Digitalization

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Introduction:

Digitalization is often described as something new and revolutionary, that will change the world and our lives radically.

But when it comes to digitalization in the industry, it is something that started years ago and has developed along with the expanding possibilities in computer and communication technology.

The industry has used data collection and advanced control equipment linked up via bus communication to SCADA systems since the end of last century.

What we are seeing now is that sensors, data communication, storage and computer power have decreased in price, which means that advanced control systems are expanding to new parts of the industry and are used more widely - helped on the way by wireless communication and smart devices.

Purpose:

The purpose of this Paper is to present some of the key elements of digitalization that are related to Industry.

It will explain the benefits and options for using data and data processing, as well as the possibilities, limitations and obstacles to take into account when digitalization reaches pump installations.

Digitalization can open doors to new areas of industrial applications and expand pump integration to the entire installation by offering energy optimisation, monitoring, advanced system protection and pump control linked to process performance of the surrounding equipment.

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Fundamentals of Digitalization

Digitalization can roughly be split into four areas:

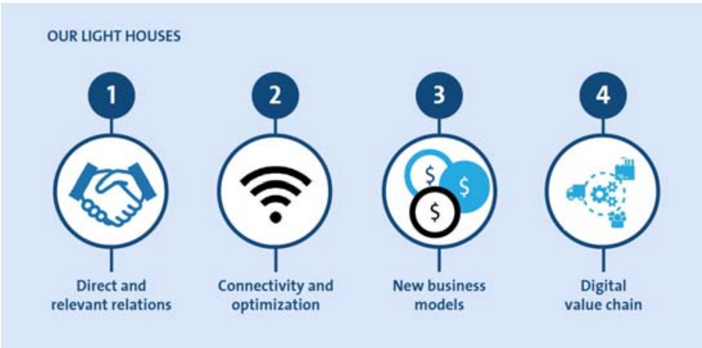
1. Data collection, analysis, optimisation (e.g. Algorithms)
2. Customer touchpoints (e.g. selection tools), sales channels (e.g. Internet sales), sales structures (e.g. services, financing)
3. Production technology, planning, distribution. (e.g. supply chain)
4. Data flow, storage, security (e.g. ownership, legislation)

Each area may overlap with others; however, they retain strong ties to their individual parts of the organisation:

I. Development and Service
II. Sales and Marketing
III. Production and Logistics
IV. Infrastructure, IT, Legal Department, Partners

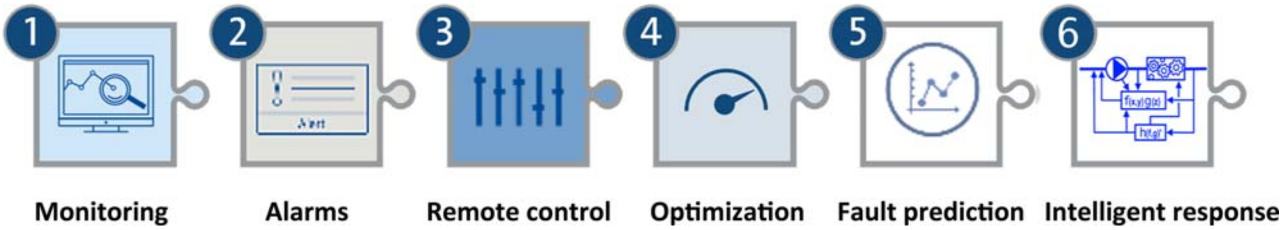
To better serve our customers, Grundfos has allocated substantial resources to Digitalization and set a goal to be on the front line in this field. The challenge here is that this cannot be handled as a large project. Because Digitalization is scattered over a wide area of functions, processes and products, it requires a new mindset, unallocated resources, fast response time and a willingness to take risks. It is expected that Digitalization will grow organically in the organisation, if the conditions are right and the organisation allows it, and we will see transformation at differing paces in different areas of the company.

The Grundfos digitalization agenda is split up in four Lighthouses:



This paper primarily covers Data collection, Analysis, Optimisation, Protection and Response that correspond to the Grundfos Lighthouse 2, and is viewed through an Industry perspective.

The Connectivity and Optimisation Project, Lighthouse 2, is defined by six building blocks:



Monitoring:
Covers measuring, data transfer, raw data processing, data storage and data presentation.
This can often depend on which other systems are installed such as SCADA (Supervisory Control and Data Acquisition) or other overall control structures.
It is necessary to evaluate which data is needed - and the quality, i.e. accuracy and measuring rate.
Data transfer can be either analogue or digital, wired or wireless, depending on what data usage, quality and amount is needed.
Raw data processing is necessary for filtering, preconditioning, compensation and reducing the data amount before transfer and storage. It can be linearising, averaging and event driven data packaging.
Data storage can be local in SCADA systems, local servers or in cloud based storage facilities, either proprietary or hosted.
Data presentation can be simple dashboards, spread sheets, CSV files or other data base formats.
Ex. Corresponding measurement of pressure, flow and power consumption - actual value, sampled values over a timeperiod, average, min. and max. values.

Alarms:
Can be direct digital on/off switches, equipment alarms, measured values that exceed thresholds.
These signals can either switch off equipment, start mitigating processes or be warnings about something deviating from normal conditions.
For easy overview and simplification, they are often presented as Green, Yellow or Red, corresponding to Normal, Warning and Alarm - either showed locally on the machinery, in the control room, on SCADA system or relayed to remote monitoring equipment, surveillance or smart devices.
Ex. Dry run alarm => Stop; Exceeded motor temperature => Warning; Normal => No action

Remote control:
Allows for quick response to avoid the inconvenience, expense and resources of being physically on site.
This can be scaled from remote start/stop, change of set point and system reset, to full access to the control system. This can include change of configuration, sub-algorithms and firmware.
These features are essential as enablers for Remote Service, Facility Management, Central Control Centers and a lot of new services addressing unmanned automated operation.
Ex. Change of set point; Change of PI controller settings; Change of firmware; Remote fault analysis

Optimisation:
Improving on systems after commissioning requires analysis of data. This can be done manually by qualified operators; however, the biggest potential lies in automated optimisation.
Automatic improvements on a system require virtual models or representative algorithms that emulate the actual system. The quality of the model and precision of the data sets the opportunities for improvement.
The analysis can either suggest changes to the system or actively change the parameter settings.
Automatic optimisation is linked to Intelligent response, meaning that the system should be able and allowed to alter related parameters
Ex. Auto tune of PI controller; Discharge pressure related to system load curve.

Fault prediction:
Reliably forecasting damage to systems and equipment breakdowns is a feature that is highly sought after by the industry to minimise downtime and scheduled maintenance.
Fault prediction requires large amounts of reference data, detailed analysis and deep knowledge about failure mechanisms and good algorithms and models of the equipment.
This is something that is expected to be developed and expanded with Digitalization due to faster and cheaper data transfer, storage and computation power. However, it is highly dependent on the right data and resources for making prediction models.
Ex. Monitoring development of wear in the pump by comparing measured hydraulic and electrical power, compare level of wear to previous breakdowns and forecast expected time to critical service - As previously introduced in Grundfos CR Monitor.

Intelligent response:
Knowing what conditions can damage equipment, or when it will fail, makes it possible to mitigate the damage. By changing operating conditions and activating protective measures automatically or by suggesting actions to operators, the technology and creates savings on maintenance and costs related to unscheduled downtime.
This again requires deep knowledge about the installation, critical parameters and priorities to keep operation going under protective measures.
Ex. In a steam boiler system with two-pump duty/standby configuration, operating near cavitation, switching both pumps on can take the system out of the cavitation zone;
Detection of air in one pump in a multi-pump Booster system allows the other pumps to decrease speed while the air-filled pump increases flow in order to flush the air out.

A quick assessment indicates that:
Monitoring and **Alarm** handling is relatively easy to implement and is being done today.
Remote control involves some technical and legal challenges unless the system is hooked up directly to a local Bus/SCADA system.
Optimisation, **Fault prediction** and **Intelligent response** will require the right data, good models and skilled analysts with application knowledge.
On top of this, **Fault prediction** also requires a huge amount of reference data on both operating and failing equipment, plus measurement and failure development analysis on systems from installation to breakdown.

The boost in Digitalization is often mentioned in relation to two abbreviations:

IoT - Internet of Things and IoP - Internet of People

IoT refers the trend that more and more devices such as everyday consumer objects and industry equipment have built in connectivity, Ethernet, Bus, WiFi, Bluetooth, etc.
That means that a large amount of electrical devices now have the ability to be interconnected to share data and can be controlled easily by users and other equipment.
It is this connectivity that is one of the enablers of Digitalization.

IoP refers to the fact that people are able to connect to each other or to equipment almost anywhere.
Telephone coverage and data connection has literally exploded since the turn of the century.
Everyone is used to being online- able to be contacted or to get in contact with other people.
Today most people worldwide carry a smart device that can connect to people, equipment and data storage, and more and more services are moving online- thereby changing the infrastructure of society.

It is important to understand that the *Connectivity* of equipment, *Cloud* based data storage and *Smart Device* interfaces are not the basis of Digitalization. They are merely practical *Tools*.

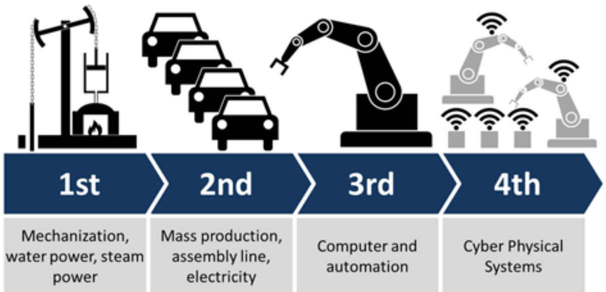
Since development of computer power, communication and data storage has developed with tremendous speed and has become less and less expensive, we have seen new standards and platforms come and go over the last decade. This has so far limited global digitalization.
Nothing so far has indicated that this technological development will slow down - rather the opposite.
In order not to waste too much on this development potential, the industry saw a dire need for a standardised development - a frame for how to manage the aspects of digitalization on a global scale.

Industry 4.0 - Standardisation of Digitalization.

Industry 4.0 is a European attempt, initiated by the German Industry, to try to set some standards and general guidelines for digitalization. In the US, a similar approach called Industrial Internet Consortium (IIC) is running in parallel, and China has also developed a frame called "Made in China 2025".
It is acknowledged that individual initiatives and propriety standards are outdated because what thrives in this world is the wide distribution of data and information - the more access, the more viability. The more we can link to other systems and structures the more we gain - we have to follow the present standards, knowing that a new update is right around the corner.

Industry 4.0 refers to the major steps in the industrial revolution, where the 4th is digitalization

Digitalization, Internet of Things and the globalisation of information is not something to be dealt with in the future, but something that we are in the middle of - it has already started and it is all around us.



Data collection, analysis, optimisation and response.

Gathering data electronically for analysis and optimisation is not new - it has been done widely over the past decades through BMS, CTS and SCADA systems or local control systems.
What is changing is the amount of data, storage and the availability that modern electronics and communication technology enables.

Digitalization is not new to Grundfos either - we started development of the Bus Communication Interface Modules, the CIM/CIU, at the beginning of the century. In 2008 we introduced Grundfos Remote Management, GRM and the CR Monitor, and thereby set the digitalization direction for the pump industry.

At the time, **GRM** was a communication device that could relay alarms, operating data and do basic remote control on Grundfos pumps, motors and controls, to a proprietary Grundfos cloud or to cell phone via SMS. The system could store data and present it to the customer, as well as see if values were exceeding set limits. GRM covered Monitoring and Alarms.

CR Monitor could collect massive amounts of data, do advanced data analysis, derive conclusions and generate alarms, warnings and initiate preventive action. The Grundfos CR Monitor used a self-learning system to detect a drop in efficiency, dry run, avoid cavitation, detect operation outside normal operating range. Alarms and data could be distributed to local SCADA system or relayed via GRM to the Grundfos cloud service.

CR Monitor covered all six building blocks in Lighthouse 2 - Monitoring, Alarms, Remote Control, Optimization, Fault prediction and Intelligent response.

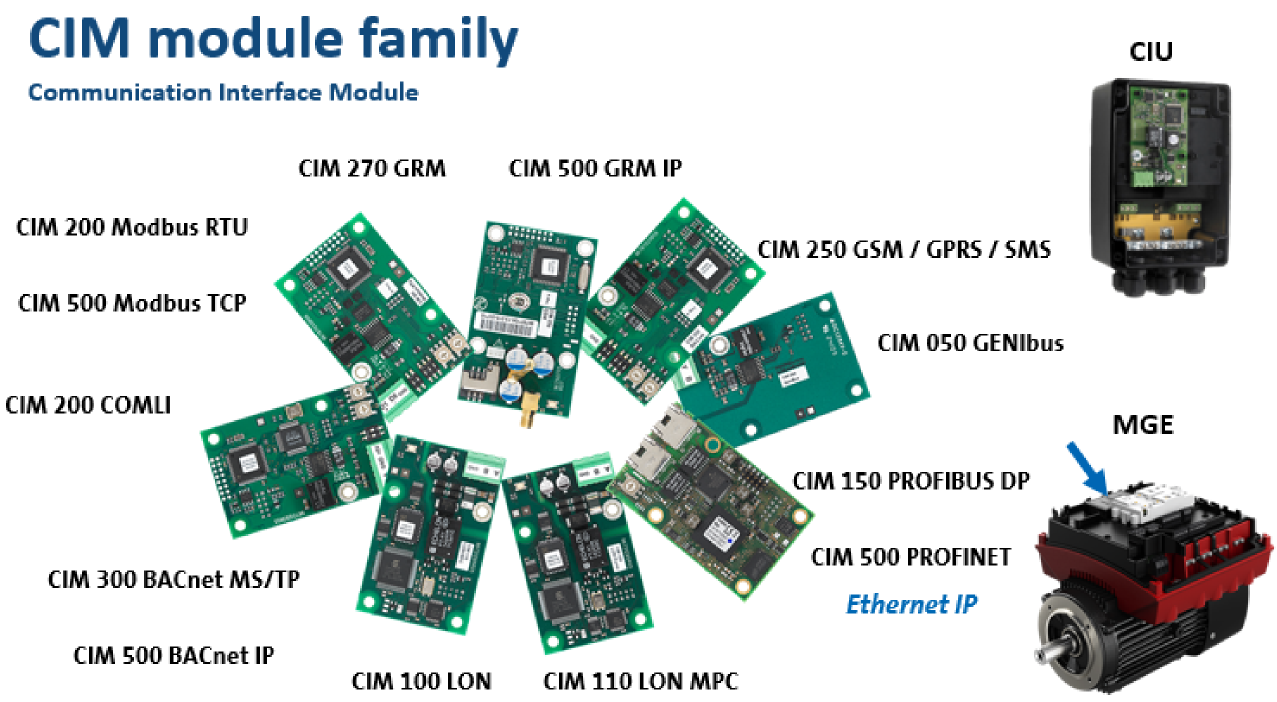
The key to rolling out Digitalization in Industry will be to follow the global standards for connectivity, data storage, availability and legislation and provide easy integration to other systems.
Where Grundfos can make a difference and utilise our proprietary pump and application knowhow is in Remote Control, Optimisation and especially in Fault prediction and Intelligent response.

Having the right products, understanding of customer needs and application knowhow (the cornerstones of Grundfos iSOLUTIONS) combined with Intelligent Connectivity, will secure Grundfos a leading role for years to come.

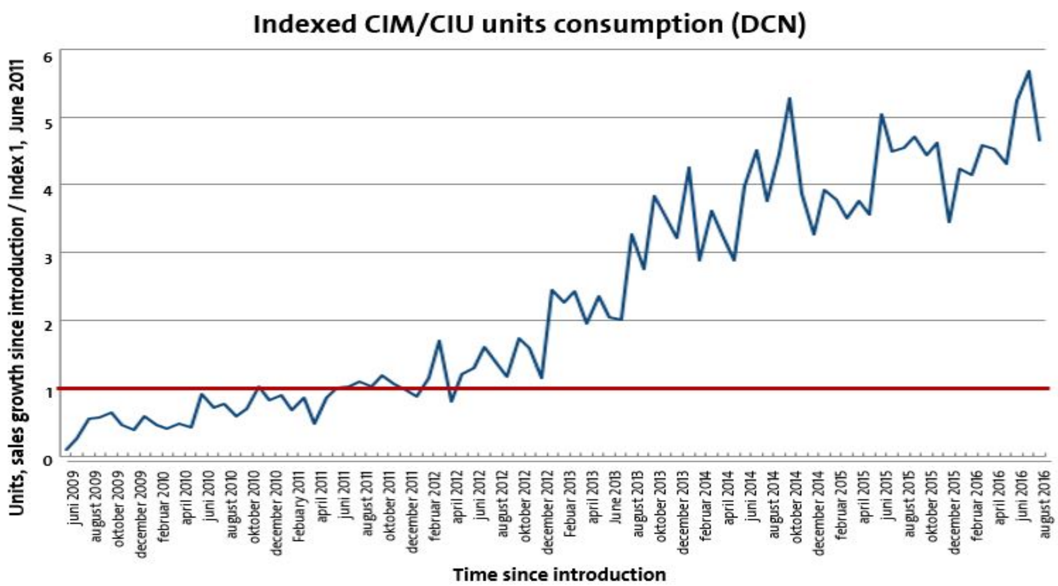
Grundfos Industry Connectivity Products

CIM modules

The basis for connectivity in the industrial environment is our CIM module family, which can connect almost all our E-motors and controls to local SCADA systems via the predominant industrial busses. That means that we can communicate with larger control systems and easily be incorporated in existing and new overall facility and control systems.
The CIM modules can be built into many of our new MGE motors and Controls, or mounted externally in the external CIU box.



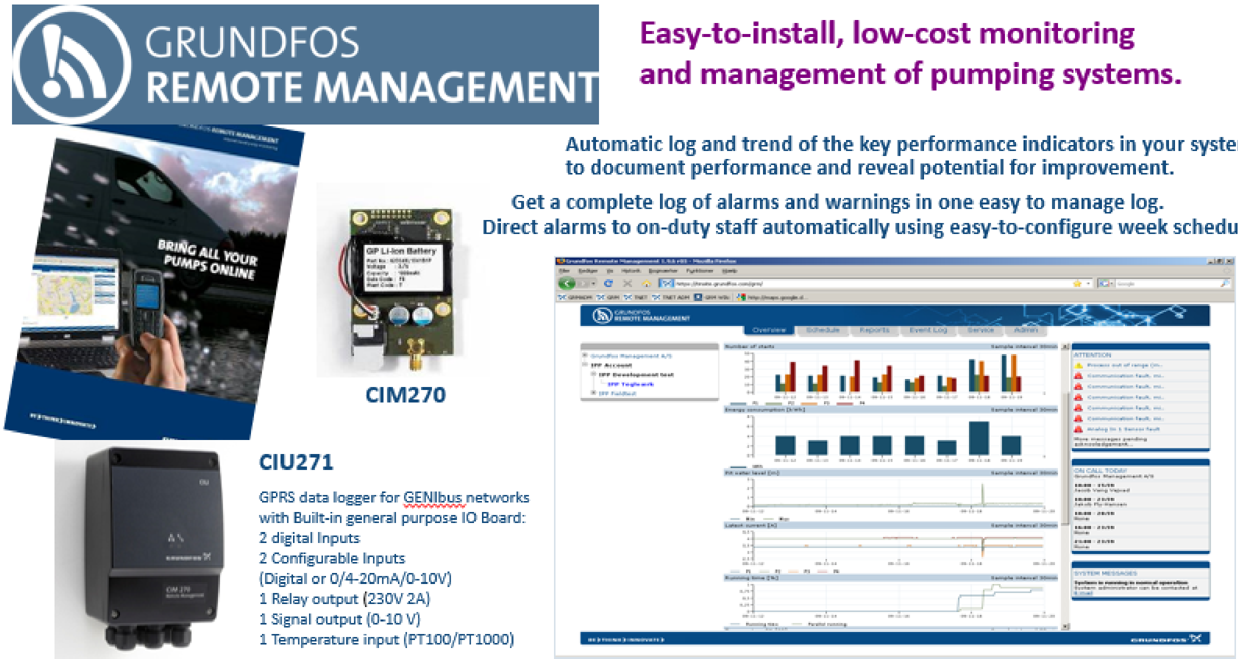
Since the introduction of the CIM/CIU communication modules, we have seen constant growth is sales:



Grundfos Remote Management - GRM

For a decade, Grundfos has been able to offer a cloud based data logging and monitoring service based on the CIM270/CIM271 modules.

This product is primarily targeted towards Grundfos products and end-customers.
GRM has been widely used by water works in remotely installed substations and similar applications.



Last comments

It is of course difficult to predict the future, but with the amount of resources and focus that we are spending on Automation, Connectivity and Digitalization in all areas of consumer and industry development and manufacturing, we can expect a huge impact at all levels.

The speed of product development will increase and product lifetimes will drop.
We will see new products and offerings that emerge quickly while some will vanish or be substituted overnight.

Where ever it takes us, it is essential to focus on what can bring real value to us and the customers and focus more on customer demands than on the new technology opportunities alone.
After all, we are a still Grundfos, the trendsetting pump company. We pump and process water, and if we can do that smarter, we will help our customers to succeed for many years to come.

The end.

APPENDIX

Elements of Digitalization

Data transfer.

On a small scale, data collection is usually done by wired connections. On a larger process and factory scale, data is mainly gathered in local bus systems; however, Wi-Fi and other wireless connections are expected to dominate the factory floor over the coming years.
Data is distributed between different parts of the company through closed and well protected communication lines.
To respond on a global level, it is necessary to share data with other companies and entities, where the data content is restricted to protect our own business or interest.
A lot of free data is available on a global scale, which can be combined with a company's own data and used to set direction, strategies and goals.

Cloud connection.

A big contributor to the fast growth of Digitalization is the development in transfer speed and data storage capability and price. We can expect that in the future all data will be gathered in real-time by a cloud service.

But for now, and in the immediate future, we will need local data processing and autonomous operation for critical equipment simply because of the price and technical limitations in central processing.
Collecting lots of data will be the key to analysis, auto correction, trend development and failure prediction, but crunching large amounts of data in real-time and responding to it immediately will require local computer power. Vibration analysis on a failing ball bearing requires FFT in a dedicated signal processor, which for now has to be local; however, it can compare results or the noise pattern to a cloud based reference.
A practical way to collect data for failure analysis could be to store a 10 second sequence of all relevant data every hour and deliver that to a central data storage facility where changes in operating conditions can be tracked over time, storing a data window 10 seconds before and after any alarm or deviating condition, or just storing data that exceeds certain limits.
That way, we can record and learn damaging patterns and failure mechanisms on equipment and thereby develop prediction algorithms for critical components.

For now, the cloud connections are mainly used to relay operating status, alarms and key operating data as well as simple remote control.
A problem that needs to be solved currently is the ability to remote control; for now it is not possible to push data through the cloud layer, but several companies are working on it.
This could open a world of possibilities for remote service, control and upgrades.

Models.

Data use is usually always based on a model derived from an understanding of how things work or interlink.
The better the model is, and the more precise the data we add to it, the better we can perform.
With a constant pressure controlled pump, the PID controller is a simple model of the system - a good trim of the PID parameters is needed for it to work, and the faster and more precisely we can measure the pressure, the easier it is for the pump to keep the pressure constant. To compensate for external factors, the model can be extended using set point influence or remote measuring.
If we want to control larger systems, we need more complex models with much more data. It takes huge insights to set up the model and gather the right data to succeed - improving a system usually requires more complex models and larger amounts of data, plus increased processing capacity.
Good examples of this are weather forecasts - in the past they were local, often wrong and only forecasted a few days ahead, compared with today where data from around the world is fed into finite

element models and processed on super computers that can predict the weather with much higher precision.

Data and data quality.

To get valuable information on a pump system, we need a model that can calculate the wanted data, and in order for it to work we need to feed it with the right data input.

In order to measure power consumtion, we need corresponding measurements on current and voltage. If we measure flow and pressure before and after the pump, we can calculate the hydraulic output of the system. That enables us to calculate the efficiency of the system using a simple output/input relationship.

This can be measured once a year to determine the figure for kW pr. m^3/h.

We can measure it every hour to get information on its efficiency during load changes.

We can also measure it every second and compare it to the pump's performance data from when it was new, and we now get information on wear-and-tear of the pump system, which can be used for predictive maintenance.

If power consumption is combined with losses in the motor and drive we can calculate shaft power, and shaft power combined with shaft rpm, enables us to distinguish whether the losses are in the pump or in the motor.

This last example opens a lot of opportunities, but the model is useless if we don’t have the measurements at exactly the same time, or if one measurement falls out or is corrupted.

Usually most analysis on pump performance is related to flow, and if we do not have a precise flow measurement, we only have limited possibilities for using gathered data for system optimisation, predictive maintenance and other services.

We can use other data for alarms, warnings and surveillance to protect the system and installation and withdraw valuable information, but this is currently a state-of-the-art feature.

Getting the right data at the right time is essential.

Connectivity.

Digitalization and Industry 4.0 is very much about gathering lots of data and using it in various ways.

Selling data, developing models, selling processed data and related services are areas where many new companies and consultants thrive through digitalization.

The battles of the future will likely be fought around ownership of data and models and what is considered a commodity and embedded in the products and systems, versus what can be sold as extra value.

For industry, we see that data is often considered private property, and it is only in limited amounts that industry allows others manage and use their data. We will be able to sell models and algorithms for incorporation into industrial systems and equipment that are compatible with the system and models – meaning that we can sell the right pumps, sensors and algorithms that deliver the needed data.

In that context, it is important that we can link up to all bus systems, wireless, etc. - whether the data is transferred through the Internet is a secondary point.

IoT – Internet of Things

A lot of the foreseen development in Digitalization and Industry 4.0 is based on free available data, new models, and the new use and combination of data - we have seen interesting examples of that already. However, just having enough data is not creating value - with the right data and the right models, the algorithms can change everything.

Data flow, storage and data security

In Industry 4.0, data and data-flow is essential; however, with higher integration in the supply chain and closer cross border co-operation and globalisation, a series of questions must be addressed. Especially questions regarding:

Who owns the data?

Where is the data stored?

Who has access to data?

These are essential questions, but we also need to answer:

What data should be stored?

How do we get the data?

How often should the data be stored?

Let's have a look at the data and where it is generated.

During the production process, a large amount of data is required. Some data carries the order information, other data is generated through the production including: results from testing equipment and other types of production equipment, data showing that the production is in control, etc. This means that there is an enormous amount of data available.

The way to capture the data in Industry 4.0 is to focus on IoT (Internet of Things), which means that future products must be connected to the Internet.

However, it makes no sense to simply store all available data; It is one thing to store the data needed to control a production, and it is something completely different to store data for analysis later on.

Let's consider an example: running constant pressure in the pump during production. The actual pressure is measured every 2ms and the control acts accordingly; however, it is highly unlikely that an analysis of the production requires data every 2ms- it might be sufficient with data every minute or every 5 to 10 minutes.

The demand for data changes over a production lifecycle. Typically, more data and higher frequency of data is required during the run-in of a production compared to a production that has been running for a long period at a stable rate.

It requires a careful analysis to find the right data and the proper data storage frequency, and to find the keys that connect the different data to each other. What is relevant in one application might not be in another.

The data analytic capabilities within a company or a supply chain are essential when talking about Industry 4.0

Data is just data if not used for anything, the real value lies in applying the analysed data. Analytic skills are critical to Industry 4.0 and companies must work to cultivate these skills in order to succeed.

Analysis of data collection and usage during 2017 reveals that:

- **Half the data in the world was created last year.**
- **Only 5% of the data has been used.**

We will probably soon see new computers like IBM's Watson that can automatically seek, access and process relevant data for new tasks and problems.