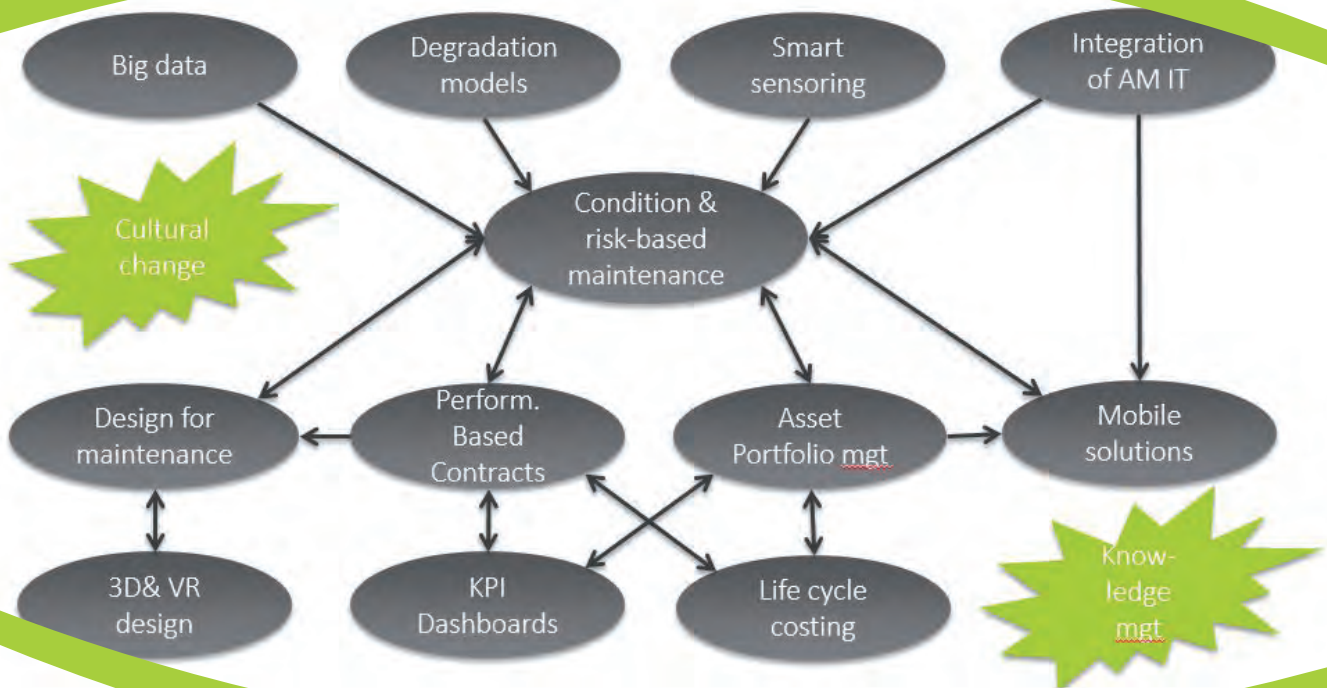


# Smart Moves for Smart Maintenance

Findings from a Delphi study on 'Maintenance Innovation Priorities' for the Netherlands



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# Preface

## **Background**

This study was originally commissioned by the former Dutch Institute of World Class Maintenance (DI-WCM) - the precursor to the present foundation - World Class Maintenance (WCM, [www.worldclassmaintenance.com](http://www.worldclassmaintenance.com)), in response to questions from its stakeholders for a 'Maintenance Innovation Agenda' to guide public and private policy-making in the field of maintenance. In 2015, DI-WCM also sponsored the involvement of the first phase of this study with support from Mainnovation, a consulting firm. In its present and final form, it is intended as a cornerstone for the overall WCM policy and the Dutch service and maintenance/asset management community. It also aspires to form an inspiration for the service/maintenance/ asset management ambitions of companies, governments, and knowledge institutes across the industrialised world.

## **Purpose**

The purpose of this document is threefold:

- Firstly, this document provides an overview of the most important innovations in the field of maintenance in 2016.
- Secondly, this document identifies and analyses the root causes which are holding back the implementation and diffusion of these innovations.
- Thirdly, this document proposes sound policies within the company, the industry, and at the level of society itself to remove these root causes and thereby boost innovation in this important field.

## **Audience**

The primary audience for this report is the community of professionals in, and managers of service, maintenance and asset management in the Netherlands. One specific audience is the people who helped to write it: the group of fifty experts who actively contributed to the Delphi study that forms the basis for the insights which are contained in this report. The broader audience for this report is formed by policy makers and executives in all sectors in which technical assets and their costs and performance play an important role: from public infrastructure to process industry, the maritime sector, the aerospace sector, the energy sector and the discrete manufacturing sector. This report is also very much intended for education and training professionals and executives, as the courses students may take tomorrow determine what skills they will have afterwards. The design and content of these courses should be driven by the stated innovation needs of society today.

## **Authors and acknowledgements**

The primary authors of this report are Henk Akkermans (professor Tilburg University, and director WCM), Lex Besselink (former director DI-WCM), Leo van Dongen (professor Twente University and CTO Netherlands Railways), and Richard Schouten (director of maintenance and turnarounds, Sitech Services). Important inputs for earlier phases of this study were provided by Klaas Smit (professor emeritus TU Delft), Geert-Jan van Houtum (professor TU Eindhoven), Corina van Unen (former programme manager DI-WCM), Deola Baauw, Pieter de Klerk, and Roderik de Wolf (consultants at Mainnovation), Paul van Kempen (director of operations WCM), and Moniek Schoofs (communications executive WCM).

## **World Class Maintenance**

World Class Maintenance (WCM) is a non-profit foundation which aims to achieve world-class levels of service, maintenance, and asset management for Dutch industry. It is associated with the FME (the Dutch employers' organisation in the technology industry). It seeks to realise its stated aim by engaging in collaborative projects with market organisations, public organisations and educational institutes in the areas of human capital and open innovation. WCM operates as a catalyst for change in these projects.

# Executive Summary

## **I. This is the time at which maintenance takes centre stage in society and business**

Historically, maintenance, service and asset management have taken a modest position in society and business. When things were going smoothly, maintenance staff were doing a good job but few people noticed. Whenever technical problems occurred, these functions received attention but not in a favourable manner. This is now rapidly changing. Presently, both the demand and the supply side of innovation are receiving a disruptive boost.

On the demand side, there is a distinction between long-existing technical assets and new ones. Most of the existing asset base in the public and industrial infrastructure in the industrialised world has reached or surpassed its original technical lifetime. This poses great challenges and provides great opportunities to extend lifetimes, increase safety and reduce energy costs and the CO<sub>2</sub> footprint. For new technical assets, the broader business trends of servitisation and performance-based contracts mean that customers increasingly want to have a 'power by the hour' mode of operating technical assets, primarily paying for availability and uptime, not for ownership. Both trends for old and new assets demand different, new, and innovative approaches to maintenance.

On the supply side, a combination of new technologies leads to a disruptive mix in which, suddenly, innovative solutions become technically feasible and economically affordable. This generates a broad wave of innovative maintenance solutions which makes today the time at which service/maintenance/asset management takes centre stage in society and business.

## **II. For the purposes of this research project, a broad representation of experts was consulted in the maintenance field of Dutch industry and academia**

The breadth of maintenance applications and the depth of expertise required in looking at present and future innovations, as well as the uncertainty inherent in the future of many of these areas, makes it obvious that a large group of knowledgeable experts has to be consulted in order to be able to develop a sound overall picture. In light of this, in the second half of 2015 names and contact details were collected for a large group of experts through a 'snowballing' round of interviews which involved over a dozen university professors in the field of maintenance management. These were augmented by input from members of the advisory board of DI-WCM and, for any blind spots that may have remained, the CRM system of DI-WCM. This assured a broad and knowledgeable representation from a wide variety of industry and technical maintenance system backgrounds (Smit, 2014).

In the second half of 2015, a total of 183 experts were invited to participate in this study, out of which 64 (35%) accepted this invitation. The survey was conducted in two rounds, with the second round providing the experts with verification and an opportunity for improvement. In the end, fifty full and usable responses were obtained from the first and second rounds. A significant subset (twenty) of these fifty experts convened in February 2016 in a so-called policy Delphi session (Vennix, 1996; Akkermans et al, 2003) to analyse what problems these innovations were addressing and what the root causes of those problems may have been. The present report is the result of subsequent analysis by the four authors of these outputs.

### **III. The key innovations for the coming years are process-orientated, rather than technology orientated**

It is the technology-orientated innovations that capture most of the attention in the press, at conferences, seminars and in government subsidy programmes. However, the message that resonates from the fifty experts who were consulted for this study is that process innovations will be far more important in the coming years (balanced by supportive innovations in technology and people). Out of our 'Top-14', seven innovations were process-based:

- *No 4 Condition-based maintenance (CBM) and risk-based maintenance (RBM):* implementing an asset control concept where assets are maintained just when they need to be, based on an assessment of their current performance. While those assets which are most important for the business receive special attention;
- *No 5 Design for maintenance:* incorporating maintenance-related considerations into the design of new technical assets;
- *No 8 Degradation models:* developing formal models which calculate the remaining useful lifetime based on current performance data;
- *No 9 Life cycle costing:* developing models which calculate the cost of acquisition, operation, maintenance and decommissioning of technical assets across the entire lifecycle;
- *No 10 Asset portfolio management:* developing a comprehensive overview of the current and anticipated costs and performance of all technical assets;
- *No 11 Performance-based contracting:* providing incentives for suppliers and contractors in order to be able to optimise performance levels for asset owners, providing incentives for asset owners to get them to optimise their collaborations with suppliers and contractors;
- *No 13 KPI Dashboards:* implementing a coherent set of asset portfolio KPIs which monitor past and current performance levels and the costs of technical assets in order to be able to assess future developments.

### **IV. Suddenly, there is a massive shift in the highest priority levels towards data-driven technical innovations**

All five technology-driven innovations in the 'Top 14' are primarily data-driven (where several of the process-driven innovations, such as CBM, are also strongly data-driven). This is a major change from the past and is in line with the rapid rise of digital manufacturing/smart industry throughout the industrialised world. These are the five data-driven technology innovations in our 'Top 14':

- *No 1 Big data:* setting up an IT infrastructure that enables the systematic and comprehensive collection, integration and interpretation of data from a wide variety of sources in order to be able to calculate when and where maintenance is needed;
- *No 2 Smart sensing:* applying sensor technology to monitor the performance of technical assets in order to establish where and when maintenance is needed;
- *No 7 Integrating Asset Management IT systems:* connecting asset management IT systems to other systems in the IT infrastructure to faster and better combine data for maintenance decision-making;
- *No 12 Mobile solutions:* applying mobile technology to increase the efficiency levels of technician activity such as tablets, workflow management systems and augmented reality;
- *No 14 3D design/virtual reality:* using 3D and virtual reality techniques during the design phase to assess the maintainability of technical assets and, during the operational phase, for an 'as built' 3D model tracking all changes digitally.

## **V. Culture/behavioural change and knowledge management are seen as essential conditions for the more rapid progress of all other innovations**

Perhaps surprisingly in a Delphi study which requested innovation in such a technical area as maintenance, cultural/behavioural change (No 3), and knowledge management (No 6) are seen as top priorities in terms of maintenance innovation.

- *No 3 Cultural and behavioural change* can remove roadblocks such as the lack of a fact-based culture, conservatism in investing in new technologies, short-term orientation management, a perceived lack of status when sharing expertise, a lack of integral perspective, a lack of entrepreneurial activities and resistance to change;
- *No 6 Knowledge management* can address knowledge-related roadblocks such as limited big data expertise, limited experience with sensor technology, a lack of experience in new Ways-of-Working, insufficient time and/or experience to conduct systematic enquiries, a lack of experience and/or expertise in the asset management processes and the technical complexity of mastering new techniques.

Further analysis reveals that they are especially important as they remove some of the key roadblocks which have been limiting progress in all other areas.

## **VI. Innovations in finance, IT management, general management and HRM are crucial for enabling innovation in maintenance**

Many of the innovations which are required for world-class maintenance are not by themselves maintenance-centred innovations. This was already true of the two organisation-driven innovations:

- The primary driving role for *No 6 knowledge management* would, in functionally-orientated organisation, come from HRM.
- *No 3 Cultural and behavioural change* has to come from the top, from general management.

But there are more:

- *No 9 Product-life cycle costing* is primarily a financial activity, which may reside more on the purchasing side of the organisation in the case of Asset Owners, or more on the sales side of the organisation in the case of OEMs and contractors. At any rate, it can work to overcome the following roadblocks which are limiting progress in maintenance: the lack of a clear business case for investing in sensor technology, a focus on capital expenditure (CAPEX) - not on operational expenditures (OPEX), a lack of experience in the AM process, difficulty in assessing life cycle costs for OEMs and a complex business case for mobile solutions.
- *No 7 Integrating AM IT Systems* is primarily an IT activity, which will normally reside with the IT department in functionally-orientated organisations, can remove roadblocks such as: the low quality of the data required, a lack of clarity regarding actual performance levels, the low maturity levels of back-office systems and difficulties in integrating the correct data with key parameters.

This clearly indicates that service and maintenance cannot move forward in isolation, but will have to join forces with the other management functions. It has to be propelled by general management in the direction of high-reliability organisations and world-class performance in service and maintenance.

## **VII. Data-driven technologies are seen as key drivers for the other process-driven and technical innovations**

Not only are data-driven innovations ranked as top priorities in maintenance innovation for the coming years, they are also seen as being key in enabling many of the other innovations, as they remove many of the roadblocks which limit progress there as well. The three data-driven innovations in the 'Top 5' illustrate this:

- *No 1 Big data* can overcome issues in: technical challenges in integrating multiple IT systems, dealing with a large diversity of possible parameters, a lack of clarity in what actual performance may be, a lack of insight in leading and lagging parameters, complexity of use and the maintenance of installations over time;
- *No 2 Smart sensing* can overcome issues regarding a lack of actual use of data expensiveness in terms of data sensing, low data integrity, a lack of insight in terms of actual costs during use, and the limited data quality of asset status;
- *No 4 CBM/RBM* can overcome issues with: aged assets with little data generation, low data integrity, difficulties in estimating usage costs during the project phase and again a lack of insight during the usage phase.

## **VIII. Those non-data driven technical innovations which are prominent in news and governmental policies are absent from the 'Top 10'**

Our panel of fifty experts - each with an estimated fifteen-plus years of experience in the field of maintenance - prioritised maintenance innovations very differently from where the main 'buzz' appears to be in the news, at congresses, and also in governmental industrial policies and associated subsidy programmes. High-profile innovations such as 3D-printing ended up being ranked at 17th, with drones and robotics in 20th place. Several of these did not even make it into the top thirty, such as self-healing materials. This may partly be caused by the relatively short time horizon which was investigated (2016-2020), but this mostly appears to be due to the experts simply weighing process-related, organisation-related and data-related innovations more heavily in favour of world-class maintenance.

## **IX. The majority of these maintenance innovations have been slumbering for decades - until now, when business management will need to take a lead in implementing them**

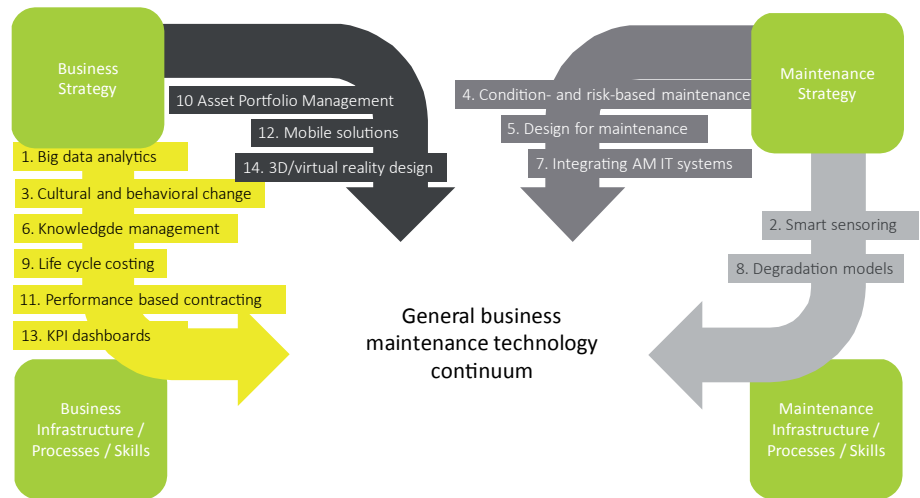
Except for data-driven technological innovations, most of the 'Top 14' maintenance innovations have been around for a long time. Life cycle costing, performance-based contracting, and asset portfolio management all date back at least to the 1990s. Even the broader use of condition-based maintenance was advocated as early as 1984<sup>1</sup>.

One key explanation for this is that, for the majority of innovations in the 'Top 14', the lead has to be in general business management, not with maintenance management. This is illustrated in Figure 1. As the top left-hand corner of this figure shows, general management and not maintenance management is primarily responsible for implementing innovations such as big data, cultural change, knowledge management, life cycle costing and KPI dashboards. Only two innovations - smart sensing and degradation models - are primarily the responsibilities of maintenance management/asset management: smart sensing and degradation models, as shown top left.

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<sup>1</sup> See Marcelis, W J (1984) *Onderhoudsbesturing in ontwikkeling*. PhD thesis, Universiteit Twente, Proposition 6 (in Dutch).

Figure 1: Various business-technology alignment strategies



Three innovations are the ultimate responsibility of general management but are delegated to maintenance/asset management, as the bottom left-hand section of Figure 1 shows: asset portfolio management, mobile solutions, and 3D/virtual reality design. Three other innovations are ultimately the responsibility of maintenance/asset management, but require active support from general management and other functional managers: CBM and RBM, design for maintenance, and the integration of asset management IT systems.

This implies that, now that world-class service/maintenance/asset management becomes key in terms of corporate survival, the management of other business functions and general management will have to join forces with technical management in order to be able to implement the required innovations sufficiently quickly.

**X. Implementation towards smart maintenance champions will require more experimentation, collaboration, risk-taking and speed**

In the past five to ten years, most maintenance managers have focused on increasing the availability of the assets, extending lifetimes and reducing maintenance costs. So far, that strategy has been successful. However, it is clear from this study that this same strategy is no longer going to be sustainable for the next five to ten years. In line with the overall digital disruption in society, organisations will have to embrace 'smart maintenance', and shift their focus from cost-cutting to innovation, from maintenance as a utility to maintenance as a competitive capability.

In doing so, it appears that organisations which are aspiring to become 'smart maintenance' champions will have to follow the same path that all organisations which are aspiring to excel in their digital strategies see before them.

According to a recent MIT report, companies with such digital strategies in all fields of business share very similar characteristics: *they all have cultural mindsets that relate closely to the idea that digitally maturing companies value experimentation and speed, embrace risk, and create distributed leadership structures. They also foster collaboration and are more likely to use data in decision making* (Kane et al, 2016, p10). These are the 'smart moves' that all organisations will have to take on their path towards smart maintenance maturity.

## **XI. Collaboration within one's own organisation and with other organisations is essential in order to be able to gain speed and direction**

Implementing these innovations will require collaboration at a much greater level than before and in more directions than before.

- Firstly, it requires collaboration in the boardroom. Maintenance, service, and asset management need to become core topics of discussion for all areas of management, not just an aspect of the operations manager's portfolio. Most key maintenance innovations start with general management and other functional managers so, without their sense of ownership and commitment being in place, progress will be too slow for it to be able to become one of the leaders in our new digitised marketplace and society.
- Secondly, it requires collaboration with other companies working in open innovation projects in the same industry, ones which are facing similar challenges. Collaboration with direct competitors will remain problematic. Together, these companies can cross the so-called 'valley of death' from a promising technology idea to a successfully operating business venture, since they can together shorten the time to market and can reduce the costs of innovating to get there. The concept of smart industry field labs as advocated by the Dutch Ministry of Economic Affairs and FME is a very powerful mechanism in terms of offering opportunities when it comes to fostering such a process of collaboration between multiple companies.
- Thirdly, it requires collaboration with education and research institutes of private companies and public organisations in these open innovation projects, but also in shaping the human capital agenda together in order to meet the challenge of having people on board with the right skill sets so that they are able to execute these new smart maintenance concepts.
- Fourthly, it requires collaboration with government, not only at the local level and the national level, but also at the European level. For many of the innovations listed here, even with open innovation projects and horizontal collaborations, the business case during the start-up phase remains too frail to justify investments. Especially for businesses that have been caught in a vicious spiral of cost-cutting in order to be able to survive today and thereby have inadvertently cut back on innovation with the result that they hurt their competitiveness tomorrow. Government support on a limited scale, but administered once again smartly, will be effective in reversing this vicious cycle into a virtuous one: one in which small-scale, funded field experiments which can yield promising results can justify larger follow-on investments by the organisations themselves. With this leading towards a successful transition to world-class maintenance performance.

## **XII. There is an important role for independent knowledge brokers / networkorchestrators/catalysts for change such as World Class Maintenance**

In identifying the most promising areas in which collaborative open innovation projects should be innovated, in bringing together the right players from education, research, business and government to staff such projects, in orchestrating such complex field labs with dozens of independent parties collaborating effectively and in helping to catalyse change in those organisations which want to become the new smart maintenance champions, organisations such as WCM



play an important role. There is a great need for independent parties who work 'for the common good' but at the same time are very closely involved in the daily work of innovation 'in the trenches' and still have close connections to those research and education institutes which are committed to the broad field of maintenance.

It is not easy to set up such an independent party. It is usually better to look for ones that already exist and to help them to grow to the size and capability levels required in order to fulfill such a role. WCM already performs such a role today, and aspires to take that role to the next level, together with a 'coalition of the willing' from Dutch industry and academia. This report outlines the content and direction of this task and makes it clear for what we as WCM are aiming and for what we can be counted in the coming years. That being said, we remain keenly aware that 'the only constant factor is change'. So we will keep a keen eye on the continued validity of this outlook for the 2016-2020 period, and will do so well before 2020 arrives...

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# 1. Introduction

## **Service, maintenance, and asset management are more important than ever for our society**

This is a special time for the field of maintenance<sup>2</sup>. It has always been a very important, but also not quite such a visible, activity in our society. These days, however, it appears that maintenance is more important to society than ever before and also more visible to society than ever before. This trend is expected to continue for some time. There are both society-related (termed 'societal') and business reasons as well as technological reasons for this unprecedented relevance of and interest in maintenance.

The societal and business reasons are very broad indeed, and touch the core of modern society. If we, as an advanced civilisation, are to survive then we will need to succeed in making society more sustainable and less energy-consuming and one which emits lower levels of greenhouse gasses. Maintenance at the world-class level has an important contribution to make in all these areas. Moreover, in Western Europe, North America, and Japan, technical assets have become aged<sup>3</sup>, which creates a much greater demand for maintenance of the same assets than, say, ten years earlier. Besides this, it creates another demand for maintenance, including life extension analysis. Many of our factories here and in the US and Japan are over forty years old; the number of incidents related to them are rising. Our public infrastructure - roads, bridges, tunnels, along with electricity, gas, and water networks - are old and are beginning to fail. In some Western countries this is even more clear than it is in others, but nonetheless all such systems are aging further. At the same time, the generation of technical staff who originally helped to build these public and private infrastructures is retiring, leading to a true exodus of deep and often tacit knowledge about how to maintain assets well.

Also the design, manufacturing, and use of new capital goods such as machine tools, maintenance, or (field) service as it is more often called here, is more important than ever. The trend of 'servitisation' is sweeping the business world, and this brings with it much more of a business focus on earning revenues and making profits with world-class maintenance. Under the trend of servitisation, the 'Original Equipment Manufacturers' (OEM) of capital goods increasingly no longer sell goods but instead sell a service. The proper functioning of the equipment they make against guaranteed performance levels. If, under such contractual conditions, maintenance is executed poorly, the OEM loses competitiveness quickly. The OEM which can design its capital goods in such a way that maintenance becomes less problematic and which can execute its service and maintenance work in a superior manner will become the dominant party in its business.

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<sup>2</sup> In this report, the term maintenance is used for activities that are often known under different names. For instance, within infrastructure, the term (technical) asset management or (T)AM is more common. In the context of capital goods manufacture, such as machine tools or automotive or windmills, the terms service or field service are better known. In defence of this, one tends to speak of sustainment. In the maritime and aerospace sectors, the most popular term is Maintenance, Repair and Overhaul or MRO. Some authors distinguish professional maintenance engineering from the broader notion of maintenance that we perform as consumers. This report acknowledges this diversity of names for what is, in our understanding, one and the same activity, but employs the generic term maintenance as a catch-all for all of them. Very often, this report will also use the trio - service, maintenance, and asset management - to emphasise the broadness of our field.

<sup>3</sup> Whenever in this report the term 'asset' is used, we refer to a technical, physical asset, not to a financial asset or personal asset or whatever other use the broad term 'asset' has in the English language.

However, this is also a special time for maintenance for technology reasons. A number of technologies come together to create a disruptive innovation in society and in particular in the area of maintenance. This means that the 'best' way to carry out maintenance say ten or even five years ago is very different from the 'best' way of carrying it out today, since there are now many things possible which were not technically or, certainly, economically feasible five or ten years ago. This may sound exaggerated but it isn't. For example, the smartphone has been around for only some ten years. Six years ago, data traffic equalled the use of voice traffic in telecom networks. Last year this had already changed to a 20:1 distribution and it is changing our lives as consumers. Likewise, the rise of the 'Internet of Things' will change our lives as professionals dealing with technical assets. If, last year or this year, the number of machines with access to the internet equalled the number of people with access to the internet, this distribution too will change to a 20:1 distribution within less than five years.

The same is true of a number of other technologies. Big data, the use of large amounts of data to discover patterns and relationships between a potentially wide array of factors, has been around for decades but is not making the transition into everyday business. No longer are supercomputers and PhDs and years of analysis needed. Instead, companies are reporting successes after some two weeks of data crunching on freely available cloud platforms. Also, a broad application of new materials and ongoing progress in robotisation (such as, for instance, drones) and augmented/virtual reality is changing the rules of the game in society as a whole, and in maintenance in particular.

So, in summary, there is much more need than ever in society for 'smart' maintenance and many more opportunities than ever now exist to carry out smart maintenance. The challenge then becomes to focus on the right ones, and this is what forms the reasoning behind the current report.

### **Innovation priorities for maintenance: seeing the whole elephant**

The problem we are facing is not that there is insufficient attention being paid to maintenance in specific sectors or a region. The problem is that an overview across sectors and topics is missing, and the problem is that this overview is radically changing as a result of the simultaneous rise in the popularity of a number of key technologies. So there are numerous knowledge institutes and professional societies and research groups that have given their attention to maintenance innovation priorities in infrastructure, in the process, aerospace, and maritime industry, the energy sector, the high-tech machine tools industry, and the automotive industry, to mention only those major industries in which maintenance has a significant direct impact on the economy<sup>4</sup>.

There have also been several studies which have focussed on new technologies and methods that are relevant for maintenance, albeit often not from a maintenance-specific perspective but often from a new product introduction perspective, such as new materials, performance-based contracts, design for maintenance, the Internet of Things or IoT, Big Data and data analytics, human factors, hands-on-tools-time, virtual and augmented reality, and so on. In academic literature, maintenance research has so far been under-researched. In contrast to the many leading and high-impact journals on similar aspects of

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<sup>4</sup> One exception in this list is civil infrastructure, ie. the consuming housing and public buildings, which is one of the biggest sectors for maintenance in terms of impact on GDP. However, despite its importance, this part of the economy has remained out of the scope of this study mainly due to the extreme fragmentation of demand and supply here: in the Netherlands alone, millions of consumers and businesses, and tens of thousands of mostly small businesses offer domestic maintenance services.

industrial engineering such as new product development, supply chain management, or purchasing or services, there are at present no maintenance-specific research journals that are broadly read, cited, and of high impact in the broader academic community. As a consequence, a published broad overview from a research perspective on innovation priorities in maintenance across industry sectors has been missing. This is precisely what this report aims to provide. It aims to fill the aforementioned gaps, by offering the following:

- a) a perspective on maintenance priorities across the main industry sectors,
- b) with special attention on those technologies that have very rapidly risen in applicability and popularity in the last one-to-three years, and
- c) from an academic and therefore non-partisan and non-biased viewpoint on industry developments.

In short, this report aims to provide an up-to-date picture of the whole elephant, where so far there have been many fine studies about parts of that great creature. The main limitation for this study remains the fact that it draws on expertise in one specific region - the Netherlands and, to some extent, Belgium. However, one may also see this region as being representative of a much broader part of the world's economy, in which aging plants and infrastructure are combined with a thriving production in innovative capital goods and associated services.

### **Contributions to and the design of this study**

This report presents findings that are based on a Delphi study in which some fifty experts from the Netherlands were consulted on what they saw as being the main innovation priorities for maintenance<sup>5</sup>, and on how they thought that these priorities would best be addressed. These experts come from various industries in which they carry out different roles, such as asset owner, contractor, OEM, consultant, researcher, or teacher. To our knowledge, this is the first study of its kind that draws on expertise from such a broad and diverse background. It is also the first study with a scope of this ambition in the new era of digital manufacturing, the Internet of Things, Big Data, and new materials.

We utilise these findings to arrive at a set of recommendations for government, industry, and knowledge institutes. These recommendations are aimed at the Dutch context but have, we believe, wider applicability. We also believe that the implementation of these recommendations will result in a society in which service, maintenance, and asset management operate at a world-class level, which will have a major impact on the sustainability and energy efficiency levels of our society, and will also generate industries with significant export potential. The structure of the remainder of this document is as follows:

- Chapter 2 will look at earlier studies and publications, especially in the Dutch context.
- Chapter 3 explains the Delphi research method in detail as applied here.
- Chapter 4 will look at the outcome of the first knowledge acquisition stage of our research, a web-based survey, which delivered a ranked list of maintenance innovations.
- Chapter 5 captures the findings of the second knowledge acquisition stage, a policy workshop which resulted in a set of root cause analyses for these innovation priorities and suggestions for action plans for them.
- Chapter 6 takes these recommendations and looks specifically at routes to implementing them in practice.
- Chapter 7 will then come up with some specific policy recommendations in the conclusion.

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<sup>5</sup>For a full listing of the participants in this study and their backgrounds, see Annexe D.

## 2. Evolving priorities in maintenance innovation

### **A pendulum of attention**

This reports looks forwards toward the future of service, maintenance, and asset management in the Netherlands. In looking forward, it can also help to look back in time. When looking back some centuries, it becomes clear that the Netherlands has long been known as a country that excels in the execution of maintenance activities. In the Dutch Golden Age (the seventeenth century) the success of the Dutch East India Company, the VOC or 'Verenigde Oost Indische Compagnie', was partly due to superior maintenance practices (Akkermans, Bakker & Besselink, 2015).

When looking back some two decades, it becomes clear that the maintenance situation as an independent innovative discipline was seriously threatened in the Netherlands. The attention towards maintenance engineering was decreasing, partly due to the rise of the 'throw-away society' mentality and the increased importance of economical, short-term-orientated arguments at the expense of technical, long-term considerations. This was mirrored in the Dutch academic situation. University professors who had occupied chairs which were dedicated to maintenance went into retirement: Professor Emeritus Smit at TU Delft in 2007, and Professor Emeritus Geraedts at TU Eindhoven in 2008. For a brief moment in time, there was not a single chair left dedicated to maintenance at any Dutch university.

As mentioned, this situation in academia was a mirror image of what had been happening in practice. Even though engineers had been designing public and private capital goods since the beginning of the last century, during those last few decades their role was pushed into the background in light of privatisation, shareholder value, and the outsourcing of activities. Here, economists, lawyers, investors, and bankers played a leading role. Soon, in most industries, maintenance was no longer regarded as being a strategic element of policy but rather a cost burden that was to be minimised.

This situation has very much changed in the last few years. The pendulum is swinging back from low attention to high attention to maintenance innovation. World-class levels of maintenance are now once again seen as strategic imperatives. Maintenance is seen more and more not as a cost factor but as a potential investment, as a promising business strategy. For instance, the Harvard Business Review dedicated a whole issue to the implications for the use of the internet-of-things (IoT) upon technology (Porter and Heppelman, 2014). The strategic importance of technology is back on the agenda in the boardroom, with the objective of enhancing the earning power of installations, guaranteeing availability and facilitating sustainable operational management. Discussions are taking place on how to promote continuity in the operational management of companies on various fronts: politicians, management, industry, employees, and consumers (van Dongen, 2011).

One reason for a greater focus on maintenance innovation may be the availability of new technology, but another reason is certainly a greater need for maintenance. Throughout the Western world industrial assets are aging, which leads to higher maintenance requirements. In a study executed by DI-WCM and BEMAS, the Belgian maintenance association, it also appears that 44% of industrial assets (value of installed base in the Netherlands and Belgian: 700 billion euro) will reach the end of their working lifetimes within the ten years. This investigation shows that 91% of companies will continue using their existing sites by means of lifetime extension programmes, modernisation projects, and dedicated replacements (Sanderink, Bastiaansen, Kurowska, 2015).

### Three types of innovation in maintenance

The innovation trends listed in the present document have not appeared out of nowhere. They are the logical consequences of innovation efforts from the past decade. There have been numerous studies conducted in various countries and sectors on the subject of maintenance innovation. In the remainder of this document we will focus on document maintenance innovation projects in the Netherlands over the last seven years, as a representative example of such innovations, and also as a geographic region of which detailed knowledge is available to the authors.

In retrospect, the first signs of the aforementioned transition from less to more attention to maintenance innovation coincide with the establishment of the former Dutch Institute of World Class Maintenance. In 2009, after consultation with Dutch industry, a group of researchers from Twente University (Blok, Hoekstra, van Houten & Kokkeler, 2009) identified six major themes in which maintenance innovation was required: (1) physical phenomena; (2) maintenance execution, and staff; (3), maintenance systems; (4) design for maintenance; (5) monitoring-based maintenance, and; (6) large maintenance programmes and shutdowns. This list formed the basis of a first strategy document laying out the direction in which the maintenance sector should move (DI-WCM 2009). In this list, attention has been paid to all three generic aspects of maintenance innovation which are distinguished in general and more specifically in this report: technology, processes, and people and organisation:

Figure 2: Three generic types of maintenance innovation



- **People & Organisation:** This group contains those innovations which are primarily related to the culture of an organisation and the behaviour of the people. It can be seen that (2) 'Maintenance Execution & Staff' would fall under this category.
- **Process:** Innovation under this group deals with changes to organisational processes and routines which are used to efficiently and effectively achieve maintenance and business objectives. This is the category in which three of the innovation priorities in 2009 would fall into: design for maintenance is firstly a process challenge, one in which both engineering and also operations and maintenance need to sit together. This also holds true for monitoring-based maintenance, which nowadays is more often called 'Condition-Based Maintenance' (CBM). In addition, shutdowns are primarily a challenge for organisation, for organisational processes and routines. Optimising maintenance execution for operational processes and logistics all falls in this broad category.
- **Technology:** The technology group consists of the systems and integration for those systems which support those innovations which have been identified under process and people and organisation. The two areas - 'Degradation Models' and 'Maintenance (IT) Systems' - may be seen as belonging primarily to this domain.



When DI-WCM was set up, it adopted the aforementioned six innovation areas from Blok et al (2009) and focused its subsequent projects on these areas (Besselink, 2010). In the remainder of this section, we will highlight some of the projects that took place in the three generic types of maintenance innovation as listed in Figure 1 (page 7).

### **Process innovation in maintenance 2009 to the present day**

Within the broad category of 'process innovations', a wide variety of innovation projects were conducted in this period. For instance, in the chemical process industry, so-called **Hands on Tool Time (HoTT)** is still problematically low. This is the time during which technicians are actually carrying out maintenance activities, and not travelling to and from the work site or carrying out all sorts of preparatory or post-job activities, or overhead work. Here, an innovation project was completed with multiple industry partners, aimed at the improvement of technician productivity (van den Brekel, 2013).

A very different type of innovation, but one which still has to deal with improving the process of work activities rather than with a specific project, is that of **performance-based contracting**. This has to be a topic that is relevant for maintenance in a wide variety of industries (such as the process industry, aerospace, the energy sector, machine tools, and so on). In this area, a DI-WCM-led innovation project led to a series of publications (van Rhee, Kaelen, van de Voort, 2008 & 2009, and Vos, Andela, Kool, van Silfhout, Habets, Koevoets, Mulder, and van Kempen, 2011).

Again a very different type of process-innovation lies in the area of **shutdowns**. Since most chemical plants are tightly integrated processes, an individual machine cannot be repaired without also shutting down the processes surrounding it. Because of this, plants are usually shut down entirely and the bulk of the maintenance work is concentrated into those days and weeks in which they are shut down. Obviously, such shutdowns are large and complex projects which, when not correctly planned and executed, can lead to major disruption and financial loss. Even if they go well, they are huge cost factors since there is no production during the shutdown period. So making this period as short as possible, and the production restart as smooth as possible, is important in its own right. Based on input from industrial giants such as Akzo-Nobel, NedTrain, Bosch-Rexroth, Essent, Gasunie, and Stork, the strategic aspects of shutdowns are discussed in Blok, Castelijin, Hoekstra, and Kokkeler (2013).

Yet another process-related maintenance issue is that of identifying and reducing **life cycle costs**, so that the cost of acquiring, using, and disposing of a technical asset over its entire life cycle, where maintenance costs often are very substantial and possibly even higher than the original acquisition costs, can get the bulk of the attention. So reducing life cycle costs often implies that both design and maintenance management get more attention (Casteleijn, Hoefkens, Olthof, Schotborgh, 2010). Besides this, there is a fundamental conflict being revealed through this subject: management life cycle periods often go up to three years (known as a 'Return on Investments', or RoI for short), but plants often operate for over twenty years. Life cycle costing therefore is not 'returnable' in three years by definition.

Adequate management of capital assets in combination with the transfer of ownership of the assets generates a new trend: **servitisation**. The servitisation roadmap by Marks, Ramselaar, Mulder, Muller, Langekamp, and Boymans (2011) describes how OEMs earn more and more revenue by providing servicing for equipment and infrastructure to asset owners after the original sales transaction has taken place. This can be attractive for both parties. The OEM finds an

additional and stable source of income, while the asset owner is relieved of the task of keeping up-to-date their technical knowledge of these complex assets, or even of having to grow it. What's more, the OEM receives feedback information about the assets during their use. This information can then be applied to the redesign of the asset or to the design of new products. There are also costs and risks which are associated with servitisation: for the OEM, design becomes more complex and often more costly to optimise during the usage phase, while for the asset owner there is a growing dependency on technical expertise outside their own organisation.

**Design for maintenance** is another process innovation that is gaining more and more in importance. This report sees this as a process innovation, since it really concerns how to involve maintenance expertise into the design process, about communication between different disciplines. New technical product inventions are rarely required; it is mostly a matter of designing a product with its use and maintenance in mind. Design for maintenance is also a cost-driven innovation. Maintenance costs are a multiple of the investment costs. The total lifetime costs for new products are said to be determined for some 70% of users by the detailed design phase, and many of these costs are maintenance-related.

Mulder, Blok, Hoekstra, and Kokkeler (2012) provide an overview of this approach by describing a set of guidelines which are based both on theoretical knowledge and experience from industry. Goel (2014) describes a theoretical framework which integrates the relevant aspects with the main objective of reducing costs for unplanned shutdowns.

Finally, development in recent years in the field of technical asset management is remarkable. The term 'asset management' originates from general management, from financial management even, as asset management broadly defined is the 'coordinated activity of an organisation to realise value from assets'<sup>6</sup>. In the context of capital goods or so-called technical or physical assets, this then refers to managing across a whole portfolio of assets across their entire life cycles. It is in asset management that general management and maintenance management and operations, purchasing, and financial management meet in the most general terms. Lloyd (2010) therefore observes that, via asset management, the board of directors can be reached better with technical considerations. He describes the challenges, possibilities, and advantages which are created by asset management and the methodology behind **life cycle costing**.

A more holistic approach to the maintenance process, so-called 'Value-Driven Maintenance', was provided in this period in the Netherlands by the consultancy firm, Mainnovation. In two books (Haarman and Delahay, 2004 and also 2015) they argue that the technical department has to be the 'improvement engine' of the maintenance process, one which combines lifetime extension, replacement, and modernisation. They present a quantitative control model with twelve KPIs and they identify branch-specific benchmarks. Another holistic view on maintenance engineering and management came in this period from the genius of maintenance research in the Netherlands, Klaas Smit, who put into writing his decade-long experience and research in the maintenance sector in an elaborate textbook on the subject (Smit 2014).

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<sup>6</sup> <https://theiam.org/What-is-Asset-Management>

### **People and organisation innovations, 2009 to the present day**

Much less visible until now have been innovations which are related to people, organisation, and culture. The biggest emphasis has been on personal safety, with good reason, of course. In practice, the last two decades have seen significant reductions in serious and fatal injuries in the context of maintenance work in several industries, with something of a 'safety ceiling' during the last five years or so. Most of this work was very practical, being based on general insights from the field of 'safety culture' in general, not safety in maintenance per se, such as the work by James Reason (1998). However, aspects of culture and organisation which are relevant to maintenance, such as the degree of short-term versus long-term biases or the level of collaboration between organisational functions, have all remained mostly uncharted so far.

In addition, those challenges which are related to knowledge management in the context of maintenance have not received much attention. How does one retain a culture of continuous learning or education permanente with maintenance staff, and how does one bridge the gap between old, experienced employees and young, highly-trained but inexperienced maintenance staff in innovative ways. These are areas which have not so far been that well studied. Lastly, the use of advanced training techniques such as simulation, virtual reality, or digital devices such as enhanced reality glasses or tablets has, in the context of published sources, not found its way into the literature on the subject.

In the Netherlands, the Dutch institute, World Class Maintenance, has in the period between 2010-2015 taken multiple initiatives in order to encourage the field of education (from secondary to scientific education) participate in these innovation developments together with industry. This was also triggered by reports that reflect upon the changing nature of the maintenance profession and what that means for the education sector and employment market (SEOR 2009).

### **Technology/product innovations, 2009 to the present day**

The field of technology is vast, and to report in this document upon all of the progress which has had some relevance on maintenance is impossible. There has been progress on new materials that require less maintenance, progress on robots or machines or drones that can conduct maintenance-related activities, progress on testing equipment, cleaning equipment, and so on. The biggest surge of technology/product innovations has been related to the generation and use of data in maintenance. There has been progress on sensors to measure the current state of assets, progress on degradation models (Tinga 2014), progress on big data and on statistical techniques which can extract insights for maintenance from data sets. One example of how the benefits of such data-driven maintenance can be harvested is the final report by the project, 'DAISY' (Dynamic Asset Information System), which describes the use of condition-based maintenance in the context of windmills (van Kempen and J Louws, 2014).

## 3. Research method

### **A Delphi study research design**

A great deal has been written on service maintenance and asset management. However, given the rapid developments in industry and enabling technology, and given the relative paucity of public and peer-refereed material on these new developments, the researchers have deemed it wise to develop up-to-date insights by listening to business experts who, collectively, have accumulated a vast amount of practical experience in precisely those types of issues which we have aimed at investigating.

For this type of exploratory, theory-building research, a Delphi study is an appropriate research design. In general terms, the Delphi study is a method for structuring a group communication process so that the process is effective in allowing individuals to deal with complex problems (Linstone and Turoff, 1975; Delbecq et al, 1975). The Delphi technique lends itself especially well to exploratory theory which builds on complex, interdisciplinary issues, often involving a number of new or future trends (eg. Klassen and Whybark, 1994; Akkermans et al, 2003).

One essential characteristic of the Delphi study is the group size of at least twenty respondents which serves to overcome any risk of individual bias which may contaminate the aggregate responses. With our survey response by fifty experts, this criterion is easily met, and the group of twenty-one participants in the final workshop where the survey results were refined and commented also meets this requirement.

Another defining characteristic of Delphi studies is the opportunity of receiving feedback on earlier comments as well as the opportunity of further elaboration on the basis of that feedback. In this particular research design, this feedback occurred on two occasions. Firstly, after the first survey round, participants were confronted with the responses of the entire group which they could compare to their own. Secondly, participant feedback was provided almost instantaneously and continuously during the concluding Delphi workshop which was supported by an electronic 'Group Decision Support System' or GDSS (Eden and Radford, 1990; Jessup and Valacich, 1993). With such a GDSS (the package used was Spilter, [www.spliter.nl](http://www.spliter.nl)), data collection and information processing can be conducted in parallel, rather than sequentially, as every participant can individually digest information and add to the overall body of data. In a larger group, this becomes essential to keeping progress sufficiently high. The downside is the large amount of post-session information processing that has to be carried out, as was also the case for this report.

The remainder of this section describes the analytical method employed by the research team so that they could arrive at sound answers for the questions described in the introduction (Section 1, above). This method can be split up into five stages, with each stage consisting of a number of steps. In total, forty-one steps are distinguished, of which at the time of writing the present version of this report (December 2016), some thirty-three have been completed:

- i. Study Definition Stage (Q1-Q2 2014)
- ii. Web-Based Survey Stage (Q2-Q4 2015)
- iii. GDSS Workshop stage (Q1 2016)
- iv. Study Synthesis Stage (Q2-Q3 2016)
- v. Knowledge Dissemination Stage (Q4 2016-2017)

### Stage I. Study definition

Table 1 describes the main analytical steps in this stage. Firstly, collaboration was sought with Professor Emeritus Klaas Smit, in order to ensure a sound framework for our analytical framework. This framework consists, among other areas, of a typology of maintenance settings for different types of technical systems. At this time it was assumed by the researchers that different types of technical systems, which pose different types of technical requirements upon the maintenance task, would also differ in the innovations they need most urgently (subsequent analysis of survey results would render this assumption invalid.) So the well-established 'Technical System' (TS) class typology of Smit (2014) was employed to structure the search for relevant experts for this study. This typology is summarised in Annexe B.

Table 1: Analytical steps in Stage I, the study definition

NO	STEP DESCRIPTION	FROM STEP	TO STEP
1	Define the Delphi scope and ambition level		
2	Choose a generic theoretical framework for study	1	
3	Customise the framework for a specific purpose	2	
4	Translate customised framework into specific survey questions	3	
5	Conduct snowball sampling interviews with relevant professors	1	
6	Solicit additional relevant names from reference board	5	
7	Send out invitations to industry associations	6	
8	Find relevant names for missing fields from CRM system	7	
9	Find relevant names for missing fields from professional networks research team	8	

Then a series of exploratory interviews were conducted with thirteen university professors in the field of maintenance, all of whom came from the Low Countries<sup>7</sup>. Here, the original focus was on refining the study's scope and objectives. Besides, the names of recognised experts in the field of service, maintenance, and asset management were collected. In a number of additional steps, also involving Dutch industry associations such as the SLF (the Service Logistics Forum) and VNCI (the Dutch chemical industry association), this list was further increased to include some 183 names.

### Stage II. Web-based survey

The second stage was delayed for some time due to staffing issues and operational pressures. Researchers were hired from Mainnovation, a consulting firm which specialises in maintenance and asset management issues. The Mainnovation consultants took upon themselves the complex and time-consuming task of detailing the survey questions, soliciting collaboration from experts, collecting the answers via SurveyMonkey, a web-based survey tool, and summarising the insights. At each step during this process, they would confer with the research team for this stage of the work, which consisted of Klaas Smit and also Henk Akkermans, one of the present authors.

<sup>7</sup> One participant came from Belgium, while all of the others came from the Netherlands. The participants were Rommert Dekker (Erasmus Rotterdam), Geert-Jan van Houtum (TU Eindhoven), Leo van Dongen and Tiedo Tinga (both U Twente), Klaas Smit (emeritus TU Delft), Liliane Pintelon and Marc Lambrecht (both KU Leuven), Cees Witteveen (TU Delft), Andreas Hartmann (U Twente), Iris Vis and Ruud Teunter (both U Groningen), Henk Zijm (U Twente), and Ivo Adan (TU Eindhoven).

Table 2: Analytical steps in Stage II, the web-based survey

NO	STEP DESCRIPTION	FROM STEP	TO STEP
10	Invite participants and obtain agreement	5	9
11	Send out first round surveys and collect responses	10	
12	Process incoming responses into clustered statements	11	
13	Conduct a peer review on draft clustering with research team	12	
14	Send out second round survey asking for feedback and ranking	13	
15	Process second round results into multiple preliminary rankings and breakdowns	14	
16	Conduct a peer review with research team on rankings and select the most relevant ones	15	
17	Write up a survey report	15	16

As can be seen from Table 3, survey experts participating in two rounds included individuals from a broad range of industries. Despite multiple efforts, it turned out to be infeasible to be able to find a sufficient number of experts from companies which were working in the field of transportable technical systems (such as mobile phones), so this TS class could not be included. However, for the other TS classes, representation was felt to be sufficiently broad. A total of 30% of the experts invited, fifty-five out of 183, accepted the invitation. Fifty experts (27% of the total number ) responded to the first round of questions.

In the second survey round, the collective results were fed back to the individual respondents with the invitation to revisit their prior answers, if applicable, and also with the request to rank the thirty-six innovations which were generated in Round 1 (see Annexe E).

Table 3: Industry backgrounds of experts participating in the Delphi study

Type of technical system	Invited	Round 1 accepted	Round 1 completed	Round 2 completed	GDSS workshop
Transportable	20	1	1	0	0
Mobile	34	13	12	7	4
Network	44	9	8	4	4
Standard	38	5	4	4	0
Specific	36	15	14	13	7
Multiple (including academics)	11	12	11	9	6
<b>Totals</b>	<b>183</b>	<b>55</b>	<b>50</b>	<b>37</b>	<b>21</b>

The final results from these two rounds of surveys were written up in a separate report (Baauw et al, 2016), which is available upon request from WCM.

### Stage III. GDSS workshop

In the second stage of knowledge acquisition, the output from the survey rounds was further discussed and refined by a smaller group of twenty-one experts (see Annexe F for a participant listing), focusing on the 'Top 15' most important innovations (during the workshop this was condensed to fourteen). The workshop was supported by a 'Group Decision Support System'.

With the aid of the system, both various questions with regard to the 'Top 14' and the respondent's comments were projected onto a central screen and onto each participant's individual screen immediately after these were typed into the

personal laptops of those participants who had logged in via WiFi to the appropriate website page. Participants could read everybody else's entries, and could comment upon them or add further explanatory text to their own original entries. All such entries were handled anonymously. Meanwhile, participants could also conduct verbal discussions either with those persons who were sitting next to them or with the facilitators.

Insights from these conversations usually - and quickly - found their way into entries which were submitted for reading by the entire group. For a more detailed description of the script used in this GDSS workshop, the reader is referred to Chapter 5 (page 36).

Table 4: Analytical steps in Stage III, the GDSS workshop

NO	STEP DESCRIPTION	FROM STEP
25	Categorise innovations in technical, process, and cultural/behavioural	23
26	Create causal maps of statements in root cause analysis	23
27	Add connections between innovations and root causes	26
28	Create a cross-reference table of interconnections between innovations and root causes	27
29	Create a causal diagram of interdependencies between innovations	28
30	Summarise recommendations into proposed actions	24

#### Stage IV. Study synthesis

Chapter 5 also contains most of the output from Stage IV. Now the key research group had become the four authors of the present report. Between them they divided specific synthesis tasks based on the survey and workshop material, and commented upon each other's intermediate results. These steps are listed in Table 5.

Table 5: Analytical steps in Stage IV, the synthesis

NO	STEP DESCRIPTION	FROM STEP
25	Categorise innovations in technical, process, and cultural/behavioural	23
26	Create causal maps of statements in root cause analysis	23
27	Add connections between innovations and root causes	26
28	Create a cross-reference table of interconnections between innovations and root causes	27
29	Create a causal diagram of interdependencies between innovations	28
30	Summarise recommendations into proposed actions	24

#### Stage V. Knowledge dissemination

In its present form, this research is still in the fifth stage of knowledge dissemination. In the months to follow, the current intermediate results will be further refined and tested for robustness and relevance in a number of iterations, with the aim of further enhancing the reliability and validity of the study's findings.

Table 6: Analytical steps in Stage V, the dissemination process

NO	STEP DESCRIPTION	FROM STEP	TO STEP
31	Write first draft report	22	30
32	Conduct a peer review between researchers	31	
33	Write second draft report	32	
34	Conduct member check with experts	33	
35	Finalise report	34	
36	Present findings to target audiences	35	
37	Present specific parts of findings to specific audiences	35	
38	Translate report into scientific article	35	
39	Present draft article to peer-reviewed journal	38	
40	Revise article based on reviews	39	
41	Publish article	41	



## 4. The survey results

This chapter focuses on the outcomes of Phase II of the Delphi research, the web-based survey in two iterations, as described in the previous chapter. The first round of this survey provided a solid overview of the initiatives and innovations that companies were doing or which they expected to be doing at the time of the survey. In the second stage of Phase II this output was grouped into a clustered set of innovations by the research teams, and then ranked along multiple axes by our expert respondents. The team then grouped these results into multiple preliminary rankings and breakdowns.

### Thirty-eight clusters of innovations

Based on the input from the first and second round, thirty-eight initiatives and innovations were identified and ranked by the participants. These thirty-eight initiatives and innovations are identified and briefly described below. A more elaborate description of all thirty-eight initiatives and innovations is included in Appendix B. The order in which they appear is not a ranked one but a random one, where every innovation cluster received a code result from the clustering work by the team, this being 'I'(for innovation)+'unique number'.

- I01 *Cultural and behavioural change*, which can remove roadblocks such as the lack of a fact-based culture, conservatism in investing in new technology, short-term orientation with management, a perceived lack of status when sharing expertise, a lack of integral perspective, a lack of entrepreneurial activity, and resistance to change.
- I02 *Asset management as an export product* in order to be able to export the knowledge which has been gained to other countries and generate revenue for the Netherlands BV.
- I03 *Knowledge management* can address knowledge-related roadblocks such as: limited big data expertise; limited experience with sensor technology; a lack of experience in new Ways-of-Working; insufficient time/experience to conduct systematic enquiries; a lack of experience / expertise in asset management processes; and the technical complexity involved in mastering new techniques.
- I04 *The use of drones and robotics* to carry out inspections and maintenance tasks in difficult-to-reach areas or even fully unreachable locations and to increase information gathering and equipment or plant reliability.
- I05 *3D design/virtual reality*. This relates to using 3D and virtual reality techniques during the design phase to assess the maintainability of technical assets, and during the operational phase for an 'as built' 3D model which tracks all changes digitally.
- I06/I07 *Performance-based contracting*: providing incentives to suppliers and contractors in order to ensure the optimisation of performance levels for asset owners, and providing incentives for asset owners to optimise their collaboration with suppliers and contractors.
- I08 *Integrating asset management IT systems*: connecting asset management IT systems to other systems in the IT infrastructure in order to be able to combine data faster and better for maintenance decision-making.
- I09 *Servitisation*, which was broadly defined within the survey as the development of new service concepts within asset management and equipment maintenance.
- I10/29 *KPI Dashboards*, which refers to the process of implementing a coherent set of asset portfolio KPIs that monitor past and current performance levels and costs involved in technical assets in order to be able to assess future developments.
- I11 *Asset management implementation* deals with asset owners so that the ISO 55001 asset management standard can be implemented in order to strategically manage the asset portfolio.

- I12 *Product data management* deals with the implementation of data management systems for production, maintenance, and capital projects in order that they can maintain all relevant information and knowledge up-to-date and secure.
- I13 *A visual plan board*, which is used to optimise the planning and scheduling of all activities using scheduling tools and a digital visualisation of schedules.
- I14 *Asset portfolio management* is concerned with developing a comprehensive overview of current and anticipated costs and the performance of all technical assets to so that objective and data-based decisions may be taken in respect to the asset strategy.
- I15/16/17 *The modernisation of assets* deals with the renewal of asset parts and equipment in order to reduce energy consumption levels and maintenance costs and to increase reliability.
- I18 *Life cycle costing* is about developing models that calculate the cost of the acquisition, operation, maintenance, and decommissioning of technical assets across the entire lifecycle
- I19 *Degradation models* are formal models that calculate the remaining useful life based on current performance data.
- I20 *Optimised 'Enterprise Asset Management' (EAM)* systems address a challenge in that the EAM system should be able to provide all necessary solutions to help maintain and manage the assets including real-time dashboarding and third party access, and should also facilitate the processes in an easy and app-like manner.
- I21 *'Condition-Based Maintenance' (CBM)* and *'Risk-Based Maintenance' (RBM)* both deal with implementing an asset control concept in which assets are maintained just when they need to be, based on an assessment of their current performance levels, with those assets receiving specific attention where they are most important for the business.
- I22 *'Overall Equipment Effectiveness' (OEE)* is the concept of being able to measure the real time OEE of the assets and to be able to optimise the maintenance programme based on the OEE findings.
- I23 *3D printing* is about utilising 3D printing technology to reduce stock levels and optimise all logistics around maintenance activities.
- I24 *Big data* is the umbrella term for setting up an IT infrastructure that enables the systematic and comprehensive collection, integration, and interpretation of data from a wide variety of sources in order to be able to calculate when and where maintenance is needed.
- I25 *Design for maintenance* is about incorporating maintenance-related considerations into the design of new technical assets.
- I26 *Hands-on tool time* measurement focuses on technician efficiency by taking frequent measurements in order to be able to improve the processes and increase overall process efficiency and effectiveness.
- I27 *Mobile solutions* deal with applying mobile technology to increase the efficiency of technician activity, such as with tablets, workflow management systems, and augmented reality;
- I28 *Replace versus repair*, also known as 'swap-and-go', is about replacing equipment and parts directly so that performance is interrupted to a minimum, and repairing equipment offline after replacing it with new, more energy efficient and reliable types.
- I30 *Smart sensing* is about applying sensor technology to monitor the performance of technical assets in order to establish when maintenance is needed.
- I31 *Vendor managed inventory* is a concept from the retail market in which the OEM or the vendor manage the inventory of multiple asset owners in order to be able to reduce total stock levels and ensure that the right part is always delivered in the right condition.

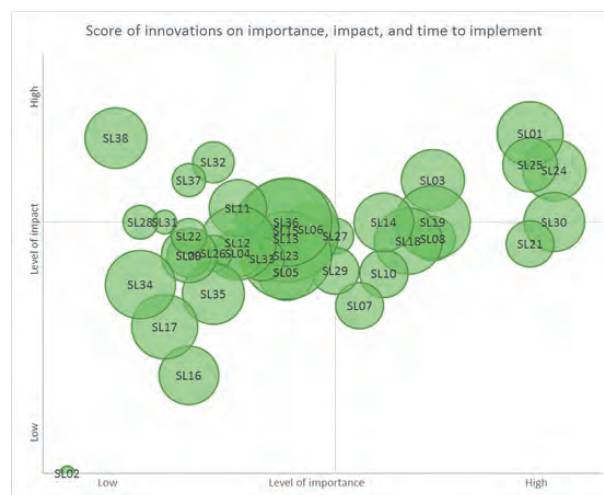
- 132 *Business process re-engineering* aims to review and optimise existing maintenance processes and to collect information from multiple organisations so best practice can be developed.
- 133 *Improve maintenance methods*: the use of new methods and technology to improve the level of maintenance and to increase equipment reliability.
- 134 *Increased cooperation between asset owners and governmental offices* is the label for the practice of investing jointly in assets to improve the level of services provided within the Netherlands, such as a new dry-dock, training facilities, test plants, etc.
- 135 *The development of parts and equipment* deals with the development and engineering of new types of parts which should make equipment more efficient, more easily interchangeable, or suited for specific applications.
- 136 *The use of new materials* focuses on the development of high-grade plastics and ceramics to be used within the assets to prolong the lifetime of, for example, piping, or the use of self-healing materials to reduce inspections and the replacement of parts.
- 137 *Apply LEAN/SixSigma* is the business practice from manufacturing that advocates the use of continuous improvement methods to close the loop and continuously improve the performance of maintenance and equipment;
- 138 *Integral (operations, maintenance, and procurement) contract management* is the label for contract management which is implemented professionally for the entire maintenance chain, including IT systems, performance evaluation systems, management, and evaluation.

### Ranking innovations

Based on the feedback supplied by the participants in Round 2 of the survey, a total of three values have been determined for each innovation:

1. The first is the level of importance for the participant. Each participant should be able to select their own 'Top 10' of the most important initiatives or innovations for the next few years. The selected initiatives or innovations nearly always included those on which the participants were already working or which they expected to start work on in the next three years.
2. The second value is the expected impact of the initiative or innovation with respect to costs savings or added value.
3. The third and final value is the expected effort that may be required to implement this particular initiative or innovation.

Figure 3: The bubble plot of importance, impact, and implementation effort for innovations



Using these values, the graph above was created where:

- a. is the level of importance of the respondent (the horizontal axis);
- b. is the expected impact upon the industry (the vertical axis); and
- c. is the expected effort required to implement it (the size of the bubble).

With respect to the importance and value, the higher the number, the higher the impact, while with respect to the effort, the larger the bubble, the longer implementation would take.

Figure 1 is also divided into four quadrants. We have looked at those initiatives that end up in the higher right-hand side of the graph, meaning that they have a more-than-average level of importance and a more-than average level of impact. This has resulted in the selection of the fourteen innovations that form the basis of the subsequent analyses in this report. These are the initiatives and innovations that should have the combined focus of the asset owners and service providers.

### The 'Top 14'

Table 7 below specifies the ranked list of the most important innovations in maintenance for the coming three-to-four years, according to our panel of experts.

Table 7: The 'Top 14' most important innovations in maintenance up to 2020

Rank	No.	Name	Importance	Impact
1	I24	Big-data analytics	21	5.6
2	I30	Smart sensors	21	5.0
3	I01	Cultural and behavioural change	20	6.1
4	I21	Condition and risk-based maintenance strategies	20	4.7
5	I25	Design for maintenance	20	5.7
6	I03	Knowledge management	16	5.5
7	I08	Interfacing AM IT systems	16	4.8
8	I19	Degradation Models	16	5.0
9	I18	Life cycle costing	15	4.8
10	I10/29	Performance dashboards	14	4.4
11	I14	Asset portfolio management	14	5.0
12	I07/06	Performance contracting	13	4.0
13	I27	Mobile solutions	12	4.8
14	I05	3D design and virtual reality	10	4.4

### Observations

So far, we have treated our group of fifty experts as one coherent block. However, it has to be noted that our experts came both from asset owners and service providers and 'others' (see Annexe D). Within the asset owners group, which consisted of twenty-one participants, various industries were represented: petrochemicals, transportation, and infrastructure. The service providers (which numbered fourteen participants) consisted of experts either from consulting companies or knowledge and innovation institutes.

#### ***No 1. The asset owners have an innovation agenda other than that of service providers***

The table below shows the percentage of experts in the respective group who did find the identified initiative or innovation to be important for their organisation. The table shows the 'Top 12' initiatives and the percentage of asset owners compared to that of service providers.

What is remarkable about this split is that the top seven are clearly on the radar in both groups, but there are considerable differences between the groups for the five remaining groups. Asset owners are much more preoccupied with integrating AM IT systems and life cycle costing, whereas service providers attach much more importance than asset owners to performance contracting, mobile solutions, and asset portfolio management (which is remarkable as far as the last of those is concerned, as one would assume that this area would also be more important for asset owners).

Table 8: Differences in innovation priorities between asset owners and service providers

Rank	Innovation	Asset Owners (21)	Service Providers (14)
<i>Seen as equally important by both groups</i>			
1	Big-data analytics	62%	57%
2	Smart sensors	57%	64%
3	Cultural and behavioural change	67%	43%
4	Condition and risk-based maintenance strategies	52%	64%
5	Design for maintenance	52%	64%
6	Knowledge management	43%	50%
8	Degradation models	43%	50%
<i>Seen as more important by asset owners</i>			
7	Interfacing AM IT systems	57%	29%
9	Life cycle costing	52%	29%
<i>Seen as more important by service providers</i>			
10	Asset portfolio management	33%	50%
11	Performance contracting	24%	50%
12	Mobile solutions	14%	50%

**No 2. The asset owners focus on people and systems, while the service providers focus on processes**

One more general explanation of these differences is that the asset owners focus predominantly on the initiatives and innovations with respect to people and systems: cultural and behavioural change, big data, smart sensing, and interfacing IT systems. Aside from big data and smart sensing, the service provider group has its focus on the process innovations, identified as being condition and risk-based maintenance strategies, design for maintenance, asset portfolio management, and performance contracting.

**No 3. Both groups, asset owners and service providers, see cultural and behavioural change as having the biggest impact and do not focus on technological innovations**

An interesting fact which is emerging from the data covering these areas is that all of the participants in both groups think that cultural and behavioural change will have the biggest impact on the business result. Both groups have estimated the impact at 6.0 or higher out of a maximum amount of 7.0.

**No 4 Both groups, asset owners and service providers, do not focus on technological innovations**

High-tech start-ups, along with the government and press, all demand attention for innovations such as robotics, drones, high-tech materials, and sustainable solutions. Although these topics have been identified by the group, they were not considered to be among the most important initiatives or innovations at this point in time. New materials ended up in sixteenth place, with 3D printing at No 19, 3D design and virtualisation at No 20, and drones and robotics at No 24. What's more, and based on the expected impact upon business value, these innovations have not entered the top ten placings. Based on this dimension, new materials ended up at No 12, while the others were at the bottom of the list; drones and robotics at No 24, 3D printing at No 26, and 3D design and virtualisation at No 31.

### **No 5. Within the 'Top 14', most of the initiatives and innovations are process related**

Another observation which is based on the results and which follows the triangle for industrial change (people and process technology) is the fact that the majority of change is focused on the process whilst one would expect that technological innovation would be leading things. Grouping together the fourteen initiatives and innovations results in the overview shown in the graph below.

The question is what this means and why the industry group has given these initiatives and innovations the highest priority. Before these questions are answered, the different innovations and initiatives, including their grouping, are explained.

### **People, process, and technology innovations in balance**

Too often, changes within organisations focus on one aspect of change, and far too often the improvement is focused on the improvement of the process, with technology being secondary, and people coming a poor third. The result is that three quarters of improvement projects do not achieve any results. In addition, the implementation of any new technologies which focus on the technology itself without taking along with them those people who are working within the organisation will result in failure for employees who have to use this new technology. Therefore it is of the utmost importance that all three elements always be taken into account, and the implementation teams should focus on the most difficult element of change, the people.

### **People and innovations**

One of the initiatives which has been ranked as one of the highest with respect to its importance and its impact upon the organisation, but which is considered as being one of the toughest elements to change is the cultural and behavioural change of the organisation. One of the conclusions to be drawn from the input of all participants on all thirty-eight innovations is that change in culture and behaviour is key to achieving the required improvements for other innovations. This conclusion is not new, but it is generically valid for managing change or innovation in any industry. However, the fact that all of the participants mention this for every innovative idea or initiative, and that the element for cultural and behavioural change is considered the third most-important topic that organisations need to work on, illustrates the fact that this aspect is higher on the agenda in technical industries. There is a strong connection between cultural change and other innovations which have been identified in this study. For example, KPI dashboards and performance-based contracting are ways in which change can be implemented in terms of culture and behaviour.

The second innovation which the participants have highlighted in respect to people is knowledge management. This topic is at sixth place on the innovation agenda and is also considered to have a high level of impact. One of the key issues which underpins the need for knowledge management is the expected knowledge drain in the technical field which is driven by an ageing workforce and the low number of students in the technical field. This, when combined with a shift in the required knowledge of the employees - from hands-on corrective actions to preventative actions provided via inspections - means that employees today need additional traits and areas of knowledge.

### **Process and innovations**

As has already been concluded, process innovations rank higher on the agenda for the industry group than they do for the expert group. One possible explanation of why this is an outcome of this study could be the knowledge within the industry group that the theoretical models are still not fully being implemented



and there are still gains which have yet to be captured both for industry and for business.

The process-related innovations are, on the one hand, existing elements of maintenance, engineering, or asset management but, on the other hand, there is not a typical standard that can be utilised in order to provide support for the implementation of the technology innovations. Standards that exist are either outdated or should be updated. All in all, these areas are at the forefront of the minds of the participants but are not used to the full extent. Utilising the process innovation elements in the right way will reduce costs, increase efficiency, add to sustainability, and deal with changing regulations, all of which is apparently the underlying assumption.

The process-related innovations can be split into two groups: the first is equipment or plant maintenance-related, being classed as condition and risk-based strategies and degradation models; the second is asset management-related, being classed as life cycle costing, design for maintenance, and asset portfolio management. On the equipment or plant maintenance side of things, all participants have identified the clearly common areas of maintenance strategies and degradation models for the different types of equipment. Developing a common knowledge database seems to be the right way to go, gathering together experts in their field and picking their brains for the common good. However, respondents have also observed the fact that having this database is something that certainly seems to be needed in order to be able to develop the right models or formulae to use in big data, to be able to reach the right decisions, and to be able to optimise data gathering by way of smart sensor technology. These two innovations have a direct impact upon the cost per unit. With well-maintained equipment that complies with the regulations there are fewer incidents to report and reliability goes up.

This is not something that all companies are ready to share since there could be a competitive advantage for companies which follow a better-optimised maintenance strategy or which have better degradation models. Companies wish to keep this knowledge in-house, and bringing those together would require a thorough discussion on intellectual property. From another perspective, a great deal is already common knowledge and is shared between companies and universities, since the maintenance industry is relative small and quite open. To jumpstart these two innovations, the knowledge institutes could take a leading role.

The second element, design for maintenance, life-cycle costing, and asset portfolio management, are typical requests for standardisation and the continuous improvement of those standards. There are already standards available, but the application of those standards is has not been especially successful, with the main reason considered to lie with the cultural and behavioural aspects of the organisations. The requirement to implement these processes are evident, since all of the participants have indicated that, as a result of not applying the methods or standards, the following areas are of concern: assets have much higher life-cycle costs; redesigns have to be carried out after completion; cheap components need to be replaced too often or exchanged during the operations phase; and poor decisions are made due to not integrating teams from engineering, operations, maintenance, and construction. Simultaneously executing all three of these innovations will automatically take sustainability, costs, and environment into account.

### ***Technology and innovations***

The innovative technologies - big data analytics, smart sensors, and integrated AM IT systems - are necessary to be able to take the next step in optimising costs and the performance of the assets. These innovations are identified as being game changers when it comes to higher levels of effectiveness and efficiencies, but they are also new techniques for identifying opportunities in respect to safety, environment, and sustainable production.

The participants of the study have come to the conclusion that these technological innovations are required in terms of gathering more information, so that more detailed analyses can be carried out and better decisions can be reached. The fact that these three topics are ranked in first, second, and seventh places shows there is a change happening in terms of technological innovations, from equipment innovations to data-driven innovations. Also, the fact that big-data analytics and smart sensors are suddenly at the top of the list illustrates the fact that a profound shift within maintenance and asset management is evident.

There are, however, hurdles to be taken. All of the participants see the need for good models in order to ensure that the right data is captured, that the right failure modes are predicted, and that the data is secure. A risk involved in using these technological solutions can be seen when it comes to taking decisions that are based on incorrect or incomplete datasets which would have a negative effect on the ultimate outcome. To be able to implement big data systems, smart sensors, and interface EAM systems will require a team of people with different backgrounds and sometimes even different skill sets which do not exist right now in most asset-intensive industries, such as data analysts and mathematical experts. The second element required to be able to successfully implement these three innovations is for the business to be their driver. These are not IT projects, they are business projects.

The combination of the three innovations also brings with it a level of complexity which is difficult to oversee and the risk of technological development proceeding too quickly and too unpredictably for the correct decisions to be taken with any certainty. Support in tooling, interfacing, and sensor technology is critical, together with a template for developing these types of systems.

The second area of technological innovations include mobile solutions and 3D design and virtual reality. Mobile technology is something that several of the participants are already working with or implementing. The key element is to have information readily available at the worksite, increasing the efficiency of the employees, and reducing time wasting and effort. The next step is 3D design in combination with virtual (or augmented) reality. This will deliver not only information to the employee in the field, it will transform information into knowledge as employees can be trained in tasks using virtual reality, or even directly in the field using augmented reality.

Currently, a problem still exists in that 3D, virtual reality, and augmented reality are expensive and, apart from the few items mentioned, sufficient tools are not yet available to use such as equipment or software. In addition, the master data and information which is required to be able to use these systems are, for most asset intensive companies which are in possession of assets that are between fifty to sixty years old, not up-to-date or useable for these systems. It requires a great deal of effort to make them available. The support required for companies involves an overview of the tooling, support from technology companies in terms of how to make use of the devices, help with what particular data is required, and help with how to efficiently and effectively create the datasets required.



For all the technological innovations which have been identified there is a firm belief that these are all game-changers in the field of maintenance and engineering. In order to be able to retain asset-intensive industry within Western Europe, efforts should be taken to develop and implement these technologies. The fact that almost fifty percent of the participants indicate that they are working on implementing one or more of these technologies shows that there is already a strong pull from the industry.

### **Conclusions**

Based on the received inputs and the validation of the Delphi study, the following conclusions can be drawn.

#### ***I. The key innovations for the coming years are process orientated, rather than technology orientated***

It is the technology orientated innovations that most often catch the attention of the press and conferences, seminars, and government subsidy programmes. However, the message that resonates from the fifty experts who were consulted in this study is that it is process innovations that will be most important in the coming years. Out of our 'Top 14', seven innovations were process-based:

- *No 4 Condition-based maintenance (CBM) and risk-based maintenance (RBM):* implementing an asset control concept where assets are maintained just when they need to be, based on an assessment of their current performance, while those assets receive the special attention that is most important for the specific business in question;
- *No 5 Design for maintenance:* incorporating maintenance-related considerations in the design of new technical assets;
- *No 8 Degradation models:* developing formal models that calculate the remaining useful life based on current performance data;
- *No 9 Life cycle costing:* developing models that calculate the cost of acquisition, operation, maintenance, and decommissioning of technical assets across the entire lifecycle;
- *No 10 Asset portfolio management:* developing a comprehensive overview of current and anticipated costs and the performance of all technical assets;
- *No 11 Performance-based contracting:* providing incentives for suppliers and contractors to get them to optimise performance levels for asset owners, and providing incentives for asset owners in order to be able to get them to optimise their collaborations with suppliers and contractors;
- *No 13 KPI dashboards:* implementing a coherent set of asset portfolio KPIs which monitor past and current performance levels and costs related to technical assets in order to assess future developments.

#### ***II. There is a sudden and massive shift in priority levels towards data-driven technical innovations***

All five technology-driven innovations in the 'Top 14' are primarily data-driven (whereas several of the process-driven innovations, such as CBM, are also strongly data-driven). This is a major change from the past, and is in line with the rapid rise of digital manufacturing and smart industry throughout the industrialised world. These are the five technology innovations in our 'Top 14':

- *No 1 Big data*: setting up an IT infrastructure that enables the systematic and comprehensive collection, integration and interpretation of data from a wide variety of sources in order to be able to calculate when and where maintenance is needed;
- *No 2 Smart sensing*: applying sensor technology to monitor the performance of technical assets in order to establish where and when maintenance is needed;
- *No 7 Integrating Asset Management IT systems*: connecting asset management IT systems to other systems in the IT infrastructure to faster and better combine data for maintenance decision-making;
- *No 12 Mobile solutions*: applying mobile technology to increase the efficiency levels of technician activity such as tablets, workflow management systems, and augmented reality;
- *No 14 3D design/virtual reality*: using 3D and virtual reality techniques during the design phase to assess the maintainability of technical assets and, during the operational phase, for an 'as built' 3D model tracking all changes digitally.

### **III. Data driven technologies are seen as being key drivers for the other process-driven and technical innovations**

Not only are data-driven innovations ranked as top priorities in maintenance innovation for forthcoming years, they are also seen as being key in enabling many of the other innovations, as they remove many of the road blocks which limit progress there as well. The three data-driven innovations in the 'Top 5' illustrate this:

- *No 1 Big data*: can overcome issues in: technical challenges faced when integrating multiple IT systems, dealing with a large diversity of possible parameters, a lack of clarity in what actual performance may be, a lack of insight in leading and lagging parameters, complexity of use, and the maintenance of installations over time;
- *No 2 Smart sensing*: can overcome issues which are linked to a lack of actual use of data expensiveness in data sensing, low data integrity, a lack of insight in terms of actual cost during use, and the limited data quality of asset status;
- *No 4 CBM/RBM* can overcome issues with: aged assets with little data generation, low data integrity levels, difficulties in estimating usage costs during the project phase, and again a lack of insights during the usage phase.

### **IV. Cultural/behavioural change and knowledge management are seen as essential conditions for the more rapid progress of all other innovations**

Perhaps surprisingly in a Delphi study which was asking for innovation in such a technical area as maintenance, cultural/behavioural change (No 3) and knowledge management (No 6) are seen as top priorities for maintenance innovation. Further analysis reveals that they are especially important as they remove some of the key roadblocks which have been progress in all other areas:

- *No 3 Cultural and behavioural change* can remove roadblocks such as a lack of a fact-based culture, conservatism in investing in new technology, short-term orientation in terms of management, a perceived lack of status when sharing expertise, a lack of integral perspective, a lack of entrepreneurial activity, and resistance to change;
- *No 6 Knowledge management* can address knowledge-related road blocks such as limited big data expertise, limited experience with sensor technology, a lack of experience in new ways-of-working, insufficient time and/or experience to be able to conduct systematic enquiries, a lack of experience and/or expertise in asset management processes, and the technical complexity involved in mastering new techniques.

***V. None of the technical innovations which have been prominent in the news or in government policies appear in the 'Top 10'***

Our panel of fifty experts, with an estimated fifteen-plus years of experience in the field of maintenance, prioritised maintenance innovations very differently from where the main 'buzz' appears to be in the news, in congresses, and also in governmental industrial policies and associated subsidy programmes. High-profile innovations such as 3D-printing ended up being ranked in seventeenth place, while drones and robotics ranked in twentieth place. Several of these did not even make it into the 'Top 30', such as self-healing materials. Partly, this may have been caused by the relatively short time horizon which was investigated (2016-2020), but mostly this appears to be because the experts simply judge process-related, organisation-related, and data-related innovations to be far more important when it comes to making progress towards world-class maintenance.

## 5. Root cause analysis of maintenance innovations

This section takes the output of the two-stage web survey as its input. In spring 2016, a group of twenty experts from the fifty respondents of the survey (see Annexe F for a list of these twenty persons) convened so that they could dig deeper into the root reasons for the 'Top 14' of maintenance innovations. In this report, we look in particular at their analysis both of symptoms and roots causes of the problems these innovations are aimed at addressing. This root cause analysis (RCA) is visualised in this section in the form of an analytical scheme as shown in Figure 4:



Figure 4: Analytical scheme for root cause analysis innovations

In this figure the rectangles denote root causes, while the hexagons are innovations, and the circles stand for problem symptoms that the innovations help to address.

### Root cause analyses for each individual innovation

#### ***No 1. Big data: no data means no insight, so no success, all because of a non-fact-based culture***

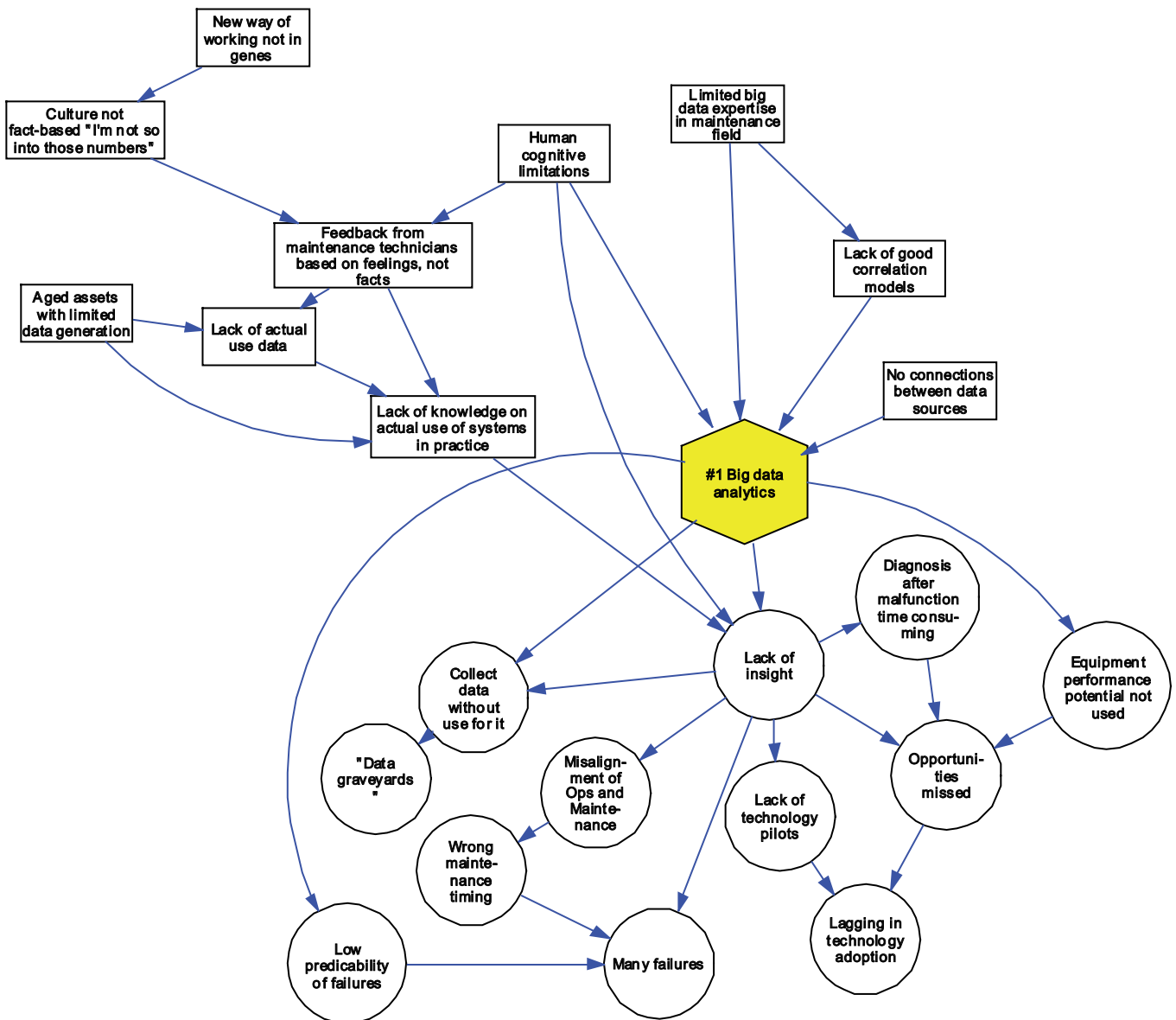
##### *The consequences of a lack of innovation in big data*

Without big data analytics, insight will be lacking. This will result in a misalignment of operations and maintenance, which will lead to maintenance being wrongly timed and a multitude of failures being caused as a result. A lack of insight will also lead to data collection data without it being used, and from there to so-called 'data graveyards'. It will also result in improvement opportunities being missed and in a lack of technology pilots, which again will lead to failures. In general, the performance potential of equipment will simply not be used.

##### *The root causes limiting innovation in big data analysis*

Root causes range from the technical to the cultural. On the technical side, there are simply not yet that many worthy correlation models in place, and it is these that are needed for sound 'big data' analysis beyond simple correlations. In addition, a lack of connections between data sources makes any data collection which is required for sound data analysis a problematic issue. This is aggravated by the fact that many aged assets generate limited data anyway.

At the other extreme, this data-driven method of working is simply, at present, 'not in the genes' of maintenance staff; the current culture is not fact-based. Or, in the words of one of the experts, 'I'm not so into those figures', existing, long-established maintenance staff may say. So feedback is given on the basis of subjective feelings, not on objective facts. All this served to combine results into a package that offered limited insight into the actual performance characteristics of equipment.



**No 2. Smart sensing: conservatism and limited experience is more relevant than business cases**

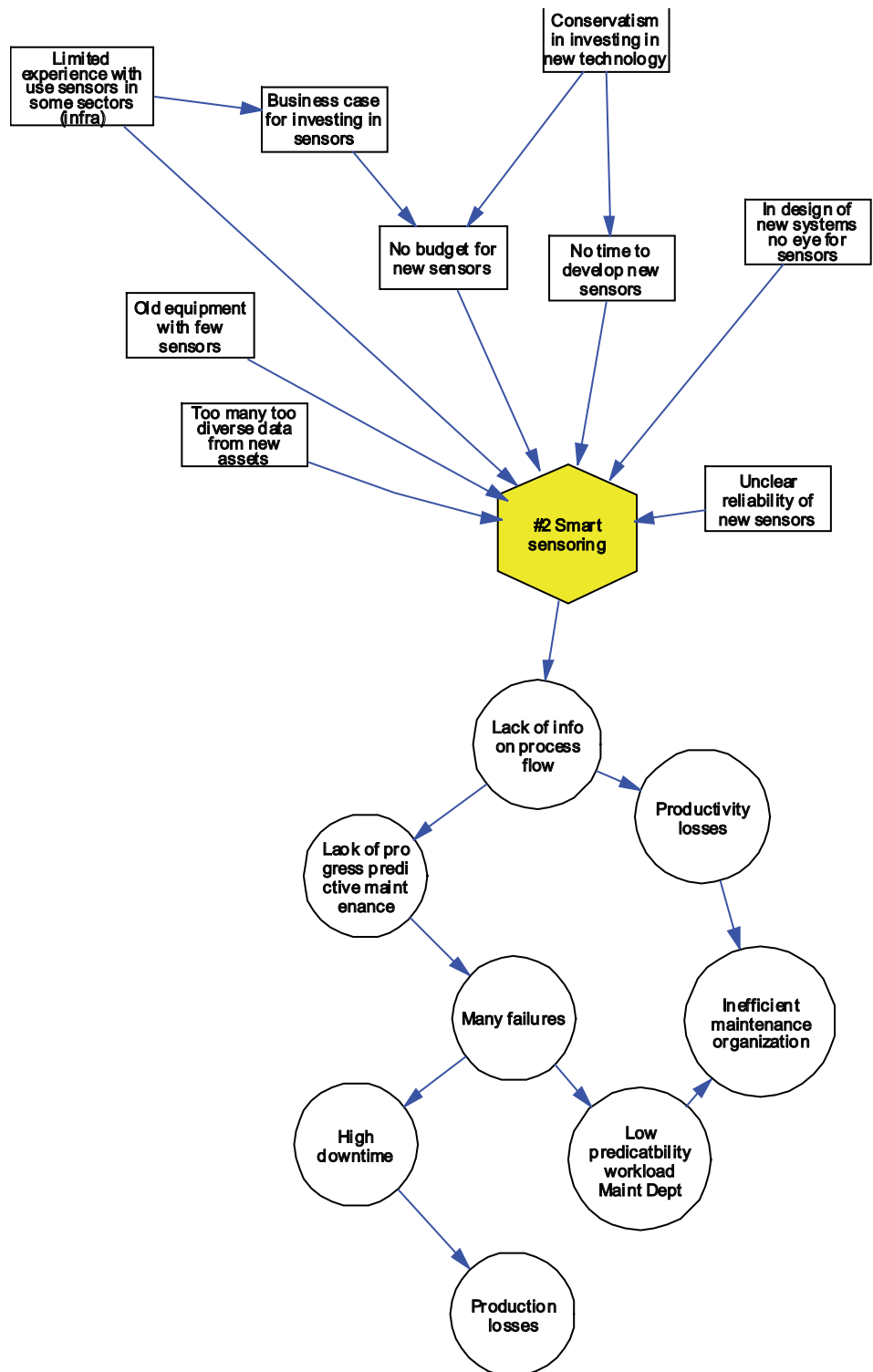
*The consequences of a lack of innovation in smart sensing*

Without condition monitoring, a lack of information exists in terms of process flow. In the immediate short term, this leads to productivity losses, as the maintenance organisation remains inefficient. In the longer term, this leads to a lack of progress in predictive maintenance. That leads to a large number of failures and then to low predictability levels when it comes to the workload in the maintenance department.

*The root causes limiting innovation in smart sensing*

If that is the case then why isn't there more smart sensing taking place? Again, a variety of causes is listed. There is no budget for new sensors and/or no time to develop new sensors. The new sensors have an unclear level of reliability. Behind this are other considerations: the business case is not clear; there is not a lot of experience in place, and a general conservatism exists where new technology is

concerned. It is accepted that there are too few sensors on old equipment but, in addition, too much data exists in relation to new equipment. And when systems are designed, there is often not an eye for developing the right maintenance-related sensors. This also comes from a lack of experience with the use of sensors for maintenance purposes.



**No 3. Cultural and behavioural change: conservatism has led to a lack of fitting-in with today's tasks**

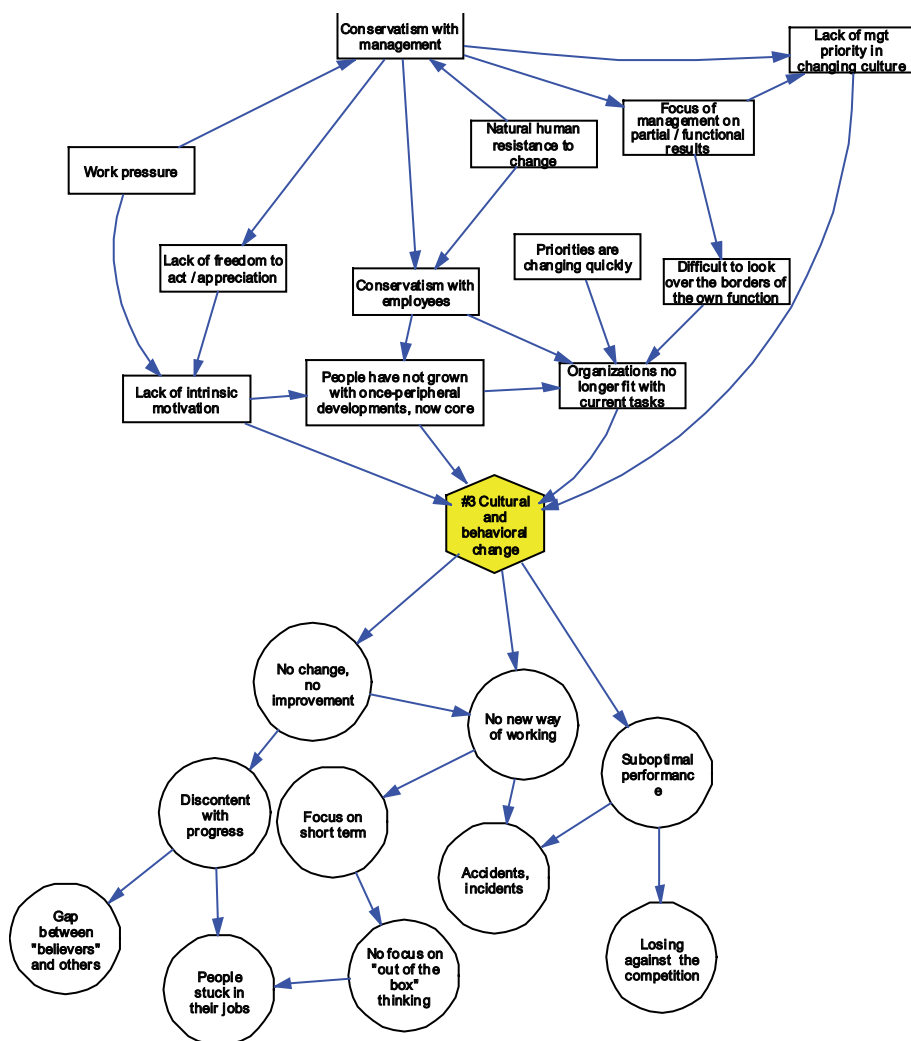
*The consequences of a lack of innovation in cultural and behavioural change*

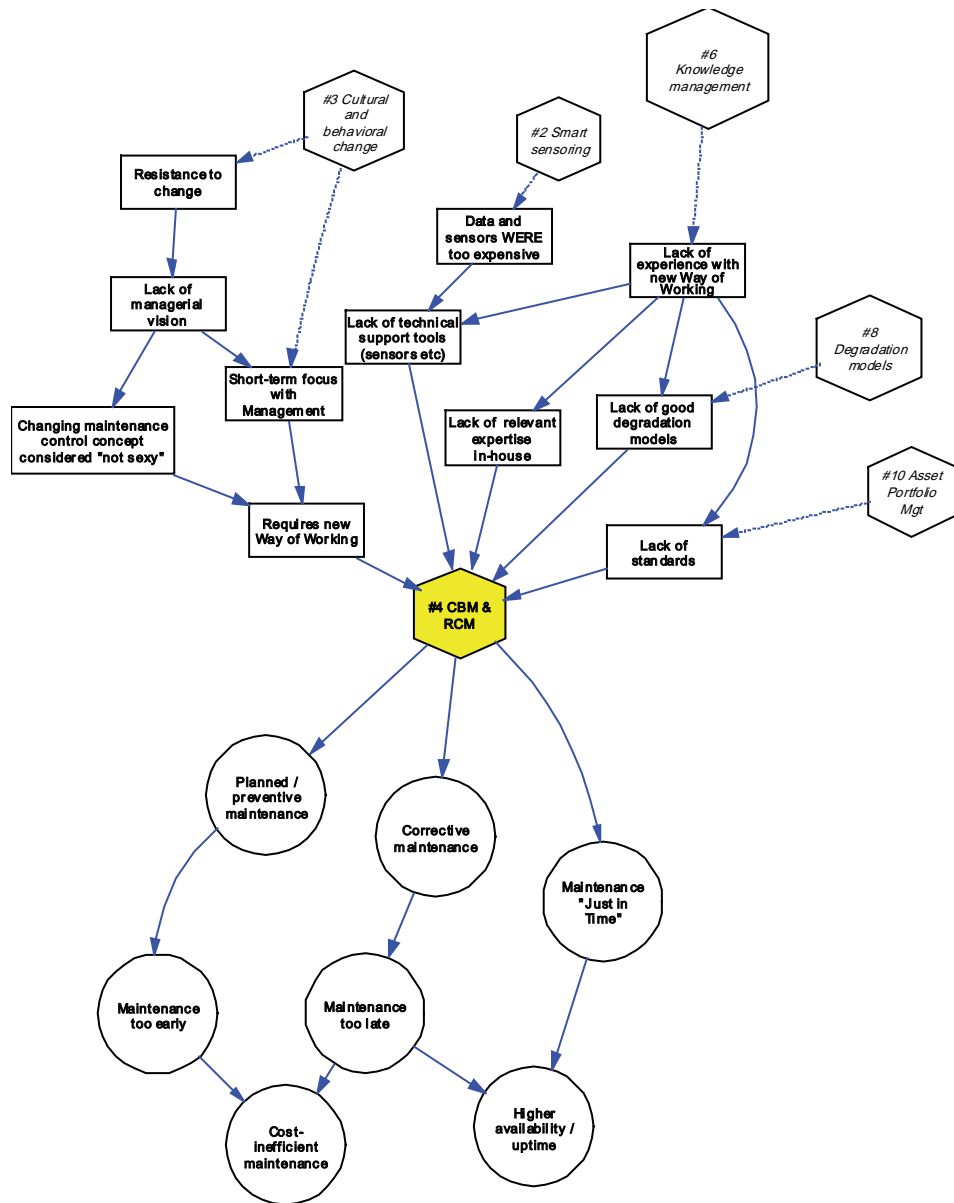
When culture experiences no change, no improvement will take place, no new ways of working will be introduced, and no 'out of the box' thinking will occur. Performance will continue to be sub-optimal. This leads to a feeling of discontent with progress and a continued focus on the short term. On the cognitive side, this leads to a wide gap opening up between the 'believers' in smart maintenance and other such areas on the one side and people who are stuck in their old, usual jobs on the other. On the material side, this simply leads to more accidents, more incidents and, ultimately, to losing against the competition.

*The root causes limiting innovation in cultural and behavioural change*

Why isn't there more cultural and behavioural change taking place? The answer is that the sense of conservatism which pervades management doesn't want to change. This is only one group of stakeholders that is falling victim to the universal, natural tendency to resist change, because there is just as much conservatism inherent in employees. Because of this managerial conservatism, the managerial focus remains on achieving local, functional results, while work

pressures remain high, freedom to act remains low, and priorities to change culture are certainly low. Over time, this results in an ever greater gap between what the organisation needs to do in order to meet its current tasks, and what the organisation is capable of doing. People have not grown with developments such as smart maintenance which were once peripheral but are now becoming core requirements.





**No 4. CBM and RBM: a lack of vision perpetuates the lack of experience with new ways of working**

*The consequences of a lack of innovation in CBM/RBM*

The consequences of not engaging in CBM and/or RBM are relatively simple, albeit far-reaching in their impact: maintenance will simply continue to be conducted either in corrective terms or when planned, the former resulting in maintenance which is conducted too late, the latter in maintenance which is carried out too early, both leading to cost-inefficiencies, and to lower uptime/availability than could be possible.

*The root causes which are limiting innovation in CBM/RBM*

More revealing is the analysis of why there is not more CBM and/or RBM. Firstly, we don't know how. There is a lack of experience in organisations when it comes to this way of working. There are also not enough good-quality degradation models in place, which are essential for both approaches. There are also no standards on how to do this. And there is also a lack of technical support tools, including the right kind of sensors. Then, from a different perspective, a good many people in organisations don't want this new way of working anyway. It conflicts with the current short-term focus with management, the whole topic of maintenance control concept is not considered 'sexy' anyway, and there is a lack of managerial vision to push hard for this new way of working.



**No 5. Design for maintenance: the project focus on CAPEX, not on OPEX, leads to a gap between design and maintenance**

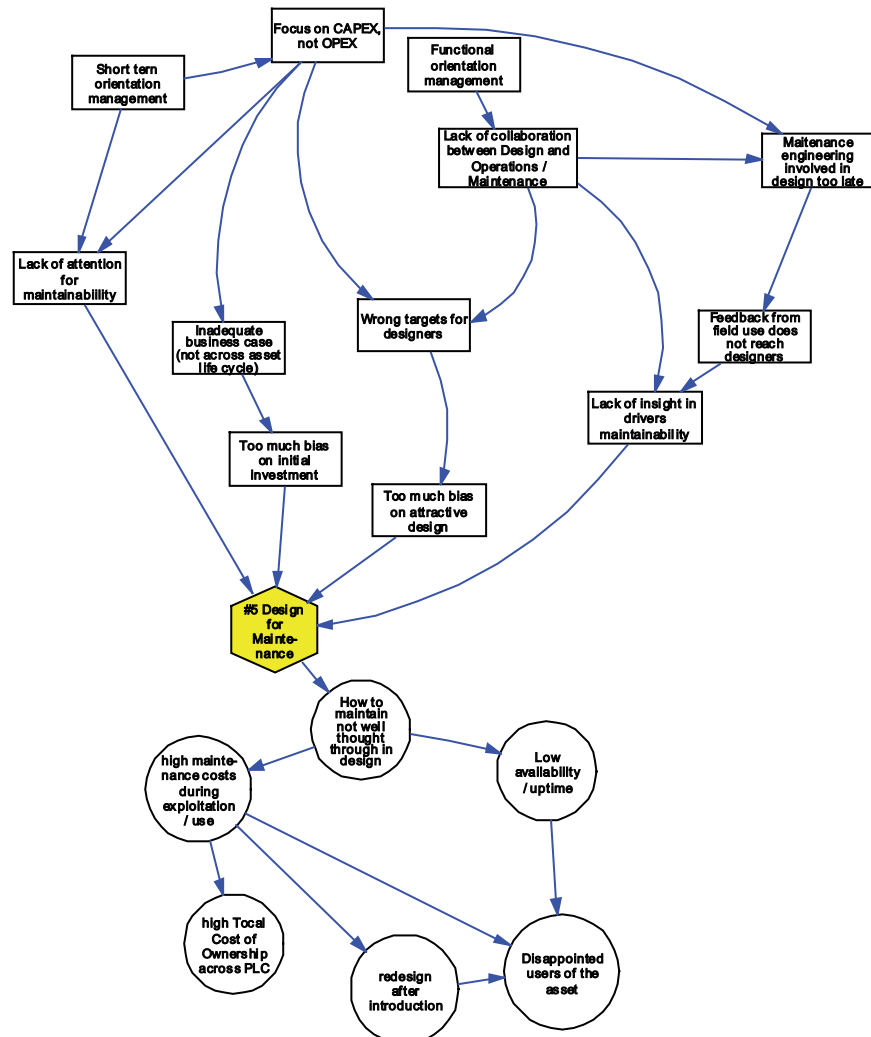
*The consequences of a lack of innovation in design for maintenance*

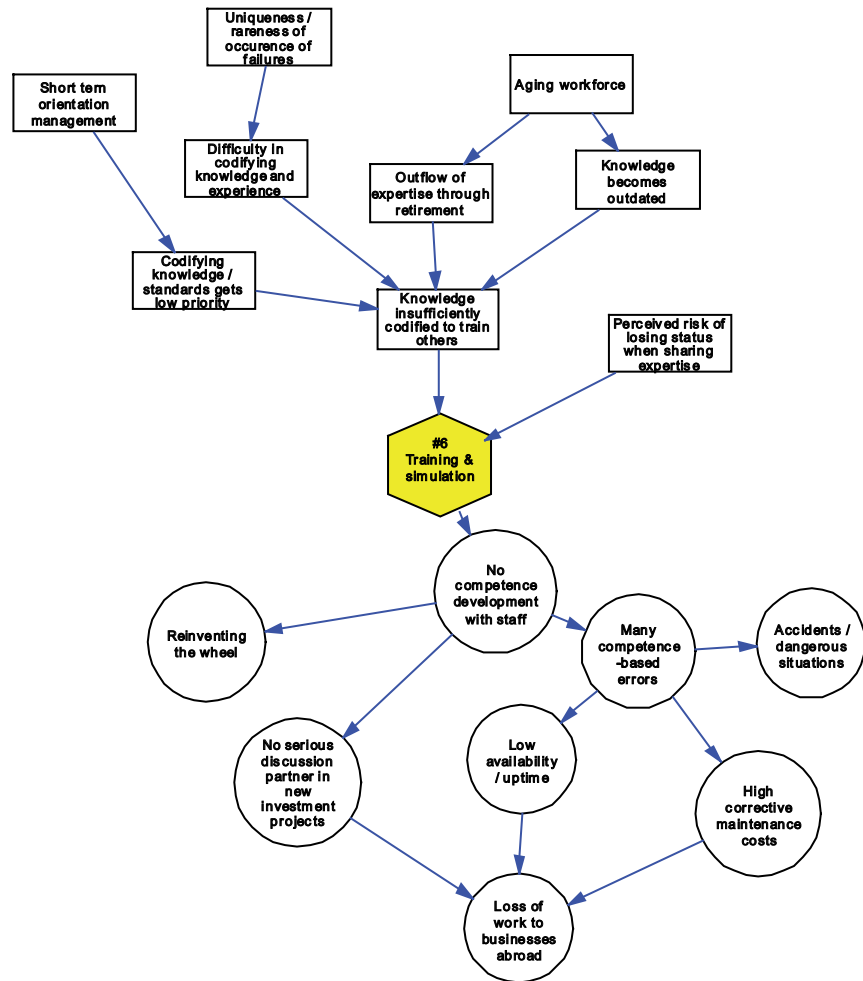
Fundamentally, the lack of design for maintenance (DfM) leads to designs in which the question of how they should be maintained is simply not well thought through, with all of the unexpected maintenance costs and availability issues that are bound to result from such design flaws.

*The root causes which are limiting innovation in design for maintenance*

If DfM is such a good idea, why is it not happening more often? An important root cause is the focus in many technical asset-intensive organisations on the initial capital expenditures, rather than on the subsequent operational expenditures. Underneath this lie cultural aspects such as the short-term orientation of management and its functional orientation, which leads to a lack of attention during design for maintainability and a bias on the initial investment and the attractiveness of the design.

At a more technical level, companies don't have enough insight into the drivers of maintainability. They could have, if there could be a closer level of collaboration between design and operations/maintenance, but there isn't: maintenance engineering is involved too late in the development process, when most of the lifetime costs have already been fixed in the basic design.





**No 6. Knowledge management: an aging workforce and little focus on codifying their knowledge**

*The consequences of a lack of innovation in knowledge management*

When there is not enough training taking place, there is not enough competence development with staff. This leads to the wheel being reinvented and to many competence-based errors. Such errors can sometimes be dangerous, but they will always result in higher costs and lower uptime. In the end, this will not just lead to high maintenance costs, it will lead to a loss of service, and maintenance work leaking abroad to companies which are better placed to handle it.

*The root causes limiting innovation in knowledge management*

If this is so obvious, then why don't we spend more time and effort on knowledge management? The root causes are partially demographical, partially technical, and mostly cultural. Demographically speaking, we are faced with an aging workforce and with an increasing speed at which knowledge becomes outdated. At the same time, there is a lack of focus on succession planning and in the recruitment of younger technical trainees. Technically speaking, codifying knowledge regarding failures, which tend to happen rarely and in unique ways, is simply difficult. And without codification learning through doing can still exist, albeit perhaps in a simulated environment.

The cultural causes once more have to do with management's short-term orientation, which assign low levels of priority to codifying knowledge, and even make it risky to share expertise because it may lead to a loss of status.

**No 7. The integration of AM IT systems: fragmentation leads to duplication and frustration**

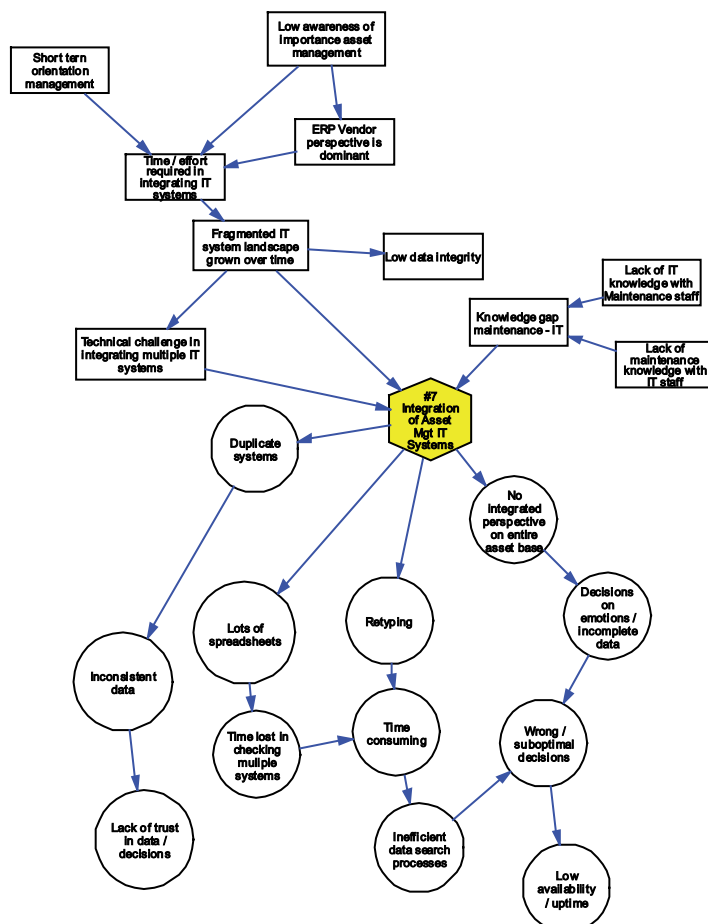
The IT situation in service, maintenance, and asset management somewhat resembles the situation in goods flow and order handling IT systems two decades ago: a patchwork of local system exists, which are cumbersome to maintain, difficult to extract data from, and almost impossible to integrate with other systems. Since the MRP/ERP revolution of the 1990s, also triggered by the Y2K bug fear, large integrated systems now exist in goods flow management. These ERP systems also have asset management modules, but these are a far cry from an integrated solution for all aspects of maintenance, which covers everything from engineering data to operations data and service data.

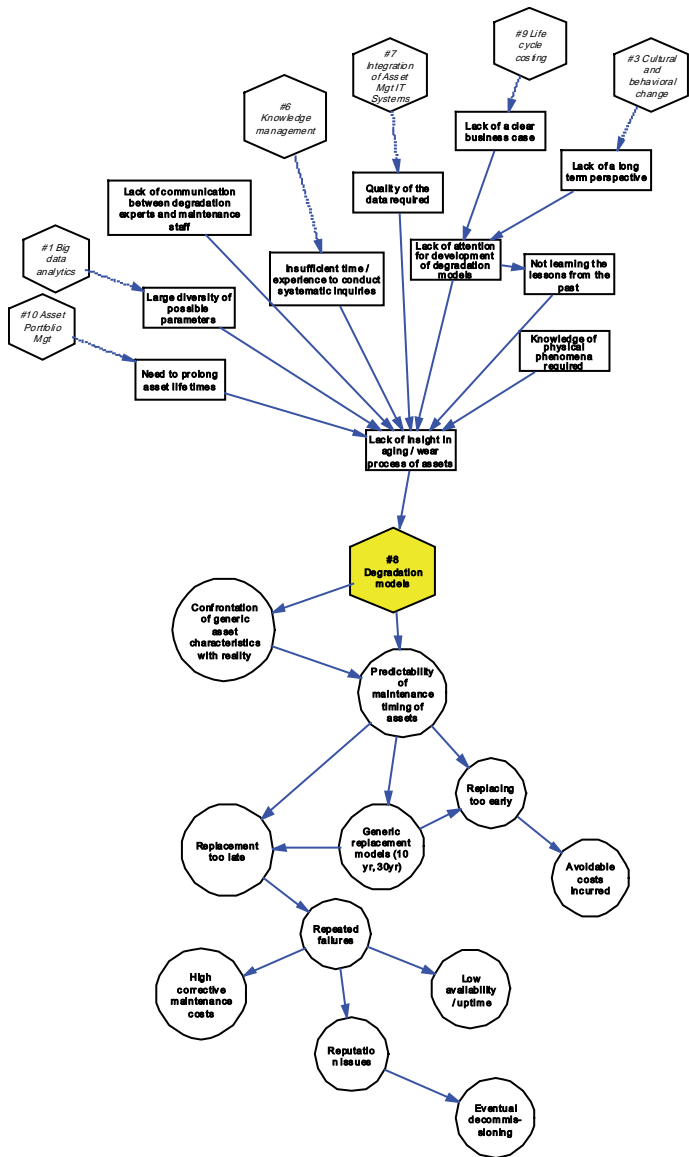
*The consequences of a lack of innovation in the integration of asset management IT systems*

The consequences of the lack of innovation at present in this area are large areas of duplication, a loss of spreadsheets and lots of time-consuming retyping from one system to another. As a result, there are large numbers of inefficiencies and opportunities for errors to occur. At a deeper level, a consequence is also the fact that there is not a single integrated data-driven perspective on service, maintenance, and asset management possible, since the data cannot be integrated.

*The root causes limiting innovation in the integration of asset management IT systems*

Why has this situation not yet been resolved, as it has in the goods flow/order processing area of the business using integrated ERP systems? First of all, it is not an easy task to achieve; it is technically complex, as it was with the previous ERP 'crusade'. Secondly, at a deeper level the issue is not technical but organisational: people have become used to the present fragmented situation and have settled with this mediocre state of events. There is no strong managerial urgency or awareness that this situation has to change. Thirdly, there is a knowledge gap, which sounds somewhat like a chicken-and-egg problem. There is little knowledge of maintenance-related matters amongst *IT staff and little IT knowledge*





**No 8. Degradation models: an essential yet difficult long-term investment in better understanding how assets age**

A crucial requirement for being able to service and maintain assets ‘just in time’, is the fact that we know what drives their functionality to deteriorate and what path that deterioration follows. In short, we need more degradation models. Presently, these are in short supply. Many of those that we have are not well known and even more of them are not used.

*The consequences of a lack of innovation in degradation models*

The most important direct consequence of this limited availability, knowledge, and the use of degradation models is that we cannot predict when an asset should best be maintained. And so we either manage this too early in order to be on the safe side, or too late, when the asset has already broken down. We use simplistic time-based replacement models (every year, every ten years, every thirty years).

At a deeper level, because we do not have a good theory of what makes assets wear out, we also do not closely monitor these specific factors, and so we cannot validate or improve that theory. We just don’t know if we are right or if we could do a better job of predicting deterioration.

*The root causes limiting innovation in degradation models*

The central root cause which serves to limit innovation in this area is the fact that we lack insight in the aging/wear process of assets. Again, there are good excuses for this. There are so many parameters that are potentially relevant. Additionally, we need some decent data before we can develop these degradation models (which is a major problem in its own right, as discussed previously). It takes a lot of time and dedication to develop such models, and time is scarce. We need to arrive at a deep level of understanding complex physical phenomena. However, once again there is a cultural element underlying this. Why don’t we dedicate the time for this? The answer is that this calls for a long-term perspective and, as we discussed earlier, the focus is on the short-term. As we don’t spend the time on this issue, progress and innovation are lacking and this in light of the urgent managerial necessity to lengthen product life times.

### ***No 9. Life cycle costing***

There is a major business need in light of the servitisation trend and the popularity of performance-based contracting when it comes to being able to translate the technical characteristics of asset performance into financial figures. If a machine breaks down only half the number of times when it is maintained based upon its condition rather than based upon a plan, how much extra may that condition-based policy cost? Or what percentage of cost-savings for OEM and 'Asset Owner' can be realised? What is the value that is being created by the move to CBM?

#### *The consequences of a lack of innovation in life cycle costing*

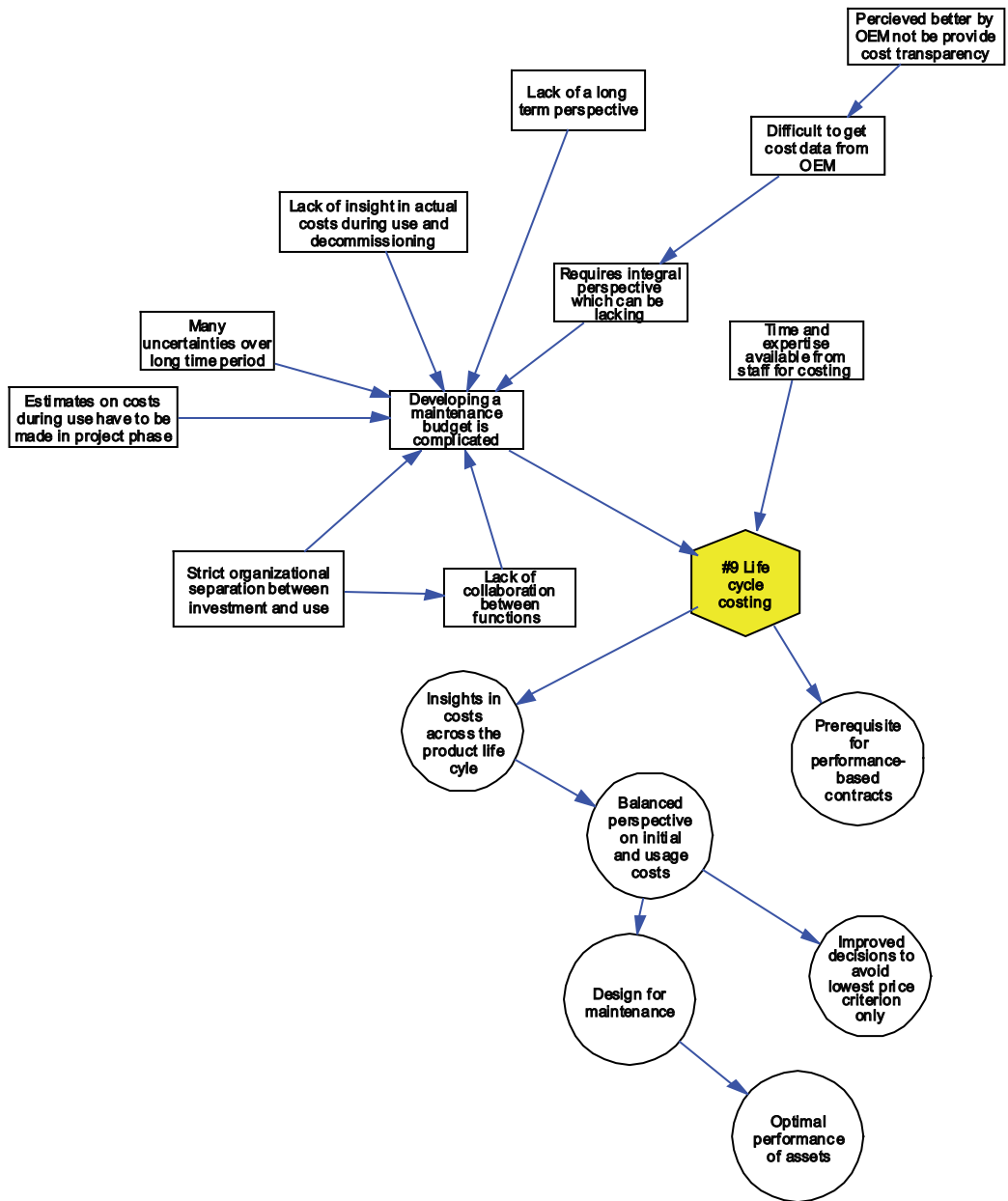
Despite its business potential, and despite its lack of technical sophistication (quite in contrast to degradation models, for instance), the use of LCC in business is still very limited.

As a result, there is still no balanced perspective in place in terms of initial versus usage costs, which is a serious limiting factor when it comes to design for maintenance, and also for performance-based contracts.

#### *The root causes limiting innovation in life cycle costing*

Although the mathematical calculation of life cycle costs is not overly complicated when compared to some of the calculations needed for degradation models for example, handling this in practice apparently is complicated. Perhaps that has to do with the many unknown factors involved, the many uncertainties over a long time period. But there also exists a data issue from the past: estimating what costs may occur in the future requires knowing what costs were incurred in the past with similar assets. There simply exists a lack of insight in actual past and present costs in terms of assets, in particular costs involved in decommissioning assets. In quantitative terms, there exists a shortage of staff who have the time and expertise to carry out such costing exercises, as it requires people able to move easily back and forth between the technical and the economical domains.

The bigger challenges, though, appear to be once again in the non-technical but cultural and organisational management area. Organisationally, there remains in most organisations a strict separation between the development of assets, or the purchase or refurbishment of them, and the service and maintenance of those same assets. There is often a lack of collaboration between innovation, purchasing, and service/maintenance/asset management. And as a result of this lack of collaboration, it is difficult to combine all of the relevant areas of data into one overall calculation so that adequate decision making can be carried out. Culturally speaking, it also requires a long-term perspective, as assets may remain in use for decades, and as we have observed repeatedly this long-term perspective is often lacking with management. Economically speaking, OEMs often have a business incentive not to share data about the life cycle costs of their assets, as this may harm their commercial offering to customers.



**No 10. Asset portfolio management**

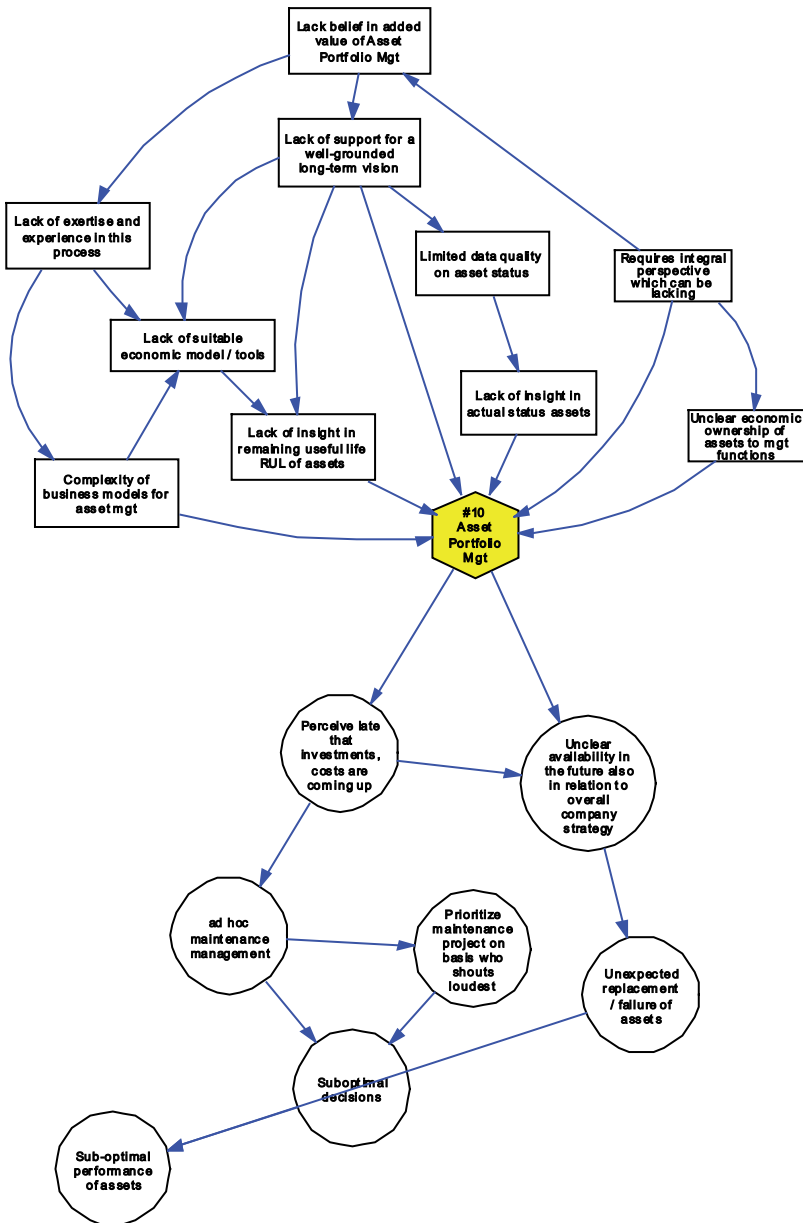
A well-operating business process in terms of asset portfolio management could help organisations greatly in making better their long-term priority assessments than they are making them today. In theory, it also seems a very obvious and straightforward concept. If organisations are responsible for portfolios of assets worth tens, hundreds, or thousands of millions of euros, surely they must have an accurate picture of what those are, what their present and past technical performance may be, and what their expected service, maintenance, overhaul, and replacement timing is for the future? Apparently, in practice, the situation is not so straightforward.

*The consequences of a lack of innovation in asset portfolio management*

The consequences of these problems are equally obvious: ad hoc maintenance management, the prioritisation of maintenance work on the basis of who shouts the loudest, and unexpected failures of assets. In short, suboptimal decisions leading to the suboptimal performance of assets.

*The root causes limiting innovation in asset portfolio management*

Less straightforward are the reasons behind why there is not more progress in this area. There exists a general complaint about the complexity of business models for asset management. However, in a technical area such as maintenance, where so many truly complex technical issues are investigated and resolved, this argument cannot hold ground. If first and second year bachelor students in economics can make these calculations in theory, surely well-trained engineers should also be able to make them in practice? A more valid point may be the fact that there is, in practice, a lack of insight into the 'Remaining Useful Life' (RUL) of assets, simply because there exists a lack of expertise within companies with regard to those models that are best used to make these calculations and, once more, due to the sheer lack of data on actual, present technical status and the past performance of all of the assets in the portfolio. Once more, these issues have a deeper root cause in the lack of an integral perspective, and the uncertain economic ownership of assets between different organisational units and functions. Why is this? Again, a root cause is suggested which involves culture or attitude: management is simply not sufficiently interested in a well-grounded long-term vision, and as a result sees limited added value in a well-oiled asset portfolio management process.



### No 11. 'Performance-Based Contracting' (PBC)

In the Delphi workshop this innovation became, for understandable reasons, a combination of three separate innovations from the Delphi survey. Understandably, since these three innovations really address the same concept, but seen from different perspectives: from that of the asset owner (I07); that of the contractor (I06); and that of the OEM (I09). In all cases, the result will be that of a performance-based contract between asset owners and the OEM and/or the contractor.

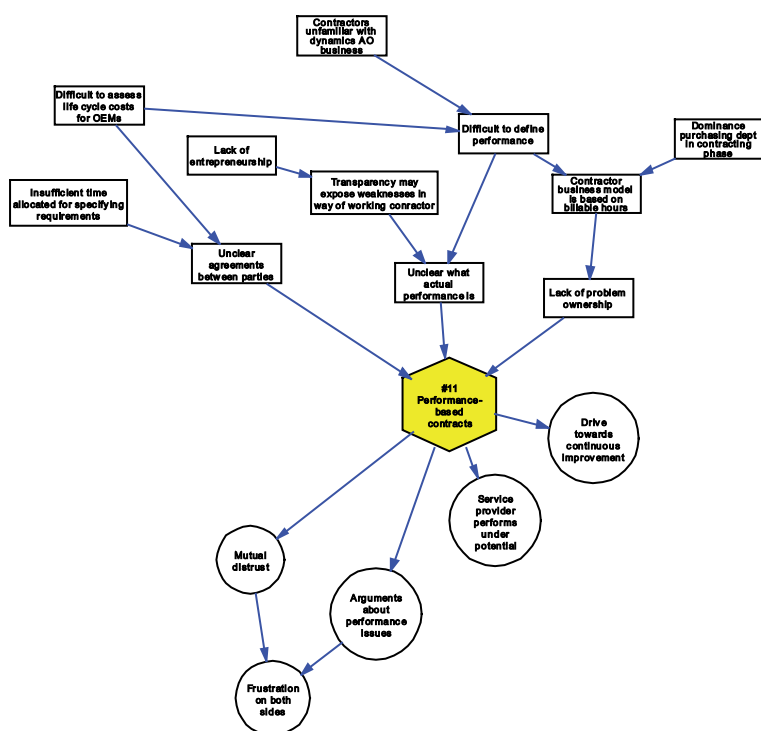
#### The consequences of a lack of innovation in performance-based contracting

Although there is no doubt that the consequences are also strongly technical and financial, our panel of experts focused on the aspect of PBCs that in practice may lead to the loudest calls for their broader application: frustration with customers thanks to a misalignment of goals between the OEM, the contractor, and their own goals. Such sentiments can have severe consequences nonetheless: several respondents mentioned safety risks and incidents as a result of a lack of effective communication, and goal-alignment was also mentioned. In the least troublesome of cases, time is wasted on arguments, re-working, and duplication of effort, and therefore no optimal performance is achieved in terms of the service provider, let alone a shared drive towards continuous improvement.

#### The root causes limiting innovation in performance-based contracting

For a concept that would seem to be so intuitively clear there appears to be an incredible lack of clarity when it comes to the root causes. In practice, the agreements between parties are not clear, and neither is the actual performance on which the contract is to be based. Also unclear is where the problem owner resides. Why is there a lack of clarity in the agreements? Firstly, because it is indeed difficult to assess this beforehand, at the time at which the contract is to be defined, or what the life cycle costs are likely to be, or on which elements the contract is to be based. Lack of time for a sound analysis is also mentioned here, along with technical complexity. It may also be difficult to come up with a good operational definition of what performance may be and even should be in a particular setting. However, a lack of entrepreneurial

activity and a fear of losing something through the implementation of greater levels of complexity are also mentioned as root causes. There is safety for both sides in continuing with the 'known', even when the known is clearly unsatisfactory for both parties. This is true both for the supplier and for the buyer: the present contractor business model is often based on maximising invoiceable hours, in a performance-based contract this objective is completely turned upside down, as payment is not based on input (hours invoiced) but on output (asset performance). The present asset owner procurement procedures are often unsurprisingly dominated by the procurement function, and here too there tends to be a preference for clear and apparently 'safe' cost savings rather than 'complex' and perhaps elusive performance gains.





**No 12. Mobile solutions**

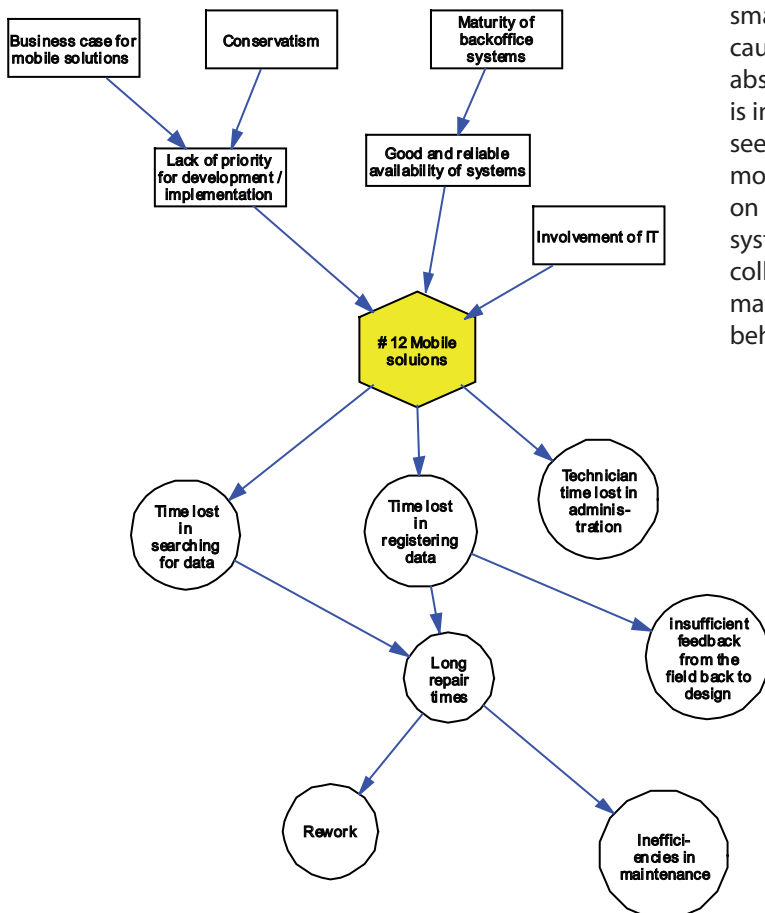
One of the few apparently truly technical solutions that ended in the 'Top 14' of the most important areas in this field is that of mobile solutions: all of the IT tools and techniques that make it possible for the technician to work more efficiently, such as a paperless office, electronic work documents, electronic documentation, handhelds and scanners, and automatic logging of work activities. However, upon closer scrutiny it does appear that this is as much a process and organisational issue as it is a technical one, as it requires integration with many other parts and systems within the organisation.

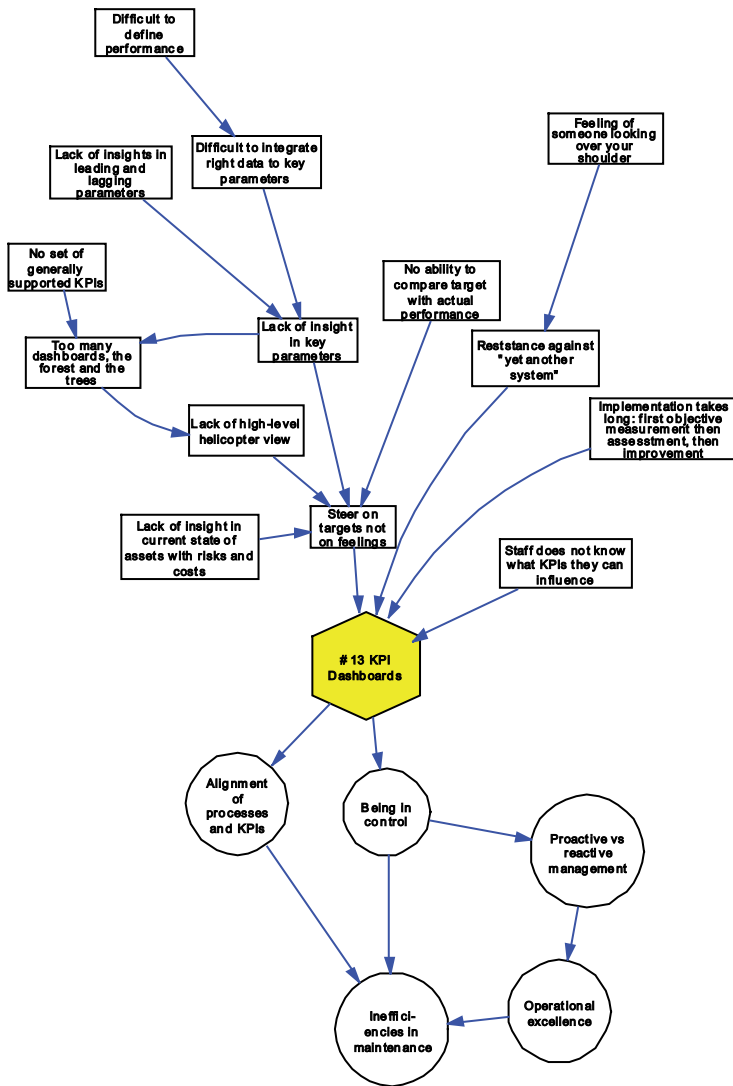
*The consequences of a lack of innovation in mobile solutions*

As stated, the main objective of this innovation is to improve efficiency. Not surprisingly, the main symptoms when this is not working well are related to time lost. Time lost in searching for data, in registering data, and in administering data. These problems lead to long repair times and so to inefficiencies. However, there is also a quality issue involved. Because all this manual administrative work leads to communicating less, and communicating with errors in place, it also leads to more re-working and to insufficient feedback from the field to the design: 'Was broken - have fixed it', is a classic entry in a manual technician log. Such an entry may be to the point, but it is not very informative for root cause analysis.

*The root causes limiting innovation in mobile solutions*

So why don't we have them already? Our panel failed to mention technology issues, and this is probably correct, because we are talking about things that most technicians would do as routinely as consumers, and not in their professional capacity, as we all use our smartphones in daily life. What was seen as a root cause is once more a lack of priority due to the absence of a business case (which sounds as though it is in contradiction to the obvious benefits), but is also seen as 'conservatism', plain and simple. And even more to the point, this innovation relies very heavily on effective integration with many of the other IT systems in the organisation, and that requires close collaboration with IT (which tends to be lacking) and a maturity of back office systems (which tend to lag behind).





### No 13. KPI dashboards

KPI dashboards, and managing performance via KPIs, is one of those innovations that rank surprisingly high to an outsider on a list of innovation priorities. They are certainly not specific to maintenance - quite the contrary in fact. However, upon closer scrutiny it becomes clear that they may be enablers of many other innovations that would be more 'usual suspects' on such a list.

#### The consequences of a lack of innovation in KPI dashboards

The advantages are obvious. Symptoms of when this is working well include companies being in control, processes being aligned, or management becoming proactive, all of which leads to operational excellence being achieved.

#### The root causes limiting innovation in KPI dashboards

If the advantages are so obvious, why are KPI dashboards at present not a standard issue for maintenance? The main root causes are knowledge-related. Of course, it has been mentioned that developing these systems takes time and effort, but the general point is that staff simply do not know what performance indicators really matter the most, something that is a prerequisite for developing any management dashboard.

Why? Because there is a lack of insight into the current state of assets, or in the direction and magnitude of the risks involved that need to be managed with these dashboards. At a deeper level, there is still a lack of insight into what the key parameters may be for those assets that are under the control of maintenance, and there is certainly lacking a helicopter view regarding them. There is also a 'dark side' to this lack of transparency. This is the risk that some staff may feel that 'someone is watching over their shoulder', as these dashboards are not only visible to them, but also to their stakeholders. Resistance to change may be a broader term for this issue.

### No 14. 3D/virtual reality design

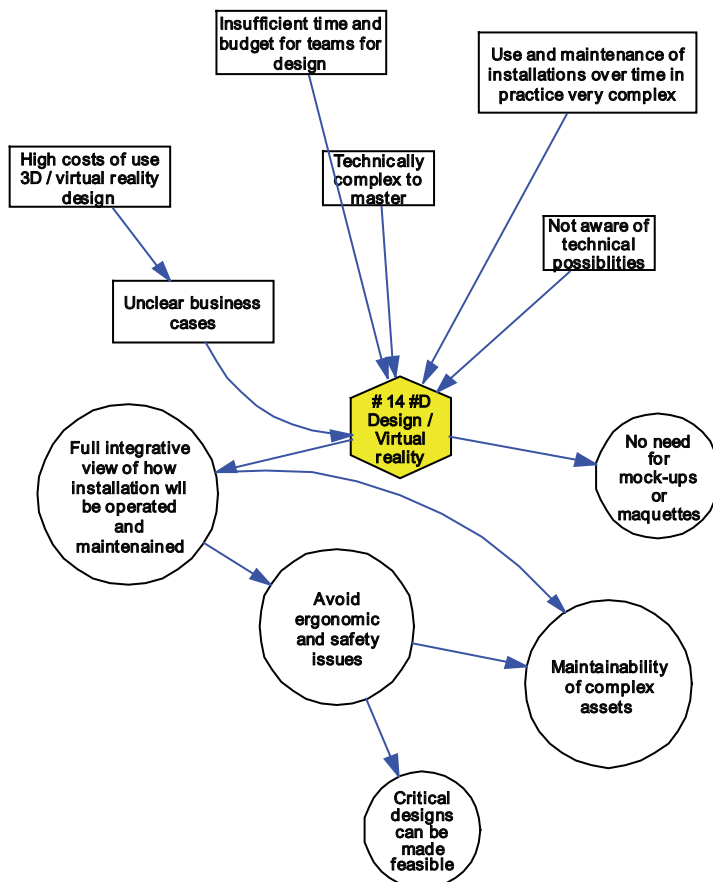
Throughout many industries, the transition from 2D to 3D design is currently being carried out. In some sectors, such as electronics, virtually all design is 3D, while in others, such as shipbuilding, design is partially 2D and partially 3D. It is obvious, though, that the bulk of the existing infrastructure, much of which was developed several decades ago, is in 2D. There, certainly, the transition from 2D to 3D offers a good many opportunities, especially if the 'as built' configuration is being maintained over time, with links to all the data that is generated and with all the changes to the actual assets being logged and incorporated digitally as well. When this happens, opportunities abound for better maintenance.

#### *The consequences of a lack of innovation in 3D design*

If we were to have full 3D drawings of assets available, fully linked and integrated with maintenance data, then we would be in possession of a full and integrated view of how the asset should be operated and managed. We would no longer need mock-ups, obviously. And we could avoid a great many ergonomic issues, as it would become immediately obvious why a certain design would be cumbersome to maintain, so definitely not 'Design for Maintenance'.

#### *The root causes limiting innovation in 3D design*

In this case, the experts are fairly forgiving in the reasons why there aren't so many of these integrated 3D designs around, even though they feel that they are very important innovations. They recognise that they are, in the case of many industries, still technically complex to master while knowledge about the technical possibilities is still limited. They also acknowledge that these systems come at a high cost, while budgets and time are under severe pressure. And they admit that to keep track of the use and maintenance of all installations over time can be a technically daunting and time-consuming task indeed. It would probably take considerable progress in several of the other innovations to make a reality of the use of 3D/virtual reality designs for maintenance on a broader scale.



### **The root cause analysis across innovations**

In this section we take the root cause analysis of the previous section one step further. For many of the root causes limiting progress that have been mentioned, there is an obvious candidate innovation that may help to take it away. For instance, if there exists too little data on the actual performance of assets to enable condition-based maintenance or asset portfolio management, then more data sensing to generate such data would be an obvious way to overcome that problem. In this way, there are a large number of correlations between individual innovations; there are many ways in which they will cross-fertilise each other. These cross-fertilisations are summarised in.

Those cross-fertilising innovations that are listed in the table (next page) were already shown in the causal diagrams for the preceding section, indicated by dotted lines between them and the root causes which they affect. In the present section, all of these links are combined in tabular form.

An analysis of this table leads to three overall conclusions, ranging from (1) people and organisation innovations to (2) process innovations to (3) technical innovations.

#### ***1. Cultural/behavioural change and knowledge management are seen as essential conditions for faster progress in all other innovations***

A very loud and clear signal in this Delphi study which inquired about innovation in such a technical area as maintenance, cultural/behavioural change (No 3), and knowledge management (No 6) are seen as top priorities for maintenance innovation. They are especially important as they remove key road blocks which are limiting progress in all other areas:

Cultural and behavioural change can remove road blocks such as the lack of a fact-based culture, conservatism when it comes to investing in new technology, short-term orientation with management, a perceived lack of status when sharing expertise, a lack of integral perspective, a lack of entrepreneurial activity, and a resistance to change. All of these are road blocks for virtually all other innovations. Similarly, knowledge management addresses knowledge-related road blocks such as limited big data expertise for big data analysis, limited experience with sensor technology for smart sensing, a lack of experience in new 'Ways-of-Working' for CBM/RBM, insufficient time and/or experience when it comes to conducting systematic enquiries for degradation models, a lack of experience/expertise in asset management processes for asset portfolio management, and the technical complexity of mastering new techniques for 3D design.

#### ***2. Innovations in finance, IT management, general management, and HRM are crucial for enabling innovation in maintenance***

Many of the innovations that are needed for world-class maintenance are not by themselves maintenance-centred innovations. This was already true of the two organisation-driven innovations: the primary driving role for knowledge management would, in a functionally-orientated organisation, come from HRM. Cultural and behavioural change has to be led from the top, from general management.

But there are more:

Product-life cycle costing is primarily a financial activity, which may reside more on the purchasing side of the organisation in the case of 'Asset Owners', or more on the sales side of the organisation in the case of OEMs and contractors. At any rate, it can work to overcome a variety of road blocks which are limiting progress in maintenance: the lack of a clear business case for investing in sensor technology, something which is needed for more smart sensing. It can shift the focus



onto capital expenditure (CAPEX), not on operational expenditure (OPEX), for design for maintenance. It can help to generate more experience and expertise in the calculations that are required for asset portfolio management and for performance-based contracts, and it can help to close the business case for mobile solutions.

Integrating AM IT systems is primarily an IT activity, one which will normally reside within the IT department in functionally-orientated organisations. It can remove road blocks such as the low quality of the data required, which is a prerequisite for big data analysis and degradation models. It can reduce the lack of clarity regarding actual performance for asset portfolio management, and it can increase the maturity of back-office systems for 3D design and difficulty in integrating the right areas of data into key parameters for KPI dashboards. These interdependencies clearly indicate that maintenance cannot move forwards in isolation. The field will have to join forces with the other management functions and have to be propelled by general management into the direction of high-reliability organisations and world-class performance in service and maintenance.

### ***3. Data driven technologies are seen as being key drivers for the other process-driven and technical innovations***

Not only do the data-driven innovations rank as top priorities in maintenance innovation for forthcoming years, they are also seen as being key in enabling many of the other innovations, as they remove many of the road blocks which are limiting progress there as well. The three data-driven innovations in the 'Top 5' illustrate this:

*Big data* can overcome issues in technical challenges in integrating multiple IT systems, which is a prerequisite for integrating asset management IT systems. It can help to deal with a large diversity of possible parameters, which is essential for progress in degradation models. Big data can create more clarity in what actual performance may be, which is something that is needed for performance-based contracts. And it can increase insight into leading and lagging parameters, which are required for effective KPI dashboards. Finally, it can reduce complexity in the use and maintenance of installations over time, which is needed for up-to-date 3D designs.

*Smart sensing* in turn can overcome issues in the lack of actual use of data, which is a road block for more big data analysis. It can also reduce the cost of sensor data, which is seen as a road block for CBM/RBM. It can improve data integrity, essential for the integration of AM IT systems. And it can help to generate more insight in actual costs during use for performance-based contracts and for asset portfolio management.

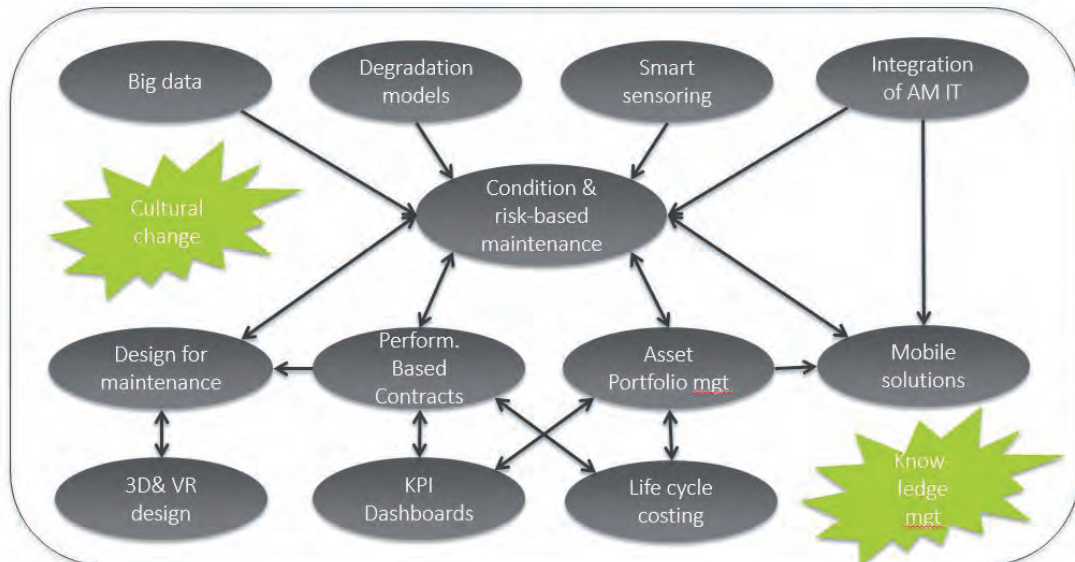
*CBM/RBM* in turn can overcome issues with aged assets which have little data generation, which presently holds back data analytics. It in itself can increase the data integrity needed for the integration of AM IT systems. It can help to remove difficulties in estimating beforehand those usage costs which may arise during the project phase, which is needed for life cycle costing for asset portfolio management.

### Graphical synthesis of interdependencies

In a final step of synthesis, is further summarised visually in the diagram shown below, which is also reproduced on the title page of this report.

Figure 5 illustrates the driving force for the IT and data-related innovations of big data, degradation models, smart sensing, and the integration of AM IT systems. It shows the pivotal role of the new maintenance control concepts of condition-based maintenance and risk-based maintenance. It shows the close interactions between the more financially-orientated innovations of performance-based contracts, life cycle costing, KPI dashboards, and asset portfolio management. It shows the prerequisites for design for maintenance and mobile solutions. It shows how cultural change and knowledge management affect virtually all other innovations with their arrows pointing everywhere.

Figure 5: Causal interdependencies between the 'Top 14' maintenance innovations.



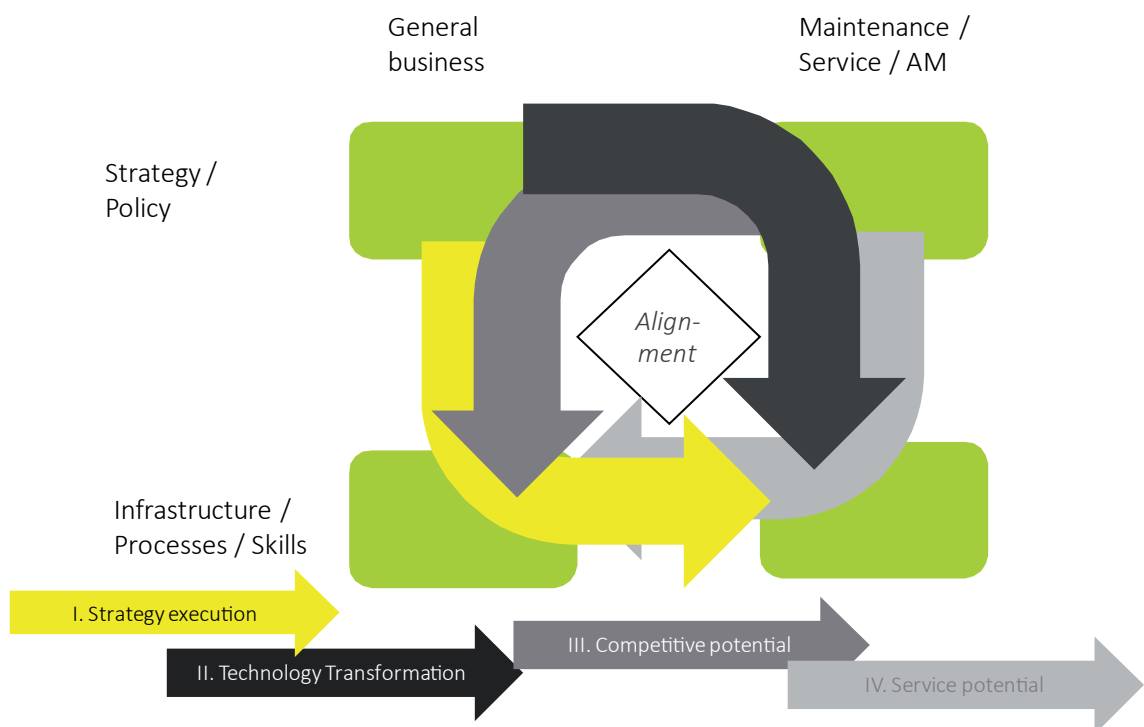
## 6. Routes to implementation: business-technology alignment

We now take yet another step back to look at what will be needed to allow the identified innovations to be implemented on a much broader scale than is happening today.

### An updated business-technology alignment model

In our analysis we borrowed from the IT field where, as early as the 1990s, the concept of a business-IT alignment was developed (see Henderson and Venkatraman, 1993, for example). The general idea behind this concept, as shown in Figure 6, is that there needs to be a close fit, an alignment, between the (maintenance) technology strategy and the business strategy, and also between the maintenance technology infrastructure, processes and skills, and the general business infrastructure, processes, and skills. In the case of a misalignment, and of a conscious policy/strategy which is aimed at re-alignment, four paths can be followed: two of them start with business strategy and two start with the maintenance strategy as shown in the figure below, which has the labels attached to show which labels were assigned by Henderson and Venkatraman in the context of IT alignment.

Figure 6: The business-(maintenance)-technology alignment model



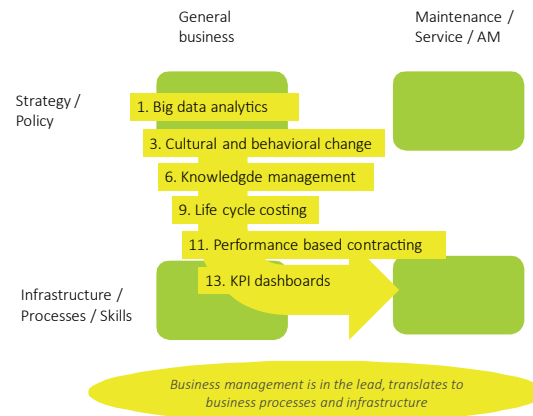
We have proceeded to map out the fourteen innovations in maintenance which have been investigated to the point of these four paths. This results in the four possible alignment modes discussed further:

#### **Alignment mode 1: business strategy execution**

The first set of innovations needs to be driven by general management. Surprisingly, almost half of the 'Top 14' maintenance innovations are not really maintenance innovations at all in the narrow sense of the word. They are better characterised as business innovations, which just happen to have a special area of relevance for the field of service, maintenance, and asset management. Choosing for a digital culture, for a 'big data mindset', is a call that general management has to make (Kane et al, 2016). This is even more true for cultural

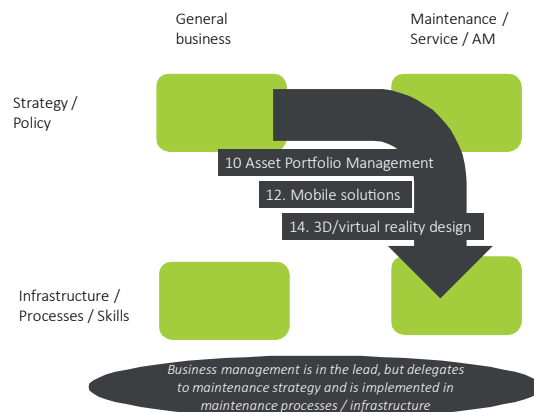


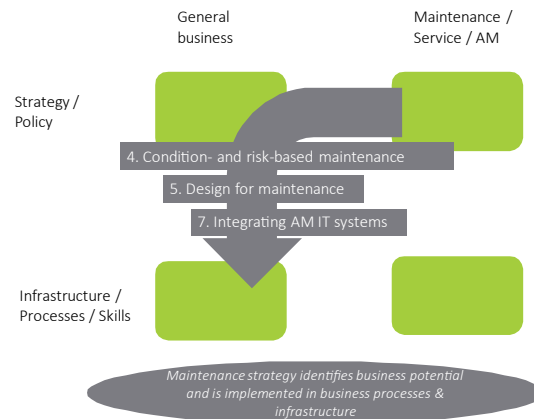
and behavioral change and knowledge management. Also, life cycle costing is first and foremost a financial activity or a sales activity (for an OEM offering servitisation services), or a purchasing activity (for an 'Asset Owner' who is seeking a value-for-money performance-based contract). However, it is, managerially speaking, not an activity that resides with the maintenance manager. The same is true for performance-based contracting, which is a procurement strategy, and KPI dashboards, which remain the core job of the (financial) controller in conjunction with the CIO. So business management and the CFO are in the lead here, and it is they who will have to translate this strategy into business processes, infrastructure and skills.



**Alignment mode 2: business management delegates to maintenance**

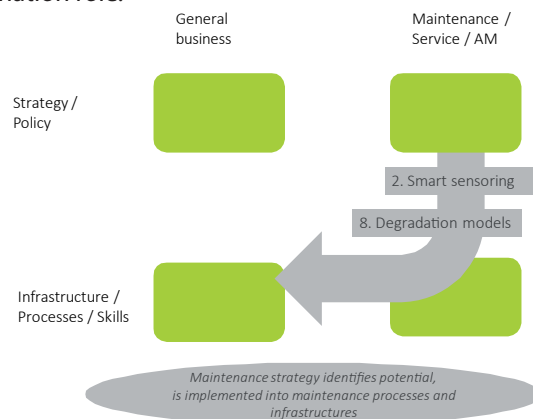
For the second set of innovations, general management may still hold ultimate responsibility, but they will generally be happy to delegate this responsibility to the service/maintenance/asset management function. For instance, asset portfolio management may refer to a large part of a company's balance sheet, but at its core it is a technical activity, one of which general management will want to be kept informed, to remain aware of any risk or financial implications for the future, but not to 'run' it. Similarly, mobile solutions will affect the bottom line due to increased technician productivity and higher levels of quality, and they will require the contribution from many parts of the business, but this will be an innovation that maintenance management executes, in conjunction with the IT function. Again, 3D/VR design does not start off as a maintenance activity but as a design/engineering/procurement activity. Nevertheless, in order to be able to keep 3D designs 'as built' and 'as maintained' up-to-date, management will look to the maintenance function in order to implement it into infrastructure, processes, and skills, in order to realise proper configuration management 'as-built' and 'as-serviced/maintained'.





**Alignment mode 3: business potential from maintenance**

The third set of innovations is driven by the maintenance function but needs the other business functions in order to make them succeed. If the organisation is to move from a conventional planned maintenance and corrective maintenance concept to a condition-based and/or risk-based management concept, this will require the consent and the collaboration of the other management functions, not least that of operations, whose work will be greatly affected by such a change. (Indeed, it should be affected positively, since this should considerably reduce disturbances generated by planned maintenance and the unplanned downtime which is incurred through corrective maintenance.) Similarly, design for maintenance requires maintenance engineers to become closely integrated into the process of developing, acquiring, and installing new infrastructure and other assets. The drive to make designs more maintenance-friendly will start from maintenance; its implementation will be a joint activity. This is also true for integration of asset management IT systems. Here, the whole business needs to be connected, while business ownership for the various systems resides with the business functions they support, and while the IT function tends to have the technical coordination role.



**Alignment mode 4: process implementation from maintenance strategy**

The final set of innovations is seen by the rest of the organisation as belonging to the domain of the maintenance function, and is also rightfully implemented by maintenance management into infrastructure and processes and skills. Smart sensors, insofar as they are not already installed on equipment for other functions, will fall under the responsibility (and also within the budget) of maintenance. The development of degradation models will be seen by everyone as a core technical capability of the maintenance function and few turf wars are likely to be fought over this innovation. Again, this will also mean that in many cases the costs behind this innovation will have to be borne by the maintenance function alone.

## 7. Conclusions: a different world requires a different approach

### **The world has changed**

#### ***Aging assets, an aging workforce, energy transition, and technology disruption***

It is impossible not to notice that major changes are occurring in all industries, throughout global economies, in the political arena, and in the environment. Most obvious is the economic downturn of the past eight years, which has had a notable impact on the world as a whole and has driven many if not most companies and organisations into survival mode. Costs needed to be reduced, margins were very low, the import and export of goods were reduced, stock values plunged, and so on. After the financial crisis of 2008, it has taken eight years between then and now to see the first indicators of growth. From a positive point of view, markets and companies have been revaluated, stock markets show more realistic values, and growth is visible. Yet many industries within Western Europe still face hard times, margins still are low, exports are not yet at the levels required, and profits are low or are even in the negative.

In the shipping industry, the largest container company only recently declared bankruptcy, but many container vessels operate at half loads, product and crude tankers are laid-up, and the feeder market shows losses. The manufacturing industry still is operating at high capacity, something which hasn't dropped during the recession; however, many of the plants are operated at an extremely low margin or even at a loss. Yet there is still no short-term view on a recovery in many markets which deal with basic materials and petrochemicals. The main reason that the chemical industry is still dominant within the Benelux Countries is the low cost of raw products, oil-derivates, and natural gas, along with the low cost of energy.

The housing and building industry is still at an extremely low level and profits are still negative or extremely low. Even in the case of housing market increases, too many companies went bankrupt over the last few years, so that it is not now possible to engage in a rapid ramp-up over the short term. Besides the economic consequences, there are also environmental consequences for industry. From a positive point of view, the new environmental realities create a complete new economy, one in which the public sector invests in solar and earth heating systems, in electric cars, electric bikes, and in LEDs. Meanwhile, the private sector invests in wind power and innovative and sustainable solutions, and all of this creates a large number of new jobs. However, the sustainability targets for the industry required high levels of investment into new systems in order to reduce the emission of greenhouse gasses and encourage lower energy consumption levels.

#### ***The successful answers so far (cost cutting and lifetime extensions) are not sustainable***

To ensure their survival during the crisis, many organisations have reduced their operational expenses and haven't invested in recent years in any renewal of their assets. Many assets have been in harvest mode for several years. It is also well known that the capital to invest in replacement assets is either not available or that the capital which is available will be required for investment into sustainable solutions instead of upgrading plants. Even so, most of the process industry will remain within the Netherlands, even without major investment and mostly without large capital projects taking place within existing facilities. Those existing assets need to extend their technical life, and for most assets this means an extension of twenty years or more. This requires another way of managing those assets; it simply is no longer possible to harvest installations and still keep operating at high levels of availability, integrity, and reliability.

Apart from the need to extend life versus the ageing of assets, the workforce is also ageing and the large pension due to baby-boomers is bound to start to take place within the next decade. The issue here is that a new, technically-educated workforce is hard to find. So existing knowledge walks out of the door and cannot be replaced since there is a shortage on the employment market of any such suitable replacements.

***The new area of major disruption is digital manufacturing, smart industry, and the 'Internet of Things'***

It can be seen that those answers which have so far proved successful will no longer work in forthcoming years. In order to be able to retain the asset-intensive industry within the Netherlands a major element of disruption is required, and this will be the fourth such disruption after (1) industrialisation, (2) electrification, and (3) automation, with (4) digitalisation now being added. Digitalisation will make things 'smart', will allow a move towards unmanned operations, towards utilising predictive and prescriptive analytics, towards 3D visualisation and augmented reality, and towards applications for the internet of things. And even though it still may seem to be quite far away, the innovation leaders, the digitally mature companies, have already begun to change their strategies so that they are ready for the day after tomorrow.

*'If you look at the history of corporate culture, you see that it's about improving efficiency, increasing margins, and eliminating risk... but none of this works in the world of the internet, where things change so incredibly rapidly.'*

*'As a result, digitally maturing companies which were surveyed placed a strong emphasis on innovation and are over twice as likely to be investing in innovation than are early-stage entities, a total of 87% versus 38%. More than 80% of digitally maturing companies plan to develop new core business lines in the next three to five years in response to digital trends. Only about half of early-stage companies have similar plans.'*

*'Talent development is an important element of the culture in digitally maturing organisations, which place a decisive emphasis on developing existing talent and recruiting new talent, a total of 76% of respondents from digitally maturing companies say that their companies provide resources and opportunities to develop digital acumen. However, only 14% of employees in early-stage companies and 44% in developing companies say that their organisations do this.'*

From Kane et al (2016), 'Aligning the Organisation for its Digital Future'

**Data-driven innovations require a concerted approach, together with process and people-orientated innovation**

***Data driven innovations need to be implemented in a concerted approach***

This study has once more emphasised the fact that the only way in which a condition-based approach to service, maintenance, and asset management will be implemented successfully is if it is implemented together with other data-driven innovations. Without progress in sensors and remote monitoring, there will be no data upon which to base decisions. Without integrated IT systems, the data which is needed so that it can be analysed cannot be pulled together from diverse sources. Without 'Big Data', the potential shown in terms of data collected will not be harvested. At the same time, without progress in degradation models, big data analyses will yield false positives and will miss many of the treasures which will remain hidden in such data, thereby creating many more false negatives.

***Process/managerial innovations also need to be implemented in terms of alignment***

Without good asset portfolio management, how can you decide which assets should be monitored? Without good KPIs, how can you measure 'success'? Without performance-based contracts, why bother to measure 'success'? Without life cycle costing, how can you determine fair targets for performance-based contracts? It can be seen that these clearly non-maintenance-specific innovations need to be lined up with data-driven innovations in maintenance, or else these will fail.

***Changes in culture and improvement in knowledge management will have the greatest levels of impact***

All these technical and process innovations are fine and also rather important, but without putting people first they will all fail. Our experts attached the biggest business impact of all to cultural change, and for good reason. Across the world of business, it is becoming evident that companies with successful digital strategies share very similar characteristics: they all have cultural mindsets which relate closely to digitally maturing companies, they value experimentation and speed, embrace risk, and create distributed leadership structures. They also foster collaboration and are more likely to use data in decision making (Kane et al, 2016, p10). These are the 'smart moves' that all organisations on their path towards smart maintenance maturity will have to take.

***The Low Countries are well positioned to become 'World Maintenance Champions'***

The Netherlands (and Belgium too) are well-positioned to become leading countries in terms of this smart maintenance strategy. Historically, we have been very successful in maintenance and today our name is a good one in the field of maintenance in many industries. To give just one example, the Netherlands occupies the third place when it comes to infrastructure for global trade, with the number one spot for harbour infrastructure and second place for road infrastructure (E. Holdony, 2015), which is due in large part to superior maintenance practices.

***Smart maintenance has become a great export sector for the Netherlands, similar to water***

With such a great global need for smart maintenance, and such a good track record already in place for Dutch and Flemish firms and public organisations, and with the opportunity for world-wide monitoring and operating that these digitised infrastructures offer, there is a clear opportunity for smart maintenance to become a great export sector for our economy, similar to the wonderful reputation that our companies which are working in the water and maritime sector already occupy. 'Call in the Dutch' could become the managerial reflex not just for maritime challenges, but for the maintenance sector as well.

**What is needed? We need to do this together**

***Implementation of the move towards becoming smart maintenance champions will require more experimentation, collaboration, risk-taking, and speed***

In the past five to ten years, most maintenance managers have focused on increasing the availability of assets, extending life times, and reducing maintenance costs. So far, that strategy has been successful. However, it is clear from this study that this same strategy is no longer sustainable for the next five to ten years. In line with the overall digital disruption in society, organisations will have to embrace 'smart maintenance', and shift their focus from cost-cutting to innovation, from maintenance as a utility to maintenance as a competitive

capability. Such experiments can only be successful if they are not conducted by the maintenance function in isolation, but are managed together with all of the relevant stakeholders.

***Collaboration within one's own organisation and with other organisations is essential in order to build up speed and direction***

Implementing these innovations will require collaboration at a much greater level than before, and in more directions than before.

Firstly, it requires collaboration in the boardroom. Maintenance, service, and asset management need to become core topics of discussion for the entire management sector, not just an aspect of the operations manager's portfolio. The majority of key maintenance innovations start with general management and other functional managers so, without their sense of ownership and commitment, progress will be too slow to allow it to become one of the leaders in our new digitised marketplace and society.

Secondly, it requires collaboration with other companies which are working in open innovation projects within the same industry, and which are facing similar challenges. Collaboration with direct competitors will remain problematic, but collaboration between companies within the same industry should be possible, such as the process industry, the maritime industry, or the infrastructure industry, all of whom face similar issues. Together, these companies can cross the so-called 'valley of death' from a promising technological idea to a successfully operating business venture, since together they can shorten the time to market and can reduce the costs involved in innovating to get there. The concept of smart industry field labs as advocated by the Dutch Ministry of Economic Affairs and FME ([www.smartindustry.nl](http://www.smartindustry.nl)) is a very powerful mechanism when it comes to fostering such collaboration between multiple companies.

Thirdly, it requires collaboration with education and research institutes from private companies and public organisations in these open innovation projects, but also in shaping the human capital agenda together in order to be able to meet the challenge of having the people on board with the right skill sets to execute these new smart maintenance concepts.

Fourthly, it requires collaboration with government, whether at the local level, the national level, or the European level. For many of the innovations which are listed here, even with open innovation projects and horizontal collaborations, the business case during the start-up phase remains too frail to justify investments by businesses that have been caught in a vicious spirals of cost-cutting in order to survive today, and thereby inadvertently cut back on innovation, and thereby hurt their competitiveness tomorrow. Government support on a limited scale, but administered once again smartly, will be effective in reversing these vicious cycles into virtuous ones, of funded small-scale field experiments yielding satisfactory results, justifying larger follow-on investment by the organisations themselves, and leading to a successful transition to world-class maintenance performance.

***There is an important role for independent knowledge brokers/network orchestrators/catalysts for change such as 'World Class Maintenance'***

In identifying the most promising areas in which to initiate collaborative open innovation projects, in bringing together the right players from education, research, business, and government to staff such projects, in orchestrating such complex field labs with dozens of independent parties collaborating effectively, and in helping to catalyse change in those organisations that want to become the new smart maintenance champions, organisations such as WCM play an important role.

There is a great need for independent parties who work 'for the common good', but at the same time are very closely involved in the daily work of innovation 'in the trenches' and still have close connections to the research and education institutes which are committed to the broad field of maintenance. It is not easy to set up such an independent party. It is usually better to look for ones that already exist and instead help them to grow to the size and capability levels that are required for them to be able to fulfil such a role. WCM already carries out such a role today and aspires to take that role to the next level, together with a 'coalition of the willing' from Dutch industry and academia.

This report outlines the content and direction of this task and makes it clear where we as WCM are aiming for, and for what we can be counted upon in forthcoming years. That being said, we remain keenly aware that 'the only constant factor is change', so we will keep a keen eye on the continued validity of this outlook for the 2016-2020 timeframe, and will do so well before 2020 arrives...

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# Annexes

## **Annexe A: List of Abbreviations**

3D: Three-dimensional  
AM: Asset Management  
BEMAS: Belgian Maintenance Association  
CAPEX: Capital Expenditures  
CBM: Condition-Based Maintenance  
CO<sub>2</sub>: Carbon Di-Oxide  
CRM: Customer Relationship Management  
CTO: Chief Technology Officer  
DAISY: Dynamic Asset Information System  
DfM: Design for Maintenance  
DI-WCM: Dutch Institute World Class Maintenance  
EAM: Enterprise Asset Management  
ERP: Enterprise Resources Planning  
FME: Federation of companies in technology driven industries  
GDP: Gross Domestic Product  
GDSS: Group Decision Support System  
HoTT: Hands on Tool Time  
HRM: Human Resources Management  
IoT: Internet of Things  
ISO: International Standards Organisation  
IT: Information Technology  
KPI: Key Performance Indicator  
LCC: Life Cycle Costing  
LED: Light-Emitting Diodes  
MIT: Massachusetts Institute of Technology  
MRO: Maintenance, Repair and Overhaul  
MRP: Material Requirements Planning  
OEE: Overall Equipment Effectiveness  
OEM: Original Equipment Manufacturer  
OPEX: Operational Expenditures  
PBC: Performance-Based Contract  
PDCA: Plan Do Check Act  
Ph.D.: Doctor in Philosophy  
RBM: Risk-Based Maintenance  
RUL: Remaining Useful Life  
TAM: Technical Asset Management  
TS: Technical System  
TU: Technical University  
US: United States  
VNCI: Verenigde Nederlandse Chemische Industrie  
VOC: Vereenigde Oostindische Compagnie (Dutch East India Company)  
VR: Virtual Reality  
WCM: World Class Maintenance  
Y2K: the Year 2000

## Annexe B: The typology of technical asset systems (after Smit 2014)

TS class	Description	Industry sectors
1) Transportable	Consumer and professional consumables fabricated in large numbers and brought to the service centre for repair by the user	<ul style="list-style-type: none"> <li>• Personal ICT equipment</li> <li>• Audio &amp; video equipment</li> <li>• Domestic equipment</li> <li>• Office equipment</li> <li>• Personal means of transportation</li> </ul>
2) Mobile TS	A fleet of unique groups of similar flying/sailing/driving assets which are maintained in MRO shops	<ul style="list-style-type: none"> <li>• Airplanes</li> <li>• Bus-tram-metro</li> <li>• Trains</li> <li>• Lorries</li> <li>• Personal cars fleet</li> <li>• Ships</li> <li>• Mobile tools</li> </ul>
3) Network	Linear systems for the distribution of gasses, liquids, electricity, or information, typically maintained by mobile service teams	<ul style="list-style-type: none"> <li>• Airports</li> <li>• Railways</li> <li>• Transport &amp; distribution networks</li> <li>• Roads</li> <li>• Waterways</li> </ul>
4) Standard	Distributed objects, often produced in series, maintained by the manufacturer's service department or by specialised contractors	<ul style="list-style-type: none"> <li>• Wind energy creation/distribution</li> <li>• Discrete production systems (plants)</li> <li>• Process production systems</li> <li>• Rotating equipment</li> <li>• Subsystems (eg. utilities/HVAC/building-specific installations/process control)</li> <li>• Buildings, constructions (of a series)</li> </ul>
5) Specific	Technical systems so large and unique that they are maintained by a specific maintenance department	<ul style="list-style-type: none"> <li>• Discrete production plants</li> <li>• Process production plants</li> <li>• Buildings/constructions (of a one-off nature)</li> </ul>

### Annexe C: A list of the analytical steps in Delphi study design and execution

	STEP DESCRIPTION	FROM STEP	TO STEP	DATE
<i>I.</i>	<i>Study definition stage</i>	<i>Q1-3 2014</i>		
1	Delphi scope and ambition level definition			Q1-Q2 2014
2	Choose generic theoretical framework for study	1		
3	Customise framework for a specific purpose	2		
4	Translate customised framework into specific survey questions	3		Q3-Q4 2014
5	Conduct snow-ball sampling interviews with relevant professors	1		Q3-Q4 2014
6	Solicit additional relevant names from reference board	5		
7	Send out invitation to industry associations	6		
8	Find relevant names for missing fields in CRM system	7		
9	Find relevant names for missing fields from the professional networks research team	8		
<i>II.</i>	<i>Web-based survey stage</i>	<i>Q2-4 2015</i>		
10	Invite participants and obtain agreement	5	9	Q2 2015
11	Send out first round surveys and collect responses	10		Q3 2015
12	Process incoming responses into clustered statements	11		
13	Conduct peer review on draft clustering with research team	12		
14	Send out second round survey asking for feedback and ranking	13		Q4 2015
15	Process second round results into multiple preliminary rankings and breakdowns	14		
16	Conduct peer review with research team on rankings and select the most relevant ones	15		
17	Write up survey report	15	16	Q1 2016
<i>III.</i>	<i>GDSS workshop stage</i>	<i>Q1 2016</i>		
18	Invite participants for Delphi workshop and obtain agreements	14		Q1 2016
19	Send out survey results to Delphi workshop participants	18		
20	Prepare Delphi workshop scenarios in group support tool	16		
21	Explain 'Group Support System' procedure and 'Top 15' to participants	20		
22	Brainstorm meaning and relevance innovations gathered from the survey	21		
23	Brainstorm symptoms and the consequences of a lack of progress with innovations	22		
24	Brainstorm action to be taken to improve progress in innovations	23		

<i>IV. Study synthesis stage</i>		<i>Q2-3 2016</i>		
25	Categorise innovations in technical, process, and cultural/behavioural	23		
26	Create causal maps of statements in root cause analysis	23		
27	Add connections between innovations and root causes	26		
28	Create cross-reference table of interconnections between innovations and root causes	27		
29	Create causal diagram of interdependencies between innovations	28		
30	Summarise recommendations into proposed actions	24		
<i>V. Knowledge dissemination stage</i>				
31	Write first draft report	22	30	Q4 2016
32	Conduct peer review between researchers	31		
33	Write second draft report	32		
34	Conduct a member check with experts	33		
35	Finalise report	34		Q1 2017
36	Present findings to target audiences	35		
37	Present specific parts of findings to specific audiences	35		
38	Translate report into scientific article	35		
39	Present draft article to peer reviewed journal	38		
40	Revise article based on reviews	39		
41	Publish article	41		

## Annexe D: List of participants in expert survey

Voornaam	Tussenvoegsel	Achternaam	Functie	Organisatie	Sector
Erik	van der	Lichte	Docent	Avans Hogeschool	Onderwijs
Frank		Jansén	Contract manager	BAM Utiliteitsbouw B.V.	Infra
Piet-Jan	van der	Griessen	Plant Manager	Boskalis B.V.	Maritime
Berend		Lindeman	Hoofd	Cargill B.V.	Proces
Ronald	van der	Slijs	Directeur	Cofely West Industrie B.V.	Proces
Sven		Asjee	Directeur Ingenieursbureau	Croon Elektrotechniek B.V.	Proces/service logistiek
Paul		Casteleijn	Manager	DSM Engineering Plastics B.V.	Proces
Peter		Eecen	Manager	E.ON Wind Energy Facilities B.V.	Energie
Ruud		Teunter	Hoogleraar	Economische en Bedrijfskundige Faculteitsvereniging	Onderwijs
Herman		Baets	Chairman	EFNMS	Branche organisatie
Louis		Grubben	Manager	Essent Energie Productie B.V.	Energie
Bart	van	Dick	Project Manager	Fees Group B.V.	proces
Jan	van der	Lans	Project Director	Fluor Consultants B.V.	diverse sectoren
Frank		Muldérs	General Manager	Fokker Landing Gear B.V.	Luchtvaart
Robert		Verberk		Fonys Hogescholen Eindhoven	Onderwijs
Giel		Jurgéns	Manager	Havenbedrijf Rotterdam N.V.	Maritime
Fieke	van der	Veeri	Manager	Heerema Marine Contractors Nederland B.V.	Maritime
Tim		Zaal	Lector	Hogeschool Utrecht	Onderwijs
Erik		Puik	Lector	Hogeschool Utrecht	Onderwijs
Robert-Jan	de	Boer	Lector	Hogeschool Van Amsterdam	Onderwijs
Henk		Maat	Lector	Hogeschool Windesheim	Onderwijs
Willelm		Brouwer	Lector	Hogeschool Zeeland	Onderwijs
Jan	van	Goolen	Manager	Huntsman Holland B.V.	Proces
Johan		Kaalem	Directeur	KD Innovatief advies	Luchtvaart
Kees		Boelema Robertus	Directie met focus op strategie	Koninklijke Marine	Maritime
Leo	van	Dongen	Directeur	NedTrain B.V.	Hightech/Infra
Bob		Huisman	Manager	NedTrain B.V.	Hightech/Infra
Tiedo		Tinga	Hoofddocent	NLDA Nederlandse Defensie Academie	Onderwijs
Kees-Jan		Mes	Directeur Strategie	PON/Mes marine	Maritime
Roelf		Venhuizen	Voorzitter Profion	Profion	Branche organisatie
Ron		Blok	Asset Manager	PWN	Infra
Elisbeth		Bronjous	Strategisch Adviseur / Asset Engineer Drinkwaterleidi	PWN	Infra
Roeland		Szaal	Manager	Robert Bosch B.V.	Hightech
Peter		Lens	Manager	Sabic Innovative Plastics B.V.	Proces
Rob	de	Heus	Manager	Sitech Services B.V.	Proces
Richard		Schouten	Directeur	Sitech Services B.V.	Proces
Jan		Pellis	Strateg	Stedin	Energie/Infra
Jacob		Zoeman	Directeur	Struikton Rail B.V.	Infra
Nico	van	Kessel	Manager Maintenance and Engineering systems	Tata Steel IJmuiden B.V.	Proces
Nick		Piscaer	Procurement Manager	Tata Steel IJmuiden B.V.	Proces
Rieky		Curran	Hoogleraar	Technische Universiteit Delft	Onderwijs
Cees		Witteveen	Hoogleraar	Technische Universiteit Delft	Onderwijs
Geert-Jan	van	Houtum	Hoogleraar	Technische Universiteit Eindhoven	Onderwijs
Simme Douwe		Flapper	Assistant Professor	Technische Universiteit Eindhoven	Onderwijs
Ivo		Adari	Professor	Technische Universiteit Eindhoven	Onderwijs
Rob		Basten	Assistant Professor	Technische Universiteit Eindhoven	Onderwijs
Jan		Braakstra	Assistant Professor	Universiteit Twente	Onderwijs
Frank	de	Wáárd	Project Manager	Van Oord Shipmanagement B.V.	Maritime
Omó	ds	Vreethé	Manager	VNCI	Branche organisatie
Fritjs	van der	Molen	Afdelingsmanager	Waterschap Aa en Maas	Infra

## **Annex E: List of innovations in maintenance**

In this appendix all of the topics are being elaborated upon based on the input and keywords from all participants. Part of the Delphi study for the participants was to provide input around a certain topic so that understanding could be reached in regard to what the participant actually means by this particular topic. Based on all of the input, the different innovations have been named.

### **I01: Cultural and behavioural change**

Based on the input from the different participants, there is a need to change the culture and behaviour within maintenance as a whole. According to the input the direction is to move from top-down management to autonomous or self-steering teams. The key element is to empower employees and to move decision-making power to the shop floor and within the team, and the key question is how this should be achieved.

Considering the fact that this topic is the No 3 innovation selected by all participants, there is a need to make this cultural and behavioural change, but this is not a new innovation. A major change is seen at the top of the organisation, where upper and middle management are struggling to work out how to empower their teams, and what their teams need to become empowered and autonomous.

According to the input that has been received, this requires social innovation, with companies and the organisation process needing to move away from the old paradigm in which the manager evaluates the performance of the team, where the manager is more highly paid than anyone else, should know more, and takes all the decisions, and employees should simply get on with their work. It is not only the maintenance sector which struggles to make this change - all sectors should try and make this move, try to change their organisational culture and employee behaviour accordingly.

Choosing the right culture and behaviour for the organisation can remove road blocks such as the lack of a fact-based culture, conservatism in investing in new technology, short-term orientation with management bodies, a perceived lack of status when sharing expertise, a lack of integral perspective, a lack of entrepreneurship, and a resistance to change.

### **I02: Asset management as an export product**

The concept of asset management is not new. In Western Europe most organisations follow the principles of asset management as described within PAS55 or ISO 55001.

According to IAM (Institute of Asset Management, 2016) asset management is the management of physical assets; their selection, maintenance, operation, and renewal; in determining the operational performance and profitability of industries which operate assets and the art and science of making the right decisions and optimising these processes. A common objective is to minimise the entire life cost of assets, but there may be other critical factors such as risk or business continuity to be considered objectively in this decision-making. Asset management represents a cross-disciplinary collaboration in order to achieve the best net, sustained value-for-money in the selection, design, and acquisition, operations, maintenance, and renewal or disposal of physical infrastructure and equipment.

Due to the development of the ISO standard, asset management is becoming a more appreciated discipline than it ever was, and the asset-intensive industries

have begun to understand the importance of good asset management. Given the knowledge which has been developed within Western Europe with respect to asset management, and the fact that most assets are remaining operational far beyond their designed technical and economic lifetime shows there is sufficient expertise to develop practices which could be exported towards developing countries and new and emerging economies.

### **I03: Knowledge management**

Knowledge management is the process of creating value from an organisation's intangible assets (Liebowitz, 1999). The creation of knowledge from the organisation's intangible assets is a process which many organisations have not yet implemented and, today, within the Netherlands, which has an aged workforce, the carry-over of knowledge becomes more and more important.

Most of the organisations within the maintenance sector foresee issues arising for the future when experienced employees retire, and this is going to happen in the next five to ten years. The result is that a great deal of knowledge and experience is going to be leaving organisations and the industry as a whole. Knowing this, many organisations are now in search of ways in which they can capture information and create built-in knowledge for the organisation.

The participants of the Delphi study focused predominantly on methods to disseminate their knowledge, such as best practice on the shop floor, in training and simulations, and using virtual and augmented reality. When considering the knowledge management cycle as a whole; discover, generate, evaluate, share, leverage (Jashapara, 2004); this can be counted as being the third step.

One important remark that should be made here is the fact that literature also emphasises the necessity of the right culture and behaviour needing to be in place for the organisation were it ever to become a learning organisation. Setting up knowledge management in the right way can address knowledge-related road blocks such as: limited big data expertise; limited experience with sensor technology; a lack of experience in new 'Ways-of-Working'; insufficient time and/or experience to conduct systematic enquiries; a lack of experience and/or expertise in asset management processes; and the technical complexity of mastering new techniques.

### **I04: The use of drones and robotics**

Developments in drones and robotics are running at a pretty rapid pace right now. Asset-intensive industries are testing the use of drones and robotics. The main reason for the industry right now seems to carry out inspections and maintenance tasks in difficult-to-reach areas or even in unreachable locations, and to increase information-gathering and equipment or plant reliability. But robotics, when combined with artificial intelligence, will probably handle much more in the future than it is capable of today.

Robotics today is used to automate anything from simple repetitive tasks up to remote driven robots which can carry out simple tasks where a human controls the robot. The future could - and should - head towards autonomous robots which can carry out tasks at speed and with levels of accuracy that no human could match. Ideas yet to be developed include microbots in process flows in order to gather more process information at greater levels of detail, serving to improve product quality and reduce downtime. Swarms of micro-drones for pipe inspections or for toxic environments are not yet feasible but they soon will be. This innovative idea is still a small one for the maintenance and asset management industry, but the developments are there and this is soon going to be a commodity.



### **I05: 3D design and virtual reality**

The participants have indicated predominately that 3D design techniques are to be used for the design of assets, to validate whether a design can be used, whether pipes match, as a 'walk around', and eliminate issues during the design phase. The next step is to keep the 3D model up-to-date, to connect all of the information to the 3D model for employees so that they are able to consult the model, and to provide connected information during the operations phase. A second element for the 3D model and for virtual reality is employee training. A brief internet search and research on websites such as [techrepublic.com](http://techrepublic.com) and [techcrunch.com](http://techcrunch.com) delivers a large number of results which cover virtual reality. Most of these concern the area of gaming and entertainment, but more and more hits are being generated that have a connection to industry, first of all in the medical and airline industries, but these days also in the capital intensive industries which are only just starting to consider virtual reality. The reason this is happening is the training method for those people who are working in the industry, less incidents taking place, and being able to bring to people the experience they require so that they can operate in areas such as, for example, a plant or manufacturing line using virtual reality which can certainly help to build experience.

A next step, one not mentioned by the participants, is the move towards augmented reality, which in turn is a tool to support employees in the field so that they can work well, and so that they have all the information to hand that they need, and to make it easier to move employees along in the field of manufacturing assets.

### **I06/I07: Performance-based contracting**

Two of the topics mentioned were basically the same; one was a performance-based contract between the asset owner and the integrated partners, and the second was between a contractor and the contracted entity. Both elements described the uses of KPIs and providing incentives to suppliers and contractors in order to encourage them to optimise the performance levels for asset owners, and also in terms of providing incentives for asset owners so that they will optimise their collaboration with suppliers and contractors.

However, there also is the tendency to integrate parts of the asset management chain towards the asset owner while other parts should be outsourced to partners, and the asset owner and asset managers should focus on building a true partnership, with a real win-win outcome for both parties.

The focus of the performance-based contract is not to achieve the lowest price per unit, which even these days is the main incentive basis for category and contract managers. Instead it has to move towards a more focussed way of thinking; one in which output is maximised at the most optimised cost.

### **I08: Integrating asset management IT systems**

Many organisations utilise a great many different systems in order to be able to manage their assets, varying from the asset breakdown structure to maintenance orders, and also covering planning, costing, invoicing, human resource planning, etc. The entire management chain is often not managed in one system for a large number of reasons.

This innovation is actually ideal when it comes to building and developing a single system using all existing applications. A system is not a single application, a system is defined by all of the loose elements such as IT applications, processes, procedures, people, and information, all working together to achieve a defined goal. The integrated asset management IT system wishes to develop a way in

which all of the different applications can be integrated, and information routing can carry out all of the tasks at the most efficient and automated levels.

Once all the information and systems have been integrated, the next step will involve being able to make better and faster decisions based on all the information that is available inside all of these applications.

### **I09: Servitisation**

According to Neele (Neele, 2013), servitisation is in essence a transformation journey - it involves businesses (often manufacturing firms) developing the capabilities they need in order that they can provide services and solutions that supplement their traditional product offerings. More formally, my colleagues and I at Cranfield University defined servitisation as 'the innovation of an organisation's capabilities and processes to better create mutual value through a shift from selling products to selling "Product-Service Systems"'. Two other definitions accompany this: (i) the idea of a product-service system - 'an integrated product and service offering which delivers value in use'; and (ii) a 'servitised organisation which designs, builds, and delivers an integrated product and service offering which delivers value in use'.

What this means is that product suppliers upwards-integrate the whole asset management cycle of equipment. This means that the supplier no longer sells a product, or provides maintenance services for their product, and instead allows the owner of the product to pay or it will be under guarantee is agreed. Instead the OEM or supplier will deliver their product against certain guarantees such as uptime or reliability, and the OEM or supplier ensures this is achieved by managing the entire chain.

Based on the input of the participants, servitisation was broadly defined within the survey as the development of new service concepts within asset management and equipment maintenance. Servitisation can also be strongly linked to I06/07 which covers performance-based contracts.

### **I10/29: KPI dashboards**

KPIs and maintenance or asset management are certainly not new. A large number of books have been written about developing KPIs for an organisation and the performance gain it could bring when having the right KPIs and manage performance in place accordingly. Today systems can be introduced which have a large number of standard KPIs with respect to maintenance and asset management, and this in itself is not new.

However, based on the input received from the participants, KPI dashboards do not work. There are two reasons given; a) KPIs are not coherent, and b) the dashboards are not properly implemented.

The innovation which the participants require is a coherent set of asset portfolio KPIs which monitor past and current performance and the cost of technical assets, including the effectiveness and efficiency of the people and processes, in order that they can assess future developments and reach informed decisions.

### **I11: Asset management implementation**

Most of the participants have said that asset management should be implemented in the near future, following the ISO 55001 standard. The reason behind implementing an asset management system is to have processes and procedures in place between the asset owner, the asset manager, and the asset operator, to become more connected, and to get teams working together in order to maximise the output of the assets.

Based on the input received, the participants require support in the development of a system which incorporates many of the other innovations which have been identified in this study, such as OEE, LTE, LCC, and other methods so that they can reach the right decisions based on information rather than on feelings, and can strategically manage the entire asset portfolio.

### **I12: Product data management**

Although the name of this topic seems to focus on products, the participants actually require a data management system for all relevant information on all equipment, processes, drawings, etc, and to be able to easily keep this information up-to-date and secure.

Most of the organisations already have systems in place so that they can manage the master data, but the fact that more and more data and information is becoming available, added to the fact that this data will become more and more complex to manage, all points to the necessity of a single system, one which is not the same as a single application.

### **I13: Visual plan board**

In many organisations the process of handling maintenance, turnarounds, and capital projects is all managed in a conventional manner. This means that there is an order or work breakdown structure in place, so that for each step time and resources are assigned and this then is rigorously scheduled inside a scheduling system. Whilst this is not wrong, in practice these steps and schedules are not followed due to a large number of reasons, and on a day-to-day basis the maintenance and production teams are trying to resolve all of the issues they have in the schedule so that they can attain their final goal in the end.

A way in which a team may achieve all of its activities is in the use of a visual plan board, which can be based on anything from an old-fashioned planning board up to a sophisticated digital system. It really does not matter which is chosen. The participants have indicated their wish to implement a form of visual plan board so that all of their activities which a team needs to carry out can indeed be managed. This includes everything from executing the work orders and cleaning up the work shop to validating design criteria and work packages. Tools are already available for this and they can be utilised. Some of these come from the Lean toolkit in which visual management and having clear measurements and colours to use show the progress of the teams.

One thing which needs to be taken into consideration is the fact that this also requires a change in culture in the teams and management bodies. Teams should become autonomous in terms of their activities and should be able to take responsibility for their work, while management has to give the team the responsibility it needs and focus instead on facilitating the teams, but should also ensure that praise is given where it is appropriate to do so and should follow up on any consequences.

### **I14: Asset portfolio management**

Asset portfolio management is concerned with developing a comprehensive overview of current and anticipated costs and the performance of all technical assets within organisations portfolio so that objective and data-based decisions can be taken with respect to the asset strategy.

From a maintenance and asset point of view, participants are not considering the decision-making that surrounds the development of new products, the placement of new assets, the foreclosure of assets, or the demolition of assets, which are strategic choices that the asset manager or maintenance organisation cannot make. Involved in this part of the asset portfolio chain is the individual equipment

of each asset, taking into consideration OEE, LTE, and costs, and to be able to make strategic decisions on upgrading or the replacement of equipment in itself. A new element which enters into the decision-making process is the environmental aspect. It may be feasible to imagine that a piece of equipment is still within its technical and economic lifetime but that a more energy-efficient item of equipment can be selected to replace it and, being part of the strategic direction for an organisation, this may require equipment to be replaced more early than expected in the equipment lifecycle.

#### **I15/16/17: Modernising assets**

Considering the previous innovative idea, it can be seen that this one falls directly in line with it. Typically, organisations have focused on economic lifetime and, specifically, upon expanding the economic lifetime of equipment based on the technical life of that particular piece of equipment. However, the focus is moving more and more towards different forms of equipment lifetime, such as statutory and compliance, environmental, and commercial lifetimes.

The requirement for these three combined innovations is to draw the three additional elements into the equation in order to be able to determine the lifetime of individual items of equipment. The questions are how is this to be done, what needs to be taken into consideration, and what effect do those elements have on the decision making process?

#### **I18: Life cycle costing**

Life cycle costing in itself is not new. It is a methodology which has evaluated all costs and benefits against the net present value to be able to determine which equipment to choose, this being the most efficient and effective choice over the lifetime of the asset. The method incorporates the calculation of the cost of acquisition, operation, and maintenance, and the decommissioning of technical assets across the entire life cycle.

The specific demand from the participants is to have a model which can calculate and estimate the costs of equipment or an asset during the operations and maintenance phase. Although not validated, this request is the result of old assets being present in industry in Western Europe, with such aging assets needing to be replaced in the near future and beyond. Having a model which can calculate the remaining life cycle costs versus replacement costs for equipment can support the decision making process.

#### **I19: Degradation models**

Degradation models are the cornerstone of all maintenance strategies. The better the models, the better adjusted maintenance can be in terms of the needs of the equipment. The participants have indicated that there is a need to review and/or develop degradation models for equipment and parts and, more specifically, for static and electronic equipment.

The participants also have indicated that degradation models should support the organisation so that it can develop and build up knowledge where the equipment is concerned, build up a library of degradation models, and have those models support calculations for the remaining useful lifetime based on current performance data.

The participants have requested the development of a database for degradation methods, and also the development of models which then can support the simulation of degradation methods and quantitative decision-making for the asset manager as part of the process of asset portfolio management.

### **I20: Optimise 'Enterprise Asset Management' (EAM) systems**

In many organisations an 'Enterprise Asset Management' system is in use. As has already been indicated in previous innovative topics, there is a need to integrate all of the different applications into a single system using interfaces and databases so as to avoid having things done twice and to avoid human error. All participants agree that this is the way forward in this specific area.

Under this particular innovative idea there is more, once the systems are linked, interfaced, work together, and the data is properly managed, there also is the need to facilitate upwards and downwards integration between the systems. Moving towards servitisation over the organisations where the information of the OEM, the asset owner, asset manager, asset operator, and service organisation come together and each equipment to be managed from one source.

One of the elements mentioned was to avoid sending emails, purchase orders, or invoices to all parties within the entire maintenance and operations chain. The EAM system should be able to provide all of the necessary solutions when it comes to maintaining and managing the assets, including real-time dash boarding, third party access, security, and facilitating the processes in an easy and app-like manner.

### **I21: 'Condition-Based Maintenance (CBM) and 'Risk-Based Maintenance' (RBM)**

CBM and RBM both deal with implementing an asset control concept in which assets are maintained precisely when they need to be, based on an assessment of their current performance, with those assets receiving specific attention that are most important for the business.

The topic, however, was not raised in order to validate or improve these methods but to have the organisation work with these models so that they can continuously optimise and improve the maintenance strategies for the equipment. Based on input received, the participants see the need to implement the PDCA circle in full.

### **I22: 'Overall Equipment Effectiveness' (OEE)**

OEE is the concept of being able to measure real-time equipment effectiveness for the assets and to be able to optimise the maintenance programme in order to improve the overall equipment effectiveness over the lifetime of the equipment and asset.

Each item of equipment has an OEE and the aim is to maximise the OEE for the total asset, continuously improving the equipment within the asset. Providing improvements like this could end up changing maintenance techniques, maintenance strategies, and operating parameters, but it could also lead to exchange equipment being necessary.

All of this again comes together in the asset portfolio management process, as identified in a previous innovative idea.

### **I23: 3D printing**

A new innovation is 3D printing. Starting with the printing of elastomers, the printers today are capable of printing large metal components, with most of the various metals being printable and more complex shapes also being available for printing. A request by the participants is to seek out those purposes for which 3D printing could be utilised. The aim of the participants is to utilise 3D printing technology to reduce stock levels and optimise all of the logistics which surround maintenance activities.

#### **I24: Big data**

Big data is seen as being the umbrella term for setting up an IT infrastructure that enables the systematic and comprehensive collection, integration, and interpretation of data from a wide variety of sources in order to calculate when and where maintenance is needed.

Many of the previously identified innovative topics can be incorporated into the term 'big data', but there is more to big data than that, especially once the data is collected centrally and is linked in a smart manner. The next step, which the participants see as the real step towards big data, is to have real-time models for the maintenance and operations departments so that they are able to continuously optimise the performance of the equipment and assets.

The models could be single variable, multi-variable, and machine-learning. These models should be developed, and the request is to have for each item of equipment available the required information and additional sensors that may be needed in order to be able to achieve the maximum effect for the model in question.

#### **I25: Design for maintenance**

Design for maintenance is about incorporating maintenance-related considerations into the design of greenfield and brownfield investments. This, basically, is a change in the organisational processes and culture in which the difference between project responsibility and operational responsibility should no longer be divided, and organisations need to focus on the OEE over the asset's entire lifecycle.

The time is soon coming to an end in which a project team is given targets which concentrate the lowest costs and the shortest project lead time and then, during the operations phase, production and maintenance have to solve many of the issues which have been left behind by the project team. It is increasingly becoming the case now that organisations consider the total asset lifecycle, and the asset manager becomes responsible both for the CAPEX and the OPEX phases of an asset.

However, now that more and more organisation are moving towards the aforementioned direction, one in which the asset manager is responsible for the entire lifecycle of the equipment, there is a higher level of interest in receiving input from the departments which are charged with the task of focussing on the operations phase of the asset, which is between fifteen and thirty times longer when compared to the CAPEX phase and is also more expensive. It should be of interest to any capital-intensive industry to focus on the whole lifecycle of an asset.

Now that organisations are moving towards this direction, there is a need to know what to focus on from a maintenance point of view. Naturally, this should be captured in a 'Reliability, Availability, Maintainability' study, but there is the believe that much can still be gained by having the right components within the study. The innovation is to change the organisation and culture and to know the right topics and elements upon which to focus.

#### **I26: 'Hands-on Tool Time' measurement**

Ever since there have been organisations, those organisations have been pondering how they might improve the effectiveness and efficiency of their employees, and this is no different for maintenance personnel. 'HoTT' predominantly focuses on technician efficiency by taking frequent measurements to improve the processes and increase overall process efficiency.

The participants in the study, however, have broadened their request and not only want to focus on the processes and process efficiency, but also on making employees aware of what efficient ways of working may be, and for the organisation to better understand what the value-added activities may be.

Based on the visual plan board, it can be seen that a good many activities which are carried out by the organisation as a whole may not be value-adding activities. If an activity is not adding value to the process and the organisation does not recognise this fact, than any personnel or teams which are carrying out this activity could become demotivated. Having a good HoTT measurement, one which is based on the organisation's value streams, means that management can better decide upon which activities to continue and focus on and which activities should be dropped.

In the end, all of the inefficiencies and flaws within the process end up at the operation layer of the organisation, resulting in a low HoTT for a technician. Therefore having a good, regular HoTT measurement which can help to identify issues in the process as a whole is a key KPI for the efficiency and effectiveness of each asset management organisation.

### **I27: Mobile solutions**

In several of the organisations that participated in this Delphi study, mobile devices have been implemented or are being implemented at the shop floor level. Most of the organisations have implemented a mobile device of some form or another, such as a tablet or mobile computer, to reduce the administrative load of the technicians and to provide technicians in the field with all the necessary and required information, making it readily available for them. In some organisations, the desktop environment is simply transferred to a mobile device, but this is not considered to be a mobile solution.

The mobile solution means being able to offer the entire system on a mobile device. This means a change in the concept surrounding how information is delivered to the user and how the user can use the information and provide feedback. Making SAP available to the user on a mobile device is not helping a great deal, for example, but developing an APP around the user process and having this APP working in SAP will help.

A mobile solution, therefore, means more than providing a mobile device and making sure that all of the applications work. It has an impact on the entire way of working and focuses on activities, needs, and user experience. This is a key element in changing this innovative topic.

### **I28: Replace versus repair**

Replace versus repair is also known as 'swap and go', and is about replacing equipment and parts directly so that performance is interrupted to the minimum possible levels. It is also about repairing equipment offline after replacing it with new, more energy efficient and reliable types. However, in capital intensive industries a swap-and-go is not as easy as in other areas such as, for example, a car in which entire components can be replaced based on the design of the car. Many manufacturing plants are not designed to carry out a swap-and-go actions since a lot more is involved. However, taking current equipment into consideration, many parts in any item of equipment could fall into the category of swap-and-go. The key element is to be able to determine what parts are involved and how the process is managed in an easy and open manner. The technician should know it exists and should be able to make this decision without having engineers and managers intervene. Again this is a matter of changing the culture and having accountability low in the organisation.

### **I30: Smart sensing**

The participants of the study have identified smart sensing as the process of applying sensor technology to monitor the performance of technical assets in order to establish when maintenance is needed. Basically, this is the next step in condition-based maintenance, in which the condition is continuously monitored versus the opposing practice of monitoring at intervals. Sensors can help a great deal in this process.

But smart sensors have the potential to move further. There are sensors already available which calculate and adjust themselves based on the verification of variables, or those which could alter the way a system handles itself based on the information they receive.

For this study however, the aim is to be able to develop sensors which can be added to the current systems, which provide additional data to be able to have a model of an item of equipment working at a hundred percent, and being able to predict equipment maintenance requirements and avoid equipment failure. The demand therefore is to work together with OEMs and suppliers to develop the sensors required for monitoring and carrying out predictive analytics.

### **I31: Vendor-managed inventory**

Today, a good many organisations have their own stock for each of their assets. Some have combined their assets to reduce stock levels, but there are not that many asset managers who are working together to minimise the required stock whilst they ensure the maximum periods of uptime. In principle there is a great deal of dead stock in the warehouses of asset owners or in terms of the financial point of view a lot of dead capital.

Moving to a vendor-managed inventory is a concept which comes from retail, where the OEM or the vendor manage the inventory of multiple asset owners to reduce total stock levels and ensure that the right part is always delivered in the right condition. There are capital-intensive organisations which already carry out this at a larger scale but often it is still for one particular type of equipment. Another element is where this is applied often by the OEM or vendor, and these percentages are relative normal, charging between 22% to 28% of the new value for that part or equipment to the asset owner in order to have it in stock. To be able to move in this direction the vendor should provide an open administration for asset owners and managers and try to minimise the costs for holding stock.

### **I32: Business process re-engineering**

Business process re-engineering was a method which was prevalent in the 1990s, at a time at which when many organisations moved towards the use of central processes, single management systems, and single IT platforms. All processes needed to be reviewed, re-engineered, and implemented. Today most of the large organisations have left this behind and the processes, which are now between twenty and thirty years old, are still being used.

However, going over all of the innovation ideas, and knowing that many organisations are working on one or more of these innovations to that they can be embedded into their organisation, a new wave of business process re-engineering is clearly required to modify the processes so that they can operate with the newer methods being used to manage assets.

The participants of this study also indicated that asset management organisations should work together to develop the best practice and this innovation topic aims to review and optimise existing maintenance processes and to collect information from multiple organisations to develop this best practice.



**I33: Improve maintenance methods**

Improving maintenance using new methods and technology to improve the level of maintenance and to increase equipment reliability is a topic which has been identified by the participants. Although this topic did not end up in the top fourteen, it is at twentieth place on the agenda and has a strong relationship with many other topics in this study.

The participants indicated that by using new techniques the maintenance of equipment could be improved. A simple example is the use of ultrasonic measurements to adjust the greasing of equipment to the levels required by the equipment instead of over-greasing it, or worse, under-greasing it. The request by the participants is to find and identify such new techniques, to have best practice worked out when it comes to the use of this new technique, and the added value of this technique within the area of maintenance and asset management.

**I34: Increased cooperation between asset owners and governmental offices**

This is the label for the practice of investing jointly in assets in order to improve the level of services provided within the Netherlands, such as a new dry-dock, training facilities, test plants, etc.

**I35: Developing parts and equipment**

This deals with the development of and engineering work carried out on new types of parts which can and should make equipment more efficient, more easily interchangeable, or more suited to specific applications.

**I36: The use of new materials**

This focuses on the development of high-grade plastics and ceramics to be used within the assets to prolong the lifetime of, for example, piping, or the use of self-healing materials to reduce inspections and the replacement of parts.

**I37: Apply LEAN/SixSigma**

This is the business practice which comes from manufacturing which advocates the use of continuous improvement methods to close the loop and continuously improve the performance of maintenance and equipment.

**I38: Integral ('Operations, Maintenance & Procurement') contract management**

This is the label for contract management which is implemented professionally for the entire maintenance chain, including IT systems, for performance evaluation systems, and for management and evaluation.

## **Annex F: List of participants in the GDSS Workshop**

Bart van Dijck, Faes Group  
Berend Lindeman, Cargill  
Geert-Jan van Houtum, TU/e  
Giel Jurgens, Port of Rotterdam  
Henk Akkermans, WCM  
Herman Baets, EFNMS  
Jaap van Emmerik, KLM  
Jan van der Lee, VolkerRail  
Jan van Goolen, Huntsman  
Johan Kaelen, KD Innovatief Advies  
Klaas Smit, Maintenance Consult  
Leo van Dongen, NedTrain  
Lex Besselink, WCM  
Mark Ammerdorffer, VOMI  
Moniek Schoofs, WCM  
Moniek Schoofs, WCM  
Monique Heiligers, Hogeschool van Amsterdam  
Onno de Vreede, VNCI  
Paul van Kempen, WCM  
Pieter de Klerk, Mainnovation  
Richard Schouten, Sitech  
Rob Basten, TU/e  
Rob de Heus, Sitech  
Ron Blok, PWN  
Ronald van der Sluis, Cofely  
Stefi Celie, WCM