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INDUSTRIAL INTERNET: THE NEXT AGE OF PRODUCTIVITY FOR EUROPEAN GT BASED PLANTS

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ABSTRACT

Lately, there has been a lot of discussion on how Industry 4.0 and digitalisation are challenging traditional business models and provide new opportunities to gain competitive advantage. The energy sector as well as the Oil&Gas sector have been early adopters of digital technologies. Since the 70's, digital techniques were introduced for decision support and process improvement and have been commonly used for well over a decade now. So, what is the recent fuss around digitalisation all about? Is it just a new buzzword for more of the same or are we really at the start of a new age of productivity? In a series of workshops, the ETN technical committees 4 and 5 have been exploring this question.

It became clear that many of the digital initiatives in the past got stuck in the information generation phase, without really providing the insights required to improve the business result. Causes for this were related to IT infrastructure and data handling issues. Recent developments, such as improved connectivity, cloud data storage, software as a service, advanced algorithms and improved sensors address many of these historic roadblocks. Industrial IT has completely re-invented itself and offers new opportunities by providing insights required to go closer to the limits of the equipment, eliminate inefficiencies and enhance the human work experience. Any new development comes however with risks that need to be carefully managed in the implementation phase to unlock the full value.

INTRODUCTION

Improving plant hardware to improve plant performance has made a huge leap forward in recent years and is reaching an area of diminishing returns. The next big opportunity to further improve plant performance is to accelerate productivity, reduce inefficiency and waste in equipment operation, and enhance the human work experience through digital technologies.

Information and communication technology (ICT) has been mentioned several times in the 2016 update of the project board R&D recommendation report issued by the European Turbine Network (ETN) (ETN, 2016). In several sections of the report, ICT was highlighted as an enabler to achieve some of the targets of the European stationary gas turbine industry. Specifically mentioned are for example predictive performance algorithms, use of analysis of operation conditions to manage sub-system lifetime, risk based maintenance approaches, use of “grey box models” for monitoring purposes, merging sensor based information with inspection and off-line monitoring results, advanced instrumentation, fault detection systems and big data storage and management.

Other organizations are also looking into using the industrial internet to improve business results. For example, in 2014, the Industrial internet consortium® (IIC) has been founded to bring together some of the main industry players, to promote the accelerated growth of the industrial internet of things (IIoT). Also EPRI, the electric power research institute in the USA, has started a project to setup a physical and virtual host test site to test the industrial internet. The name of the project is I4Gen (Maley / Espinoza, 2016), which stands for insight through integration of information for intelligent generation.

As we have seen elsewhere in other industries, the digital transformation is challenging traditional business models and presents new opportunities. Players who are quick to embrace this transition will gain a unique competitive advantage as they will increase income through a better control of their operations and will keep costs down in an increasingly demanding industry.

This paper will review what new opportunities the IIoT provide, associated risks and how GT based plants in the Oil&Gas and the power generation industry may benefit from the adoption of the industrial internet.

Unlocking the full value of the data involves more than just an IT project, it requires a transformation of value creation processes within the company. The final chapters of this paper will therefore share some recommendations on how to successfully master the digital transformation in your organisation.

NOMENCLATURE

AI	Artificial intelligence, the field of computer science dedicated to solving cognitive problems commonly associated with human intelligence, such as learning, problem solving and pattern recognition (Marr, 2018).
CHP	Combined heat and power
CMMS	Computerised Maintenance Management System
CPS	Cyber-physical systems, mechanism that is controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users. In cyber-physical systems, physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioural modalities, and interacting with each other in a myriad of ways that change with context (Wikipedia).
EHS	Environment, health and safety
Edge	Edge computing is the part of the system at the edge of the network, where IIoT connects to the physical world. Edge devices collect, pre-process and perform local computing tasks in addition to providing a seamless link between the IIoT and the cloud. In addition to connectivity, edge computing provides privacy, reduces latency (delay) for applications where network delays cannot be tolerated and provides additional connectivity robustness.
EPRI	Electric Power Research Institute
ERP	Enterprise Resource Planning (business management software)
ETN	European Turbine Network
FFT	Fast Fourier transformation, e.g. used for vibration spectrum analysis
FE	Finite elements
GT	Gas turbine
HMI	Human machine interface
ICT	Information and communication technology
IIC	Industrial internet consortium®
IIoT	Industrial internet of things
IPR	Intellectual property rights
LoRa	Long range, low power wireless platform, based on the unlicensed radio spectrum.
KPI	Key performance indicator, metric that characterises the process performance, used for high level tracking (e.g. plant efficiency). When it deviates, drilling down to sub-KPI's is needed to diagnose the reason.
M&D	Monitoring and diagnostics
OaaS	Outcome as a Service, an offering where products and services are bundled as required to guarantee a desired business outcome.
OT	Operational technology, hardware and software used to monitor and control physical devices, as used in industrial control systems. Traditionally, often not networked because either mechanical or based on proprietary protocols.
SaaS	Software as a Service, software license and delivery model in which software is licensed on a subscription basis and is centrally hosted. Also referred to as "on-demand software" (Wikipedia).
SCADA	Supervisory control and data acquisition, a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as programmable logic controllers and discrete PID controllers to interface to the process plant or machinery (Wikipedia)..
SSO	Single Sign On
TC	Technical Committee. ETN TC4 covers "condition monitoring and instrumentation" and TC5 covers "asset management".
VPP	Virtual Power Plant, a cluster of distributed, usually small-scale, generation installations that are collectively managed as a single facility through a central control entity.
WLAN	Wireless local area network is a wireless computer network that links two or more devices using wireless communication within a limited area.

INDUSTRY 4.0 AND THE INDUSTRIAL INTERNET

Industry 4.0 (see Figure 1) refers to the 4th industrial revolution. In the first revolution, the world changed from a society depending mainly on agriculture to create value, to a society that relied on industrial production, driven by water and steam. In the second revolution, electricity was introduced as a driving force, and assembly lines were created to increase productivity. Later, in a 3rd industrial revolution, assembly lines were automated, supported by electronics and IT systems. In Industry 4.0 all steps of the lifecycle of a product will be connected by a single digital thread, operated through a single platform. Sustainability becomes a key factor, together with the integration of smart systems for control and monitoring. A major part of the digital journey is based on data and connectivity. Connecting all machines to the internet and consolidating all data sources on a single platform are stepping stones to creating the insights required to improve processes and go closer to the limits of the equipment. A key enabler for all of this is the introduction of Cloud Computing technology which helps to provide a safe, central repository, available through the Internet.

The most important pillar in the breakthrough of industry 4.0 is Internet of Things, or Industrial Internet of Things (IIoT) (Wikipedia) The concept is to connect all hardware and software components within an industrial environment, providing complete visibility into operations at any time, at any location. The IIoT is not really a new technology, but it refers to the mixing of the industry with the open computing and communication systems developed as part of the Internet Revolution. The convergence of machinery and smart data allows for constant and real-time adjustments and provides insights required for smarter business decisions. The aim of this integration is to open up new frontiers to accelerate productivity, reduce inefficiency and waste, and enhance the human work experience.

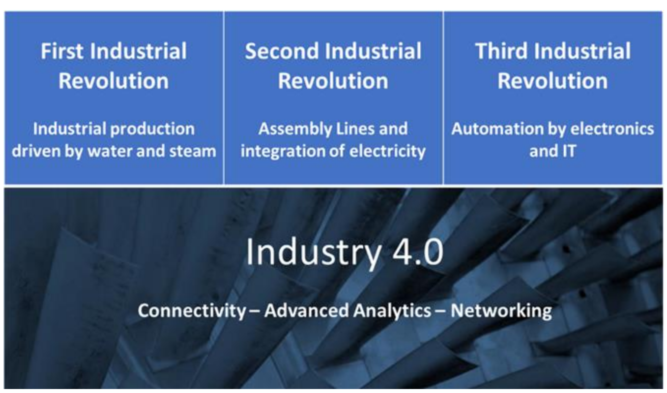

Figure 1: Industry 4.0

The IIoT brings together:

- Intelligent machines with embedded technology to sense and interact with their environment (advanced sensors, better models and controls);
- Advanced analytics (physics based, predictive, …) and machine learning;
- Networking of people at work through discussion groups.
- Faster decision making and improved interaction, thanks to new generation HMI solutions in both work or domestic environments.

HISTORIC ROADBLOCKS

The graph (Figure 2) below is a typical graph used for introduction of knowledge management. Starting from data extracted from activities and processes, data becomes information when put into context and made accessible. This information in turn becomes knowledge when adding insight gained through understanding. The real value only comes from the actions or decisions taken based on these insights, which ensure long term sustainable and profitable operation.

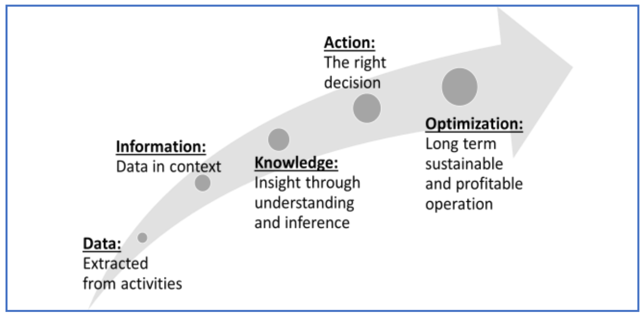

Figure 2: Knowledge Management

The gas turbine based industry has started implementing remote M&D, performance models, neural networks and condition monitoring for several decades. But when asked in which stage of implementation most plants are, the ETN technical committee members agreed that it is usually somewhere between "information and knowledge". Similar feedback was received at similar discussions organized by EPRI in 2016 in the USA.

What are the historic reasons we did not get any further and have not been able to create a breakthrough in creating added value? Below is a list of reasons from a brainstorming, held at the ETN annual general meetings in 2016 (Prague) and in 2017 (Oberhausen):

- Data access and connectivity:
  - Data islands:
    Missing inference with other data / information sources or lack of bridges between data islands: e.g. no access to maintenance history, subsystems of different suppliers often use different data loggers or control systems, … Decision support only works when all inputs are available. Historically, most of the effort in problem solving is related to finding the required data.

- Time continuity of data:
  Moving of assets to other locations, so no data continuity over the history of the equipment.
- Incomplete data model:
  Many influence factors are often not considered in the design and therefore not monitored (e.g. chemistry, previous inspection results and fleet experience).
- Data resolution:
  Sampling is too slow to make transient analysis, e.g. for real-time monitoring of fatigue supported by FE. This is often caused by storage limitations or lack of effective data compression techniques.
- Data browsing limitations:
  Navigating through large amounts of data and finding the right extract is often a challenge, both because of the lack of possibility to effectively zoom out and because of processing capacity limitations.
- Physical limitations to access the data:
  Stand-alone systems in the control room can only be accessed when physically going there. This makes data use of the generated data by specialists inside and outside of the company less efficient. In addition, internet access to remote oil&gas or power generation facilities may be limited or non-existent.
- Disputes over data ownership.
  Unclear situation regarding final data ownership and other IPR related issues.

– System / platform management and maintenance:
  - Hardware or software update issues:
    Issues related to hardware obsolescence, missing software updates, regular data back-up, software/hardware interface protocol changes, etc. With the lean staffing on power generation or oil&gas facilities, the access to professional IT management staff is limited.
  - Hardware limitations:
    Limited storage place or processing capabilities require compromises in data storage or analysis.
  - Different data formats:
    Difficulty to transfer and automate analysis of data other than simple time series, e.g. FFT, pictures, heat maps.

– Data management and maintenance:
  - Incomplete data:
    If the data is not used pro-actively, but only looked at when there is an issue, it is often discovered that part of the data is missing, disturbed or not available.
  - Data validation:
    Limited data plausibility checking or validation capabilities.

– Data security:
  - Access limitations because of security requirements:
    It is often time consuming or impossible to give all stakeholders access to the data, especially if they are part of a different organization, such as OEM's or other service providers.
  - Risk related to 3rd part access to critical infrastructure control platforms.

– Analysis and analytics:
  - Modelling limits:
    Limitations of models to mirror future reality, and all possible future degradation schemes, transferability between sites, individual site characterization.
  - Effort / cost involved with the maintenance of the models:
    Keeping models up to date is important to avoid false positives or false negatives, but often requires a lot of effort.
  - Expertise:
    Lack of access to the knowledge required to interpret the data and establish the necessary relationships.
  - Risk management:
    How much risk is acceptable. Lack of acceptance by deterministically educated engineers for risk based decision making. Lack of acceptable ways to quantify risk make it difficult to accept risk.
  - Economical evaluation and market models:
    Lack of maturity of such models to be used on an industrial level. It is however important to integrate these models in the decision-making process in order to generate useful insights.
  - Human factors:
    Organizational barriers, such as fear for job loss or unwillingness to share information. There is often not enough focus on creating a win-win situation.
  - Uncertainties related to the pay back / cost-benefit:
    What will be the "real cost"? How much effort is justified to invest for "non-noble parts"? What is really needed and what is "nice to have"?

WHAT IS NEW?

The on-set of the IIoT has provided a number of new features that will help to deal with many of the historical challenges discussed in the previous chapter. This was reviewed in the ETN workshop held in Genoa (Italy) in October 2017 (Decoussemaeker, 2017).

– Data access and connectivity through use of the cloud:
  - Single source access to data from different data sources, such as operational data, plant floor technical data, financial data, supply chain / ERP, maintenance planning system (CMMS) and maintenance history, dispatcher/grid system, weather data, smart metering, information on volatile / distributed generation resources, control systems, sensors, configuration data, lab results, inspection results, design information, instruction manuals. The possibility to query and combine data

from different sources as if it is in a single data pool is also often referred to as big data. All the data is "just there".
  - Possible to integrate data islands related to older, legacy systems or data in different formats.
  - Different connection/access technologies are available (e.g. 4G/5G at locations with limited wired internet, WLAN, LoRa, …).
  - Access through mobile and remote devices, from various locations inside and outside of the plant.
- System / platform management and maintenance:
  - Software as a service (SaaS) moves away the system responsibility from the end user. Responsibility for hardware and software maintenance and updates is transferred to a professional IT service provider with latest state of the art hardware and software.
  - Improved reliability by moving away from individual machines that may fail. Disaster recovery is now managed through a professional organization and supported by redundant systems.
  - Possibility to store and handle different data types, including higher resolution data. Not just time series data but also other types of data can be handled, such as patterns, pictures, compressed data, aggregated data etc.
  - Handling of data streaming from control systems, SCADA systems, energy management systems, equipment sensors, plant historians, and many other sources. This different data sources must be organized, combined and made available to many end users to get an effective optimisation.
  - Scalability is designed into cloud based systems. It is easy to scale number of users, applications, storage or processing capacity.
  - Technology (cloud) is not "GT industry" specific, leading to economies of scale, and rapid technology advancement.
  - Open platform, can receive applications from different developers (3rd party apps).
  - Reduced cost because it is no longer necessary to purchase and maintain your own IT infrastructure. But also, in general, IT hardware costs have gone down in the last decade.
  - Cost of edge (on-premise) devices has reduced, and processing power has improved. This helps to connect additional local devices and also enables local control as well as remote control and updates through local control devices.
- Data management and maintenance:
  - Improved data quality because it is easier to maintain the data if it is all at a single location. Data from different sources also provides more validation options, e.g. through comparison with other data, or with virtual or soft sensors.
  - Short term storage on edge computing devices (see chapter 10) allows dealing with periods when connectivity is temporarily interrupted.
  - Improved HMI solutions to navigate through the data history and visualise data in different ways. This also includes capabilities to effectively sort through large amounts of data and zoom into specific areas of interest.
- Data security:
  - Oil and Gas facilities and Power plants are strategical assets: if data is transported away from the plant, into the cloud, it reduces the risk of direct access to the plant and therefore reduces the need for access restrictions.
  - Secure data storage through central identity management in the cloud by means of the use of a "single" cooperate identity (SSO).
  - Secure data transfer through encryption techniques.
  - Data diode to protect undesired external access to the plant strategic assets.
  - Making data or information available through links is more secure than distributing documents and other files by (e-) mail. Centrally stored information can be better monitored compared to data on private disks or folders.
  - Central version control of updates ensures the implementation of the latest security patches.
  - A downside remains however that all data is stored at a single location, so if someone gets in, the consequences may be larger.
- Analysis and analytics:
  - Advanced analytic techniques and self-learning systems have become more available, more effective and user friendly. Maintenance efforts have been reduced through self-learning systems.
  - Code sharing and standards help to reduce programming effort and cost.
  - Virtual plant or digital twin models can be used for different applications, e.g. project validation, new controls testing before installation, but also to monitor existing installations for deviations.
  - Increased amount of visualisation options, e.g. through cockpit charts that allow to drill down to more detailed KPI's.
  - Ease to provide data access to different users and user groups. This does not only facilitate user management, but even more important is that it helps to break down organizational silos (e.g. EHS, different plants of the same owner, reliability team, operations, maintenance, trading, …), through sharing of experience and expertise in a common system. It also becomes possible to give access to specialized companies to help the end user with the interpretation and effective usage of the data.
  - Hybrid Plant Networks allow to manage Virtual Power Plants (VPP).

- Faster fault analysis and efficient disaster recovery solutions, combining remote access to plant data and virtualization & simulation of the plant network.

− Sensors:
  - Improved sensors: better accuracy, higher temperature resistance, longer life, more robust and versatile.
  - Better and faster processing technologies leading to faster measurements and processing, e.g. surge detection, flame monitoring, 3D exhaust flow monitoring.
  - Lower cost, or improved functionality such as smart transmitters with on-board diagnostic features.
  - Wireless technologies make it easier to integrate new sensors in existing systems.

PITFALLS AND RISKS

Regarding the loss of business continuity, the risk perimeter increase is the common factor when connecting hardware and software components within an industrial environment (IIoT).

Below is a listing of some of the risks that need to be considered when implementing the IIoT:

− Cyber Security:
  - Hackers who want to harm the IT system, or the plant:
    Hacking a professionally maintained system is more difficult, but in case a hacker does get through, there is potentially access to a lot of data. However, value of plant data is usually less interesting to criminals, assuming that other market players will not engage in criminal activities. In addition, by moving data away from the plant into the cloud, the threat of sabotage to plant equipment is reduced.
  - The convergence of OT and IT systems:
    The introduction of internet capable control and supervisory systems, makes OT systems more vulnerable to malware and external interference, potentially leading to acts of sabotage.
  - Competitors who get insight in
    This may happen through internal data leaks and misuse or external unauthorized access. As discussed in the previous chapter, it is easier to control data and information in the cloud compared to uncontrolled (e) mail or hardcopies.
  - Privacy concerns:
    Are less of an issue for “machine” related data.

− Skills:
  - IT skills:
    This requirement is reduced through SaaS.
  - OT skills:
    Power plant reliability is the driving need for these requirements. In fact OT skills are driven by the stability and interoperability demands to correctly use and maintain still working legacy systems (e.g.: Windows XP) as well as to effectively protect more modern internet enabled OT technologies. Remote support helps to address this challenge.
  - User skills:
    Some training and internal promotion will be required when introducing new systems and technologies, especially with older generations. However, millennials that have grown up in the digital environment will expect this as well in their “new” work environment.

− Abundant data by itself solves nothing:
  - It is important that leadership and process know how carriers are part of the implementation project teams and that their expertise and requirements are leveraged. A pre-condition to generating useful insights is to connect all the right data sources to the processes that need them and that there are no gaps that need to be filled with individual “work arounds”.
  - However, to some extent, it may proof useful to pool more data than strictly needed by the application. It may help to deal more easily with future requirements.

− Ownership:
  - Data access and property conflicts related to historic data:
    Data is owned by the organization that generates the data. A contractual license agreement needs to be in place to arrange the usage of the data by 3rd parties.
  - In IIoT, the software is provided as a service, therefore ownership of the software and the system remains with the service provider. The software is provided on a subscription basis.

VALUE

How can the industrial internet create tangible value to the end-users? Three (3) areas of value were identified in the definition that was given in the earlier chapter in Industry 4.0:

− Accelerate productivity (increase income):
  - Go closer to the limits of the equipment (e.g. surge protection, lean combustion, life consumption, adaptive control approaches) through better sensors and models. This will improve capacity or flexibility (e.g. reduced minimum load, better response time).
  - Better short and medium-term demand forecasting based on complex interaction of many parameters (weather, time of the day, season, end-consumer behaviour, etc.) to better anticipate load / operation management and provide a better service to the customer (grid).
  - Trade-offs between market opportunities and cost / life consumption.

− Reduce inefficiency and waste (reduce spending):

- "Off design" tuning (e.g. part load, ambient fluctuations, duct burner use) for optimum efficiency.
- Predict and avoid defects and unplanned breakdowns through early warning, lifetime monitoring or more effective maintenance planning.
- Reduce life cycle cost (investment, maintenance, consumables, …) through risk and condition based maintenance, based on better insights from the available data on condition and business impact (risk).
- Fleet level comparison to optimize operations, benchmarking between plants (e.g. fuel consumptions, maintenance tasks).
- Better alignment between internal organizations through better visibility of priorities.

− Enhance the human work experience:
  - Mobile worker becomes more efficient through easy access to all required information and reduced reporting efforts.
  - Robotic inspection technologies reduce costs and outage time and often also provide better data.
  - Learning with the aid of virtualization minimize risks related of possible damages to physical equipment and downtime.

MATURITY MODEL

Industry 4.0 or the smart factory concept relies upon cyber-physical systems (CPS), which link the physical and virtual worlds by communicating through an IT infrastructure, the Internet of Things. The good implementation of Industry 4.0 enables distributed, highly automated production. Differently from traditional production, smart factories will control and monitor the production process and, in the final mature phase, will guide themselves autonomously through production. The smart factory is a production environment in which the production systems and logistics systems largely organize themselves without human intervention. This is what happens in the smart factory environment. Industry 4.0 also involves digital modelling through the smart gathering, storage, and processing of data. In this way, the smart factory concept ensures that information is delivered and resources are used more efficiently. This requires a real-time, cross-enterprise collaboration among production systems, information systems, and people. These integrated systems produce large amounts of data that are processed, analysed, and integrated into decision-making models.

Most companies will not start from zero. To get started in the digital transformation journey, it is important to understand where a particular organisation stands in terms of digital maturity. Digital mastery does not only require the right technology, but also requires the right governance to manage the transformation. This topic was extensively review at the ETN annual general meeting in Bucharest in 2018. Assessing the Industry 4.0 maturity level can be done according to the following two main dimensions:

− Digital capabilities [IEA, 2017]:
  - Data:
    How good is data collected, stored and made available? How much of the process is reflected in the data, e.g. do we use advanced sensors, do we collect diagnostic information from local instruments and controllers? Is the infrastructure scalable, performant and safe?
  - Connectivity:
    How effective and efficient is the infrastructure in connecting the devices and the users of the date.
  - Analytics:
    Are digital twin models in place to perform analytics? Does the organization also use prediction or optimization algorithms?

− Leadership and organisational aspects (Westerman et al, 2014).
  - Management:
    Is there a clear vision, plan and KPI's linked to the expected business outcomes.
  - Organization and implementation of digital capabilities:
    How is the adoption? How is the relationship with the IT department? How is training for users organised?

For each of these dimensions, a list of questions has been developed to perform a self-assessment (Decoussemaeker / Dagnall, 2018). Questions should be answered on a scale of 1 to 5:

- 1 strongly disagree / not at all;
- 3: neutral / partly;
- 5: strongly agree / fully in place.

Results can then be average in each category. Finally, the results of the different categories can be averaged according to the two main dimensions on plotted on a XY graph (see Figure 3) (Westerman et al, 2014).

Companies in the "follower" quadrant are quick to take up and experiment with new technologies, but may lack governance to get the full value out of their investment. Companies in the "conservative" quadrant have a good control of the development of their capabilities and the required investments, but may be too slow to adapt. In the "master" quadrant, companies have mastered to find the right trade-off between implementation of new technologies and improving their processes and capabilities in-line with the opportunities the new technologies provide.

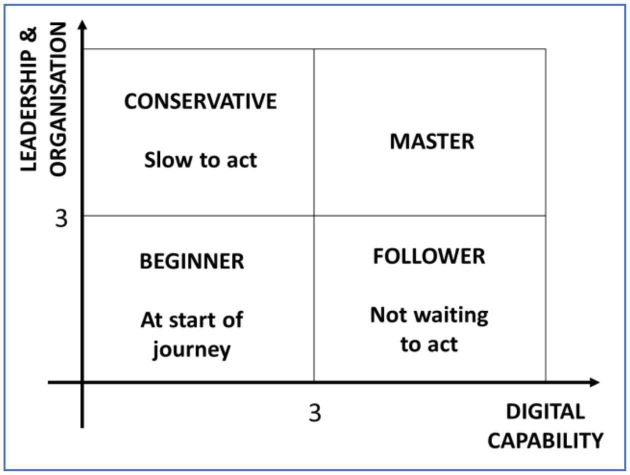

Figure 3: Result of self-assessment

IMPLEMENTATION MODEL

To implement an Industry 4.0 model, new technologies and organizational methods need to be merged with existing technologies and processes. A successful implementation requires that an organisation goes through a number of steps and considers both the technology development, leadership aspects and the issues related to sustainable organizational development.

Whereas traditional IT infrastructure projects depended on clear design and well-structured plans, more recent IT projects often engage in test-and-learn strategies, based on experiments. However, doing major implementations of new technology in a learning-by-doing approach could be dangerous. It may increase rework, waste money and introduce security risks (Westerman et al, 2014). A two-speed approach that does not work around systematically addressing any IT issues is therefore recommended:

- Start by building up a digital backbone with interfaces to legacy systems. It is important that in parallel, any of the old IT processes continue to receive full support. This project has to be performed in a careful and systematic manner in order to avoid any security issues and re-work.
- Once this digital backbone is on place, various capabilities can be developed in a fast, agile and flexible manner. The continuous deployment ensures a rapid feedback of users and business and the effectiveness of the implementations.

A best practice implementation process consists out of four phases:

1. Create a Digital Vision:
   At the start of the process, it is important to create management awareness of the importance and an associated sense of urgency. It is also important to know the starting point or the digital maturity or the organisation. The self-assessment proposed in the previous chapter is a good tool for this. Once this is clear, company transformative vision around its strategic assets needs to be defined, together with a clear business expected business outcome.
2. Project planning:
   In this phase, goals need to be defined, an implementation plan needs to be developed and the budget for the transformation process and the subsequent operation needs to be defined. Part of this effort is also the return on investment calculation.
3. Implementation project:
   The IT backbone needs to be implemented and first applications need to be developed. These pilot projects should represent quick wins to gain acceptance. Try out different alternatives and adapt the organisation to support this.
4. Consolidation:
   Expand, learn, check progress and compare to planned resource attribution. Correct where needed to achieve sustainable processes. Training and building up of the required digital skills is important in this phase.

SUCCESS STORY

A large US utility was faced with the challenge of providing economic and reliable power as demand and fuel prices fluctuate. At the same time, the leadership recognized the value of leveraging data from their plants to make more informed decisions about operations and market opportunities.

To achieve this, they worked with GE's team of experts to implement GE's Predix based Asset Performance Management application at a pilot plant. The system captures data from machine sensors and applies analytics to create insights that drive more profitable decisions. An M&D center was created to help drive the key performance indicators for system availability, thermal performance and operational flexibility.

This resulted in an integrated view that puts the plant manager and their trading counterpart on the same page. Automatic notifications alert the plant manager about any operational anomalies in order to prevent risky operations. Cloud-based visibility, insights and actions keep leadership focused on achieving their continuous improvement initiatives including identifying opportunities to improve thermal performance, increase operational flexibility and reliability. Because of this digital power plant initiative, the plant reached the top quartile for heat rate, reduced fuel costs during startup and achieved 1% improved reliability. It allowed this older combined cycle plant to remain competitive even after newer, more efficient plants began operations in an already very competitive regional market. The company has since decided to extend the system to its other fossil plants and future plans also include the nuclear fleet (Overton, 2016).

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