply selling machines to providing services, in response to stagnating sales and the broader industry's move to Asia.

Since then economic value has continued to move downstream. Indeed, in most sectors, revenues from downstream activities like service and maintenance are significantly greater than the value of the underlying product sales themselves. In 1991, the average household spent 5 times more on auto-related expenses than

Dealer revenue and profit mix (in%)

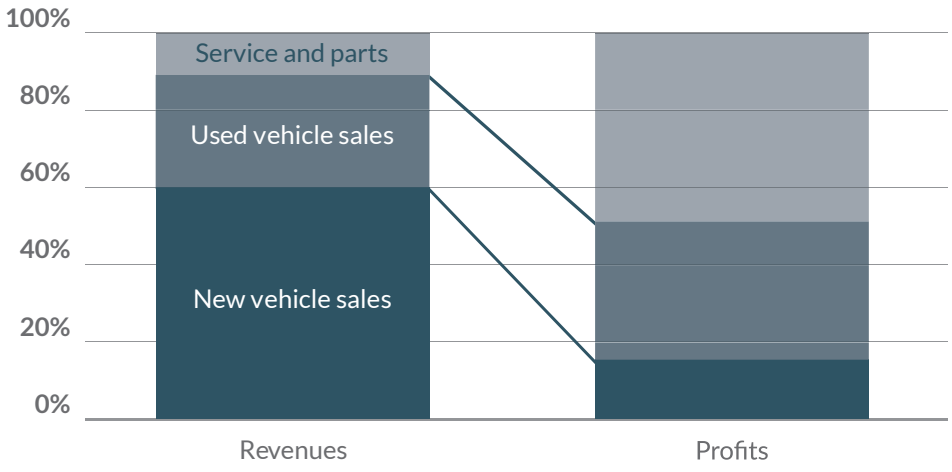

Figure 3: European auto dealer revenue and profit mix (1999, Bain & Co)

on the purchase of a new car. Within the industry, auto dealers made almost 60 percent of their revenue from new car sales; yet services and parts, which was just over 10 percent of sales, accounted for over 50 percent of profits (*see Figure 3: European auto dealer revenue and profit mix (1999, Bain & Co)*). In almost every sector, the money is not in the product itself, but in its operation[1] and upkeep.

By providing transparency into operations and helping predict, prevent, and

The economic impact of PdM analytics

According to the US Department of Energy, predictive maintenance solutions can have a significant impact on maintenance costs. Their 2010 guidelines, for instance, demonstrate that the implementation of a PdM program in the oil & gas industry can reduce maintenance costs at least 25 percent, eliminate over 70 percent of breakdowns, resulting in a 20-25 percent increase in production while providing a 10x return on investment.

The same applies to the power generation sector - maintenance costs for predictive maintenance programs at $9 per horsepower per annum were half that of a reactive maintenance program (fixing after the fact), and 30 percent lower than a preventive program.

[1] Go Downstream: The New profit imperative in Manufacturing, HBR, September-October 1999

optimize around failure and a host of other characteristics, **PdM analytics will allow companies to capture more of that value chain than they could have otherwise.** This explains why, in our research, we found that companies such as telco operators – with no prior experience in manufacturing or PdM, were seeking to build and offer a suite of PdM solutions to offer to their clients. GE, long a leader in the industrial services market, has also been one of the first to make a move into the PdM market, positioning Predix as the platform that delivers analytics services. This industry trend mimics Apple's move from hardware manufacturer to platform provider.

By providing transparency into operations throughout the supply chain, PdM analytics will enable companies - particularly the OEM and owner / operator - to potentially capture more value in their industry, to the detriment of everyone else.

The barriers to adoption

Despite the obvious benefits (*see Figure 4: The PdM opportunity in Oil & Gas*), actual PdM adoption has lagged far behind the promise. A 2014 study by Roland Berger[2] found that only 15 percent of time was spent on predictive maintenance activities vs. 40 percent on reactive maintenance and 45 percent on preventive maintenance. As a result, only 22 percent of managers were happy with their maintenance programs. The challenges fall into two categories – issues intrinsic to industry, and those relating to the maturity of technology. One of

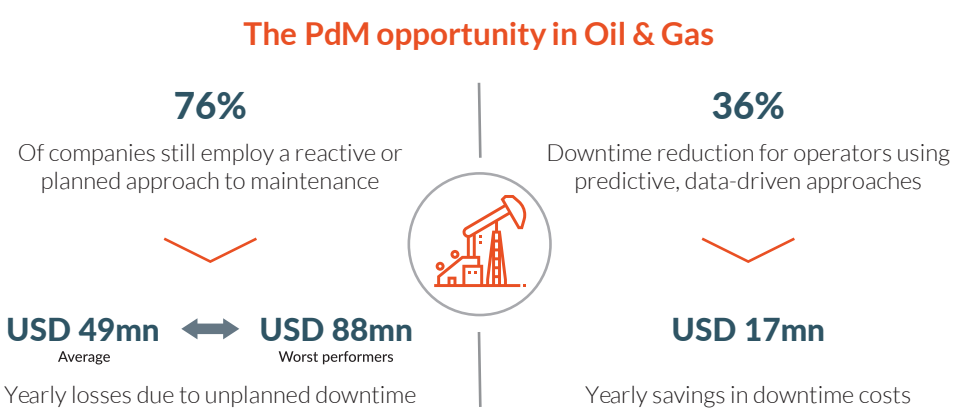

Figure 4: The PdM opportunity in Oil & Gas

the intrinsic hurdles to adoption is human. In most industries, there is a deep reverence for experts. However, advances in artificial intelligence and machine learning are happening so fast that managers in **many of the industries where new technology could be most revolutionary don't even realize what is now possible.** Understandably, job security concerns may also dissuade experts from embracing technologies that might help them improve performance, at the risk of undermining their own role in the company.

The technology industry is accustomed to rapid cycles of product and architectural evolution, with today's state-of-the-art expected to become dated in 3 years. In the industrial world, especially where critical equipment is involved, these cycles can last up to 40 years. As a result, many industrial businesses will often postpone adopting new technology, because upfront costs are expensive, technologies may not be proven, and leaders may be resistant to change processes that may have

[2] Predictive Maintenance: Is the timing right for predictive maintenance in the manufacturing sector? Roland Berger, November 2014

been intact for over 30 years. **Ironically, the lure of new features and the dynamic pace of change in PdM may cause many industrial firms to delay decisions until the dust has settled.**

Another intrinsic challenge is the **limited availability and ownership of data.** In our research, we found that while the solutions we assessed delivered economic benefits when fully up and running, implementing them in the first place was more difficult than expected. In most cases, a large company needs much more time to collect, scrub, and share necessary data than a startup needs to train the solution itself. The problem is even more pronounced in industries where ownership, operation, and maintenance of the machines and thus data ownership may be split across different parties; or where there is a large proportion of legacy assets – which is often the case today.

Although the declining cost of sensors and data management technologies, increased connectivity and the adoption of standard platforms are helping to alleviate these challenges, it is still unclear who will eventually own the data and if the analytics application providers will have the access necessary to build mature solutions. Data availability and ownership remain key hurdles facing the industry.

Finally, at least two additional technical challenges have also held back adoption.

First, PdM solutions have typically required a high degree of vertical customization - with specific models developed for each use case (we refer to this as a **model-driven approach**). This approach offers a high degree of accuracy, but at higher cost; the lack of horizontal replicability across industries reduces economies of scope and hinders widespread adoption. Furthermore, developing new models for any specific use case is laborious. This partly explains why condition monitoring – which is largely a horizontal and repeatable solution – has been the most widely adopted. The industry is changing, however, as a newer generation of artificial intelligence powered solutions moves to **data-driven machine learning approaches** that accelerate deployment and training cycles.

Second, PdM applications **need to address a richer array of business problems and serve up actionable solutions to users,** not simply flag failures. We are starting to see this happen as predictive and prescriptive maintenance applications integrate ever-larger sets of input - delivering more useful output not just at the asset level, but for the factory and eventually the enterprise (*see Figure 5: PdM analytics classification framework*).

These two trends – the use of data-driven vs. model-driven approaches, and the move to higher forms of intelligence, will mean that as the market matures, PdM solutions will dynamically support a wider range of assets and deliver insights that incorporate a wider range of variables. The result for end users will be lower cost, better ROI and eventually higher levels of adoption.

Interestingly, even as PdM solutions expand their reach, the space may also be encroached on by startups entering from other segments. As pointed out by Vito Ventures, there is a generation of industrial security companies that conduct passive data monitoring for anomaly detection. As the data they monitor grows and includes machine performance data, there remains the possibility for these companies to expand into delivering maintenance problem detection and prediction.

Industrial maintenance by the numbers

A 2014 study by Roland Berger found that maintenance is increasingly seen as a strategic business function as opposed to a necessary evil.

- In manufacturing, only 15% of time was spent on predictive maintenance
- 40% of time was spent on reactive maintenance
- 45% of time was spent on preventative maintenance
- One in every three dollars spent on preventative maintenance was estimated to be wasted
- Manufacturers would like to spend 33% of their time on predictive maintenance
- In the end, only 22% of managers were happy with their maintenance programs

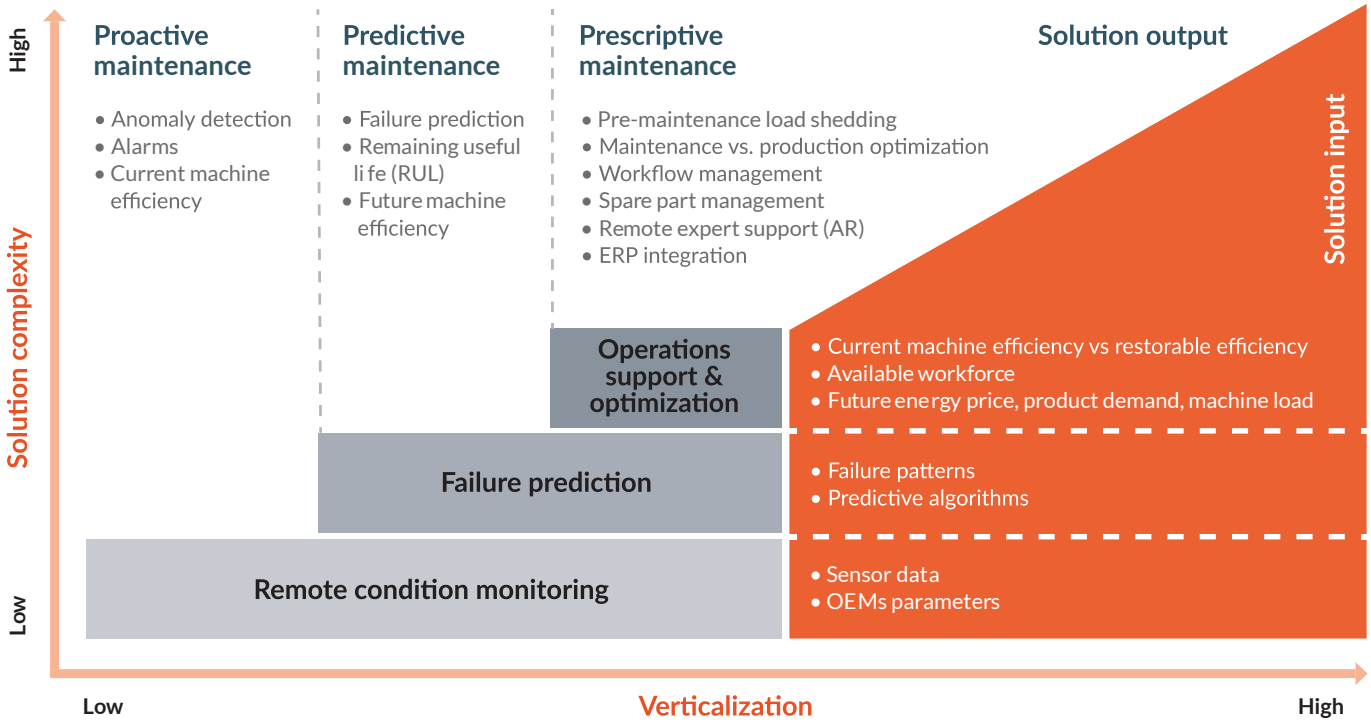

Figure 5: PdM analytics classification framework

The determinants of success

So, what determines if a solution is going to be useful to the end customer and therefore successful in this market? We evaluated companies on a range of technical and business variables (*See sidebar: PdM solution elements for success*). What emerged was a heterogeneity of approaches, incorporating different inputs and delivering increasingly complex value - with the goal being seamless optimization.

Ironically, while most startups touted the accuracy of their prediction engine as a key differentiator, we found this of limited use to the end customer beyond a certain threshold.

Initial cost and total-cost of ownership (TCO) considerations appear just as critical in assessing whether a solution can be adopted within a particular industry. For instance, we found an Israeli startup with a relatively simple technical approach experienced great success in the wind turbine industry – largely because the solution and its sensors were easy to install on off-shore wind turbines. In this case, the cost of setup proved the key determinant to whether any solution was adopted.

Second, **business model considerations** are critically important. In the absence of widespread standardization around the underlying technologies (sensors, platforms, software Application Enablement Platforms– or AEPs), most solutions were built around a vertically integrated technology stack. However, as industrial platforms deploy at scale we anticipate that focus will increasingly shift toward the value-creating elements – specifically predictive and prescriptive applications.

For instance Elisa, a leading Finnish telco, recently launched a competition seeking partnerships with startups with a particular interest in helping it extend PdM analytics capabilities to its clients. The catch is that solutions must run on Elisa's own platform (ThingWorx), and therefore must be deployable in brownfield applications. Increasingly, providers' focus will shift from offering an all-in-one solution to offerings that provide users the ability to work across different platform and data sources.

Third, the **go-to-market strategy** itself can be relevant. Solutions that require significant customization by the customer to derive full benefits will require direct sales channels and/or well-trained indirect sales partners. This is particularly true for optimization solutions that are still in their infancy and require a deep understanding of on-site operational processes. Conversely, solutions that are already highly verticalized and require machine parameter tuning will benefit from partnerships with OEMs.

Finally, while technology is a limited indicator of potential success, the approach is a critical technical consideration. Model-driven approaches require human tuning, are vertically focused and offer a high degree of accuracy. However, data driven approaches are increasingly emerging as broadly applicable tools that are "good enough" for a range of use cases. They may not be as accurate, but they can be developed and deployed faster – assuming the underlying data is available. While each approach offers specific benefits, hybrid approaches that employ human intelligence to combine model- and data-driven approaches might be necessary in the near term to realize the full solution potential.

PdM solution elements for success

1. Initial cost and total-cost-of-ownership

2. Business model

3. Go-to-market strategy

4. Vertical specific approach

An innovation market map

Walk the halls of any major industrial trade show this year and it will be hard to see a booth that does not showcase predictive maintenance solutions. Indeed, PdM seems to be the "use case of the year" for Industrial IoT.

With increasing data availability, the race is on to deliver competitive PdM solutions. Younger companies have been at the forefront of this innovation race, often ending up as acquisitions for those incumbents looking to close capability gaps – as evidenced by the acquisition of DataRPM by Progress.

Interestingly, the level of competition is higher, and likely to get higher still.

From our analysis, we developed a market map of startups active in four verticals, which confirms what we have heard anecdotally (*see Figure 6: PdM startup market map*).

First, **condition monitoring is relatively commoditized,** with many companies offering simple solutions. While many were focused on specific verticals, the technology itself is horizontally applicable.

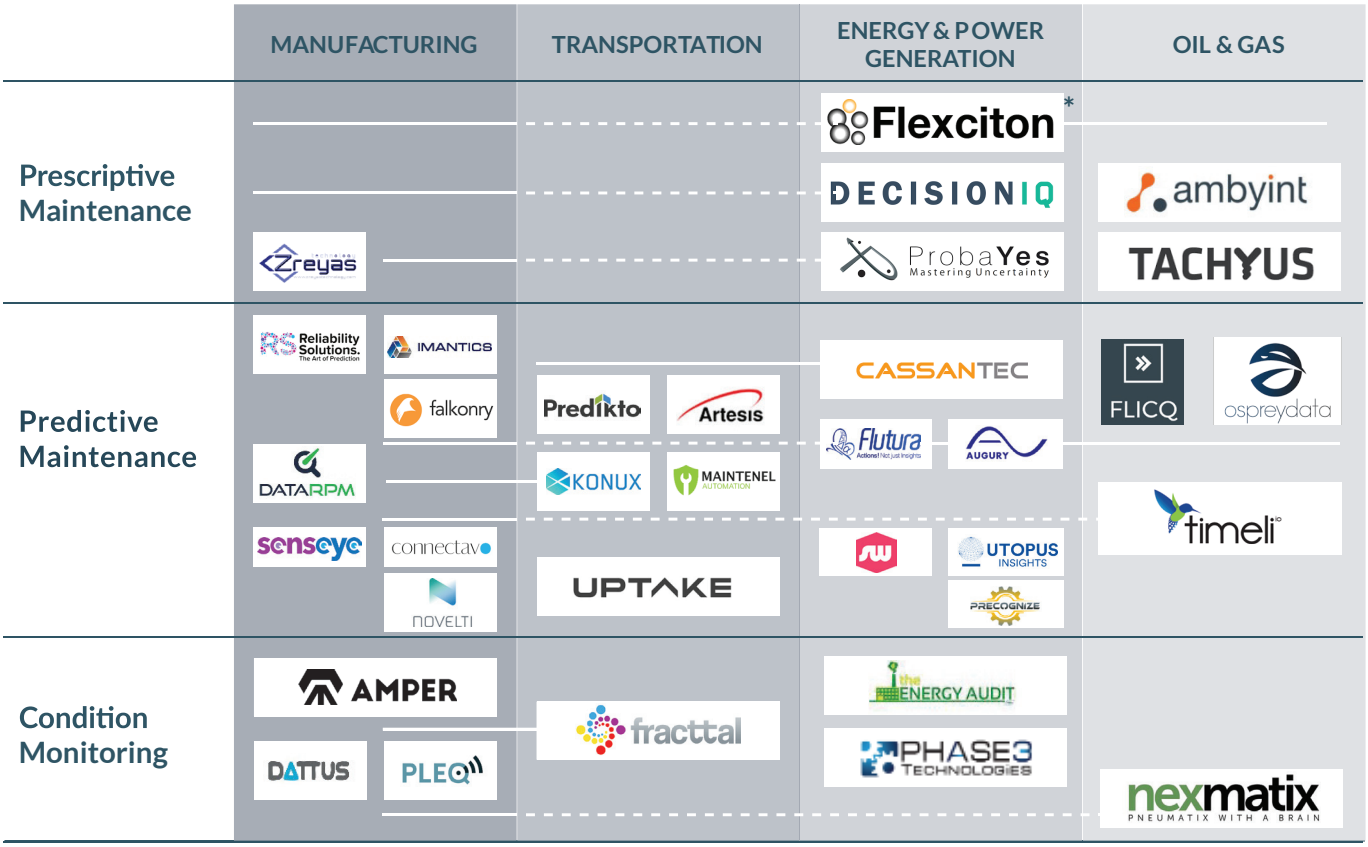

Figure 6: PdM startup market map

*Company provides only optimization

Second, the **predictive maintenance landscape is extremely fragmented and competitive.** While numerous companies highlight their algorithmic capabilities as key differentiators, we find limited differentiation in technology, lack of adoption from customers, and confusion amongst startups as to where real value lies. The emergence of data-driven models promises to solve some of the problems inhibiting adoption. However, these solutions always have to be positioned vertically both to identify key pain points, but also to convince customers to buy. Furthermore, it is unclear if any technology differentiator will truly emerge to provide companies with enduring advantages.

Finally, **prescriptive maintenance is an extremely rarefied space.** Only a handful of startups understand that predicting failure is of limited use if customers don't know what to do with that information. To address this, some companies such as DecisionIQ are combining prediction with decision-making, while others such as Flexciton are partnering with prediction providers. Others such as Solopex are going further, looking to optimize a full suite of operational and scheduling problems, with maintenance just one subset.

These higher-level intelligence functions are just starting to emerge and the level of vertical customization required continues to be high. As noted by Steffen Funck, investment manager at Statkraft Ventures, "It is unclear how incumbents can most efficiently adopt the capabilities of such solutions into their processes and realize the full value potential. Will this be solved by technology automation and if so will it be provided by today's analytics companies or is this going to be the job of traditional consultants?"

Nonetheless, this is where the true value of PdM solutions will eventually manifest. By integrating operational data with ERP, we will have solutions that finally "close the loop" for business.

> *"It is still unclear how incumbents can most efficiently adopt the capabilities of such solutions into their processes and hence realize the full value potential. Will this be solved by technology and if so will it be provided by today's analytics companies or is this going to be the job of traditional consultants?"*
>
> **Steffen Funck,**
> Investment Manager at
> Statkraft Ventures

Conclusions

The era of real-time, inexpensive, and reliable data from industrial equipment has arrived and the race is on for the killer maintenance app that goes above and beyond the niche applications we have seen to date.

Given the pace of change, deciding where to put your money either as an investor or an equipment owner or operator can be a daunting task. The challenge hasn't dissuaded an increasing number of incumbents from experimenting with PdM solutions.

PdM is still mostly in experimental stages though, and **the pace of technology innovation continues to outpace actual industry deployments.** There are too many startups, each with little commercial traction. The bottom line is that many companies still employ preventive, scheduled-based maintenance and are only just moving to remote condition monitoring. Moving to higher value forms of preventive and prescriptive maintenance is further out.

Today there is real demand for solutions that are simple and easy to install, that help customers start their journey along the PdM innovation curve. Condition monitoring and dashboarding are popular and commoditized. Once entrenched with customers, we anticipate them evolving quickly.

Interestingly, we found that **the prediction algorithm is not the key determinant of success.** As we noted, deployment scenarios and use cases within any given industry have unique sensitivity to specific variables (e.g. installation cost, TCO, or data requirements). First and foremost, we need to identify how and where any solution will be deployed even if the solution is horizontally applicable. For marketing and adoption, applications always need to be positioned in specific verticals.

Most important, **closing the decision loop is an emerging but compelling differentiator.** Solutions that help companies make better decisions, rather than simply predicting failure, are emerging. As analytics get commoditized, true value will emerge where companies can combine data and rules to drive business decisions.

The origins of predictive maintenance analytics

While the hype around PdM analytics is new, the field itself has been gradually evolving over the past 15 years. To understand some of the critical challenges in the space, it is useful to look at how we got here.

Evolving technology foundations

The PdM landscape has evolved in several discrete phases. Condition monitoring solutions began to take hold in the late 1990s and early 2000s. These offerings provided simple, high-level visibility into the conditions of machines and facilities. They did not do much to prevent system failure, but they could be helpful in getting early warning for major failures, but their biggest use was post-mortem analysis. From 2007-2012 software as a service (SaaS) diagnostics solutions started to emerge, offering the additional ability to identify and highlight common problems and causes of failure. These solutions were all model-based, that is, used hyper-specialized algorithms to accurately solve the underlying physics equations and identify problems. The downside of SaaS diagnostics applications was that they were hard to scale and usually required complex set-up and tuning.

Higher-level PdM intelligence functions are just starting to emerge.

The next evolution was predictive maintenance (PdM) which occurred between 2012 and 2016. The declining cost of sensors and computing power drove the development and adoption of far more sophisticated algorithms designed to "predict" failures. This first incarnation of PdM was still model-based and inherited some of its downsides. In the last year, artificial intelligence (AI) –based (or data-based) applications have emerged that apply machine learning approaches to the same problem. The use of AI allows for simpler setup, with less dependence on the accuracy of single sensors.

Business models evolve past early limitations

The technical advances from condition monitoring to AI-driven analytics have been accompanied by changes in how providers monetize these solutions. Condition monitoring was mostly a hardware driven model, with minimal data access fees. Generally, these solutions have been successful and have often been tied to insurance for critical applications.

Diagnostics/SaaS solutions typically involved a small set-up fee and recurring subscription fees for delivering analyses. The success of these business models is mixed. Many attempts failed due to the difficulty in sustaining savings and/or demonstrating repeatable value, and solutions often required human intervention.

More recently, predictive diagnostics proved successful in niche applications, but never gained widespread traction because of the lack of scalability. Historically, these solutions were extremely sensitive to the accuracy of sensor data and often required constant human attention, limiting their economic value. Value-sharing business models have proven difficult to implement from both the customer and vendor side due to revenue and budget predictability.

Case Studies

Augury

Monitoring and predicting failure in smart building infrastructure

Augury is a SaaS startup using AI to power predictive maintenance solutions. Using sensors that detect vibration and other characteristics, Augury's analytics are derived and tuned for specific models of machines – notably heating and cooling systems. One of Augury's customers is a large private university with 15,000 students spread out across 120 buildings on a 1,000-acre campus, running 5000+ machines overseen by 150 maintenance staff. A central heating and cooling plant provides 90 percent of the heating and cooling on campus, with critical equipment including air compressors, chiller systems, primary and secondary pumps and cooling towers. Augury applied a risk assessment to critical assets quantifying the cost of repairs and downtime, providing suggested diagnostic strategies to provide ample alert time of potential equipment problems.

Augury's solution detected and prevented unscheduled downtime on multiple occasions. They detected advanced bearing wear for a cooling tower, helping the university avoid up to $20,000 in bearing or full motor replacement cost because the system was still under warranty, while also avoiding $30,000+ in annual risk. Augury also detected structural mechanical looseness in the boiler feedwater pump, which would have put 50 percent of hot water at the facility at risk – which avoided up to $10,000 for equipment replacement and $60,000+ in annual risk. For a chilled water system pump, Augury detected a misalignment between the pump and motor. The cost for alignment and coupling replacement was $2,000 compared to a cost of up to $30,000 for full replacement.

Connectavo & Pruftechnik

Smart holistic maintenance for a sewage treatment plant

Connectavo GmbH is a Berlin, Germany based startup providing industrial maintenance software (CMMS), including proprietary machine analytics. PRÜFTECHNIK Dieter Busch AG is a mid-sized global maintenance technology company that offers products and services for alignment, condition monitoring and non-destructive testing. One of their joint clients is a sewage treatment plant with numerous motors and pumps with high (>90%) availability requirements. Due to high initial costs of online systems, the client was using PRUFTECHNIK handheld vibration analyzers.

The solution, combining PRUFTECHNIK and connectavo technologies, enables the client to both monitor assets locally for critical exceptions and to drive maintenance actions using data in the Connectavo portal. The portal delivers smart monitoring and maintenance actions that combine traditional maintenance and predictive maintenance, tracking alarm thresholds, dynamic trends and performing anomaly detection to provide a holistic view of machine health. The total cost in the first year was less than EUR 25,000, declining in subsequent years due to the SaaS based model.

The companies delivered an integrated solution based on existing vibration analyzers and the cloud-based maintenance portal, helping streamline processes and reducing mean time-to-repair (MTTR) significantly. As a result, the plant was able to perform integrated machine health scoring that **reduced expected downtime by 10%, delivering full ROI in the first year.**

Founded by deep practitioners in the Connected Industry space, **Momenta Partners** deploy their industry-leading Advisory, Executive Search, M&A and Venture Capital practices to accelerate the growth of Connected Industry companies and companies preparing for digital transformation.

3 Practices Hyper Focused on the Enterprise IoT

Momenta Advisory helps companies at all life stages capture the Connected Industry opportunity, providing strategic and operational guidance for digital transformation.

Momenta Venture invests in early-stage Connected Industry companies and advises clients in buying or selling strategic Connected Industry assets. Interacting with hundreds of Connected Industry companies worldwide, we have a pipeline of M&A targets and market knowledge inaccessible to our competitors

Momenta Executive Search is the top retained executive search firm for Connected Industries. We have placed exceptional, strategic talent across all functions, within all major vertical markets in every continent for Fortune 500 leaders and venture-backed innovators.

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