From wrench to algorithm

The evolution of maintenance: from "seeing" to "self-optimizing"

What do monkey wrenches and computer algorithms have in common? Surprisingly, wrenches and computer algorithms are both invented in the same year 1840. The monkey wrench was invented by American knife manufacturer Loring Coes. On the other side of the ocean countess Ada Lovelace produced the very first "computer program" for the mechanical Analytical Engine (A.E.), invented by Charles Babbage named the father of computers, to calculate Bernoulli numbers. Ada Lovelace was not only a brilliant mathematician, she also discovered the full potential of this engine, developing the first algorithm[1] for the A.E. and becoming as such one of the first computer programmers. And now, some 2 centuries later, computers and wrenches seem to come together in a new era of maintenance.

Nothing has changed but everything changes

Maintenance and repair have been around as long as mankind exists. From the time-based sharpening of man's earliest spears and tools to the maintenance concepts for modern equipment and technologies. Over these last couple of centuries maintenance has made an evolution and gradually merged from a corrective approach known as "break and fix", over a preventive or time-based maintenance towards a predictive or condition-based maintenance. And now we are moving into the new era of an integrated and digitized phase of prescriptive maintenance, combining algorithms of computer science with common maintenance techniques. By using artificial intelligence (AI), we can now master all kinds of data like asset health data, process data, historical maintenance data and contextual-operational data from various sources. We get better and in-depth insights on asset behaviour, allowing us to act before failure modes are manifested. With the AI approach we can now forecast asset failures modes, and thus optimize not only the asset performance but the total plant performance and production cycle.

Even though our machines, industry and technology changed over time, the true foundational elements of how assets fail remain unchanged, i.e. the failure patterns and the P-F curve. To see what our future brings, it's wise to know our past, and that's why we'll make a brief journey through the history of modern maintenance.

[1] As a matter of facts algorithms can be traced back to the 9th century and linked to the Persian mathematician-astronomer Abdullah Muhamad bin Musa al-Khwarizmi, father of algebra(..)

From the first industrial revolution until WOII

During this period maintenance gradually changed from “break and fix” to “time-based maintenance”. This is the era of ***descriptive maintenance*** where engineers ***“see” and “feel” failures***.

Maintenance management has its origins in the manufacturing industry. The invention of the steam engine, together with other inventions like telephone and radio announced the start of the *first industrial revolution* in the 18th century. At the same time a gradual shift from human labour to machine production began. The maintenance strategy was very simple: keep the machine running until it fails, only fix when broken. This is also known as corrective maintenance. Machine breakdowns were tolerated and considered “normal”.

During the *second industrial revolution*, mid-to-late 19th century, electric-driven machines were invented and those required a more sophisticated maintenance approach. Plant engineers became more “proactive” to maintain their equipment. They put a time-based maintenance strategy in place, and machine parts where replaced at specific time intervals. Unfortunately, this maintenance strategy was, and still is, quite expensive, as machines need to be shutdown causing production losses, and wasteful as parts are being changed according to a strict schedule whether this is necessary or not.

Machinery at that time was rugged and “slow running”, instrumentation and control systems were very basic. Economy and production requirements were not as demanding as they are today, and breakdowns were a less critical issue. A break and fix approach and/or time-based maintenance strategy were adequately enough. At that time machinery was “over-engineered” and build very sturdily and inherently reliable.

Post war till late sixties

During this period maintenance matured from “Planned preventative maintenance” to the first concepts of “Reliability Centred Maintenance”. This is the era of ***early diagnostic maintenance*** where maintenance engineers “***investigate” and “understand” failures***.

From the 1950’s onwards, the post war economy picked-up quite rapidly. Industries needed to be rebuilt, especially those of Japan and Germany. International economy started flourishing, creating a more competitive marketplace. Machine downtime was no longer tolerated and labour cost became an important factor leading to mechanization and automation. Machinery became less sturdy, was built lighter and ran at higher speeds. Equipment was used more intensively causing more wear out, more vulnerable and so less reliable.

Japanese engineers started following the manufacturer’s instructions. This was also the period that the first maintenance associations and societies were created, and first global networks established. That trend gave birth to what we know as “preventive maintenance” today. Gradually, those associations encouraged technicians and other specialists to develop time-based maintenance schedules: machine lubrication, machine inspections, reporting any observations to help prevent machine damages. Maintenance and inspection checklist where used but the disadvantages of this strategy soon became obvious. The fact that very often machines needed to be shut down to perform these inspections, caused production losses. Repetitive and often boring interventions lead to negative *“human behaviour”* such as “PM creep” (adding or increasing frequency of PM’s to the program for no failure mode related reason) and “pencil whipping” (signing off on work that has not been done) causing ineffectiveness and unnecessary costs.

With the arrival of the Boeing 747 in the late sixties, the aircraft industry needed to improve reliability and therefore defined a detailed maintenance strategy reducing the risk of equipment failures. Risk had become a new driver for maintenance. This challenged the current maintenance strategies and the long-established basic assumption that the older equipment gets, the more likely it is to fail. Reliability centred maintenance (RCM), a new maintenance strategy approach was developed by Nowlan and

Heap. The term was first used in public by United Airlines. Shortly after, the concept was quickly adopted by other industries.

With time, other industries began understanding the value of maintenance and realised that it had a strategic impact affecting the bottom line. Since then proactive elements were increasingly integrated in well-balanced maintenance strategies, giving rise to other methodologies such as risk-based inspections (RBI), overhaul, etc.

While predictive maintenance, focussing on eliminating failure modes, had become common practice in the aviation industry, the more conservative industry was lagging behind and still relying on time-based maintenance.

From late 60's till late 80's

During this period the notion of "maintenance service" and "condition-based monitoring" emerged. This is the era that ***diagnostic maintenance*** made its first steps into the broader industry.

Between the 1960's and 80's, maintenance was considered a side activity and seen as of minor importance, only necessary when a breakdown occurred. The maintenance department's scope was restricted and mainly limited to electrical, mechanical repairs or greasing work. The notions of prediction or prevention were not at all integrated, and maintenance often suffered from a bad image.

The industrial world, as well as the implications of failures, were however very different from the ones we know today. At that time, industry was burgeoning, consequences on production lines weren't the same at all. Production shutdowns disrupted the production but weren't leading to huge losses like today. During this period companies became progressively aware of the impact and importance of safety. Due to industry gearing to mass production, machines had become fast running, more advanced, more complex and were driven to their limits, causing higher risk.

Hence, maintenance gained importance. The first maintenance procedures were developed, reducing working accidents and avoiding critical breakdowns. Interesting to note is that the main driver was human integrity (safety) rather than economic reasons. That gave a boost to the maintenance evolution in this period. Maintenance norms and standardization were progressively implemented, and they became necessary to train and certify technicians. The first trainings and certifications were implemented in this period.

Precision maintenance slowly became common practice, extending the lifecycle of assets by integrating proper procedures and standards during installation or repair of equipment.

From the 80's till early 2000

During this period maintenance and reliability engineering methodologies start becoming common practice in industry. This is the era of ***predictive maintenance*** where maintenance engineers are ***"prepared for what will happen next"***.

Surging globalisation gave rise to a further evolution of equipment and technology. Between 1980 and 2000, the industrial world changed in many areas: IT, maintenance, purchasing, communications, production, quality, safety. In the maintenance world "optimization" became crucial to survive. New concepts such as total productive maintenance (TPM), total quality management (TQM) and "lean" originating from Japan were implemented. The industrial sector was forced to modernize and adapt to secure their place on the globalizing market. It is then that computer maintenance management systems (CMMS) and quality management standards such as ISO-9000 (1987) and others were implemented.

Many industries focused on increasing production and lowering production costs. So, equipment reliability and availability became of the utmost importance. Early detection of failures, increasing meantime between failures (MBTF), reducing the meantime to repair (MTTR), performing pro-active maintenance activities became the focus of maintenance departments.

Engineering departments started taking maintainability and reliability considerations into their design, extending the asset's life cycle. The awareness grew that the maturity and quality of a maintenance program is determined by being ahead of the P-F curve.

During this period industry and their maintenance departments were confronted with increasingly and numerous hurdles. Apart from the fact that economic drivers put margins under pressure and cost control was often affecting maintenance departments first, maintenance also struggled, and even so today, to attract young and skilled people. This is mainly due to a lack of good image and the true understanding of the job content and how rewarding it is.

Although much has happened since the start of the industrial revolution the past 200 years, it appears that the most dramatic changes have occurred within the last 30 years. Especially from the year 2000 onwards (the IT bug-century flip) to date, innovations in technology in every area of life are more than they have ever been in human history and maintenance management is not left out. A growing awareness of the value of continuous improvement and optimised asset management became obvious. During this period, an accelerated shift and interest in developing failure mode driven equipment maintenance plans, boosted predictive maintenance.

From early 2000 to 2025

The period where maintenance is evolving from "analysis to analytics" – the quantum leap. A new era of ***prescriptive maintenance*** where asset managers, maintenance managers and operators jointly use artificial intelligence to predict asset behaviour and define ***"what's the best that can happen"***. We are gradually entering a period where algorithms predict and allow automated ***self-optimisation*** actions and humans get a new role defined!

Leveraged by accelerated technology evolutions and driven by globalised market mechanics and a fast-changing world of "instant" and "green" expectations, the need for continuous perfection and optimisation have now become prime for various industries and are key to survive. More than ever this new truth and the need to transform from flexible production to agile production becomes clear, now that mass production is quickly moving towards mass customisation. Current strategies are being questioned and many amongst us find ourselves at the tipping point between exploitation and exploration of our businesses and individual roles, often leading to new business models.

Even though one already understood that the true value of asset management lies beyond the physical asset itself, it now becomes possible to connect asset data with context-, process and organizational data in a better and more efficient manner. Or to phrase in our language: "Failures leading to losses due to technical problems, generally referred to as special cause losses, can now be blend with operational inefficiency parameters, referred to as common cause losses. Here lies the *new window of opportunity* to excel, improve and gain that last overall equipment effectiveness (OEE) or total plant performance improvement.

With the emergence of Industrial IoT (IIoT) collecting data from equipment is moving from paper-based, excel sheets and manual inspections to fully automated systems, enhancing both data quality and quantity. IIoT enables remote asset monitoring, also exponentially increases the quantity and variety of parameters that can be monitored and this at a better cost. With artificial intelligence (AI), predictive analysis (deductive) will shift to prescriptive analytics (forecasting), allowing us to move from 'what happened' to 'what's the best that can happen', improving total plant performance instead of only uptime.

In this early 21st century period, driven by advanced analytics, we can notice *two major strategic shifts* in maintenance strategies.

A *first strategic shift* is one that moves our maintenance practice from a failure mode driven asset strategy to an OEE driven strategy. By combining equipment data with process data, quality data, performance data, contextual-operational data and other relevant information, artificial intelligence provides new insights in equipment and process behaviour. This will provide maintenance technicians, planners and operators with comprehensive new, accurate and real-time insights into asset performance, risks, (..) and allow them to maintain higher levels of asset availability.

Root cause analysis (RCA), by applying fi. fault-tree analysis as well as cause-and-effect or failure-modes-and-effects analysis (FMECA), is a fundamental part of any organization's maintenance and reliability strategy. Today, however, these activities are often conducted manually, and their outcomes are rarely recorded in a centralized manner. Hence through digitization and advanced analytics these methodologies will be automated and updated continuously. Possible root cause(s) will be suggested by the system in which the maintenance expert and/or operator will acknowledge the 'real' root cause, so improving the accuracy of the analytical models. Similarly, this can also be applied for reliability centred maintenance (RCM), helping teams choose the right maintenance strategy for each (critical) equipment. This is a gamechanger in predictive maintenance.

A *second strategic shift* is moving from an OEE-driven to an Operational Excellence driven strategy. Combining OEE data with loading, planning and product supply chain data allows to improve total plant performance. Maintenance schedules will be aligned with production schedules to optimise total production, balancing demand and supply. Using AI within production enables now to shift from mass production to mass customization.

Further integration of the digital and physical world enables close interaction between machines, algorithms and humans. New digital maintenance execution systems augmented (AR) and virtual reality (VR) will support technicians in real-time to perform standardized repairs in a safe way by using the right tools, procedures and instructions. Know-how will be captured digitally, visualised and made available for everybody. Operators will receive optimized setpoints for their production lines, can feed the systems with additional relevant information that will further improve the analytical model. *Digitisation and humans go "hand in hand"*.

From 2025 and beyond: The future is a concept – it doesn't exist.

We now enter the unknown era of exponential change, new business models and renewed anthropocentrism. The self-optimising prophecy now becomes reality.

In spite of what I stated above and recognising an accelerated evolution and change in our asset management landscape, realise this: ***"we ain't seen nothing yet"***. Until present evolution, even though continuously accelerating, still was very much a linear evolution. The way we think, work and act are still very much the same as they always have been. Admitted, we evolved and matured, got wiser and our working models went from a very "centralised" way of thinking, organising and behaving to a "de-centralised" format in the '90s. But the reality today is that change, boosted by technology is shifting gear into an exponential acceleration. A mind trap is that often we overestimate the change that will occur in the next two years but underestimate the change that will occur in the next ten, affecting our strategic judgement. Think fi. about *quantum computing*, a technology rapidly maturing in the shadow of today already for some seemingly futuristic scenarios.

As IIoT will make everything and everybody interconnected, and everything is continuously changing and interacting in these new agile environments, we need to accept and embrace new *distributive models*. Boundaries becoming vaguer, our world and our industries will continue to converge. We are undergoing an exponentially accelerated merge between the physical and the digital world. Therefor we need to escape from our traditional way of thinking, working and organising within our maintenance or production silo, and step into this volatile and complex new environment. We need to re-invent ourselves, our methods and our solutions and stop ignoring this change by progressing in a stubborn linear pattern: *"We cannot solve our future problems with the same way of thinking we used when creating them."*

Based on real-time information we will be able to accurately predict and balance supply and demand improving our company's bottom-line without compromising the quality of service and reach an almost optimum performance, by increasing productivity and profit to unseen limits. The newly required skills often go beyond our human capacity and that's where technology gives us a helping hand. It is up to us, people, asset managers to question, master and control that change.

Blockchain technology will verify every step of the production process or provide full transparency in contracts between companies, suppliers and vendors. Digital fingerprints (encoded asset certificates) of each asset and process will be created, ensuring reliable and qualitative information. All information will be indisputably and incorruptibly recorded in appropriate registers, ensuring increased security of information. Smart automation will help us to transform processes that require interaction, data interpretation and decision making. Robotics will allow us to perform smart operations by automating processes.

I could continue and elaborate on many other new technologies, but the moral of this story is: ***"nothing has changed, but everything changes"***. Allow some slight exaggeration here, but we are not inventing anything new, though. We're just using old, improved algorithm technologies from the 9th and 19th century. Just like we used thousands of years ago hieroglyphs to communicate between different tribes, today we call them *"emojis"*. Wrenches will probably still be used, but with an improved design or attached-integrated to a robot. And algorithms will not be calculated by human brains but will run on supercomputers.

Conclusion: "Prediction is very difficult, especially if it's about the future …"

At "The Grain" we strongly believe that combining artificial and human intelligence is key for future success of both our industry and humanity, hence our well-being and our welfare. The role of people will remain strategic, only the content of our jobs will change. Thanks to technology we can get rid of repetitive and often boring routine work, in many cases leading to malpractices, and concentrate on rewarding and true valuable input. Or to put it simple, "We are for questioning, AI for answering". Einstein already stated it clear: "If I had an hour to solve a problem, I'd spend 55 minutes thinking about the problem and five minutes thinking about solutions." Hence, Technology provides the know-how, humans the know-why.

The most important impact of technology is how it changes people. Therefore, it is at its best when it brings people together and services our purposes! Hence, we should not be concerned about the exponential change in artificial intelligence or robotics, but more about the stagnant attitude in human intelligence. Beware however, it is not the robots taking over, but it is the men who play with toys that are to be feared. That's were ethics enters into the equation. Technology is ethically neutral, until wrongly applied by us! Let us embrace technology and use it for the right purpose with a clear anthropocentric focus, i.e. for the use and benefit of humanity and in this case our maintenance engineers, operators and asset managers in general. Allow me to quote Einstein once more, confirming that indeed nothing really changes: *"Why does this magnificent applied science which saves work and makes life easier bring us so little happiness? The simple answer runs: Because we have not yet learned to make sensible use of it."*

Well dear Albert, we might get there. Humans will remain human, technology will just leverage our skills, if done right! Man, and machine will keep living and working side by side like they've done for ages, but now for the better. AI will provide answers and insights to our questions in maintenance, process and organisation. Thanks to AI, we have the opportunity to embrace that necessary change. We are heading for a renewed era of Uber-anthropocentrism, unlocking human potential and driving a new industrial renaissance. Human ingenuity will excel!

Dirk De Nutte, CEO THE GRAIN- june 2020

Would you like to discover more about the future of maintenance and asset management 4.0? Feel free to follow one of our inspiration sessions. More information can be found on our website www.thegrain.pro.