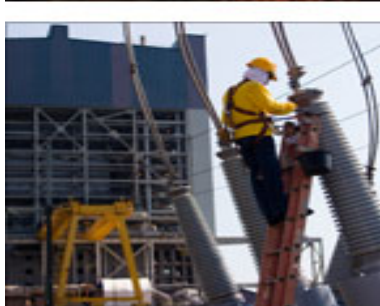


2016

Industry 4.0 and Maintenance



Ruben Ravnå

Per Schjøberg

For: Norsk Forening for Vedlikehold (NFV)

Forward

This document on Industry 4.0 and Maintenance is prepared for Norwegian Maintenance Society (Norsk Forening for Vedlikehold).

The purpose of this document is to introduce the reader to “Industry 4.0” and its consequences for maintenance management. For companies planning to change a factory to benefit from these new ways of manufacturing, reading this booklet will provide important aspects to consider when taking decisions.

Norsk Forening for Vedlikehold

Postboks 73

N-1325 Lysaker, Norway

First Edition

Copyright © 2016 by Norsk Forening for Vedlikehold, Lysaker. Printed in Norway. All right reserved. This book or any parts thereof, may not be reproduced, stored in a retrieval system, or transmitted in any form without the permission of the publisher.

Contents

1	Introduction	2
2	Background	2
2	What is Industry 4.0?	4
2.1	The vision of Industry 4.0.....	4
2.2	Key components of Industry 4.0	5
2.2.1	Cyber Physical Systems (CPS)	5
2.2.2	Internet of Things (IoT).....	5
2.2.3	Internet of Services (IoS)	5
2.2.4	Smart Factory / Factory of the Future	7
2.3	Cyber security	8
3	History of maintenance	8
3.1	Computerized maintenance management system - CMMS.....	9
3.2	Condition monitoring.....	10
4	Maintenance management challenges	11
5	Factors for decision-making	12
5.1	The Industry 4.0 innovation cycle	12
5.2	Small data	13
5.4	New business models	14
6	Summary	16
7	References	16

1 Introduction

The purpose of this document is to introduce the reader to “Industry 4.0” and its consequences for maintenance management. For companies planning to change a factory to benefit from these new ways of manufacturing, reading this booklet will provide important aspects to consider when taking decisions.

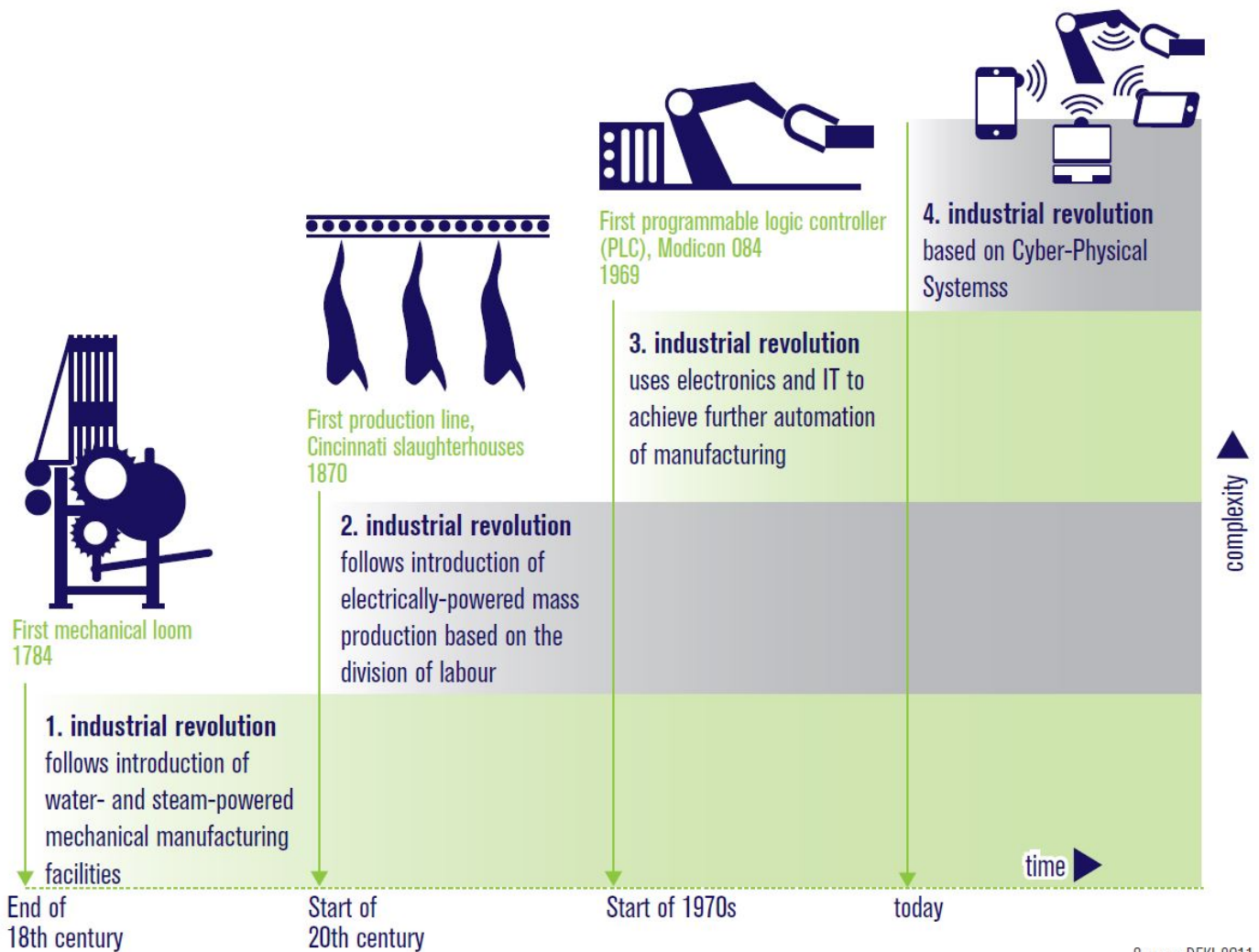
It is now about 45 years since the last industrial revolution, and many new technologies have been introduced into manufacturing environments. A new initiative in research and practice is working to define the parameters of the next revolution. It is important that these parameters also define maintenance planning and asset management for the factory of the future.

2 Background

There have been three notable industrial revolutions through the ages [fig 1]. In 1760 the process of switching from manual work to take advantage of steam-powered machines in production started. Industries that emerged in this period included textiles, chemicals, metallurgy and cement.

The second industrial revolution, also called the technology revolution, began in the 1850's. Several technologies were invented that would facilitate mass-production, beginning with better ways to produce steel for both products and production equipment. The first production line was used in an American slaughterhouse in 1870, but the concept was adopted soon thereafter in other domains as well.

From about 1970, the third industrial revolution began, also called the digital revolution. From the moment the transistor was invented, the technology has become more and more important to the industry. This has led to automated production lines and processing industries controlled primarily by digital technology.



Source: DFKI 2011

Figure 1 - Four stages of Industrial revolutions, [1]

Historians identified each of these revolutions long after their impact and influence on industry and society were observed. However, in 2013 the vision for the next industrial revolution was presented, and named, Industrie 4.0. This is very suitable given the great advances in recent technologies and their potential to improve the manufacturing environments. Without a crystal ball to predict what it means to revolutionize industry for the future, this is still a vision that provides a roadmap for development. Much of the information in this booklet is based on a recent review of articles regarding the implications of Industry 4.0 [2].

2 What is Industry 4.0?

“The next industrial revolution” has emerged from Germany where the government gathered a working group with the intention of formulating the next steps toward the future for factory automation. The result was Industry 4.0, which describes the transition to a “smart” industry. To achieve this, eventually the entire supply chain is accessible and controllable through the internet. This applies to reading sensor values from an individual machine, as well as to communication with the external environment and other assets in the trade. Applied implementation techniques are being discussed and prototyped in the academic community. The only thing that is agreed is that the transition must be adapted to each individual plant and partner. Nevertheless, there are key elements that should be included in every transition to the factory of the future.

2.1 The vision of Industry 4.0

German government and academia have taken the lead in articulating the vision for Industry 4.0 with recommended actions to support the transition. Here is a little snippet from the summary of their announcement [1]:

In the future, businesses will establish global networks that incorporate their machinery, warehousing systems and production facilities in the shape of Cyber-Physical Systems (CPS). In the manufacturing environment, these Cyber-Physical Systems comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently. This facilitates fundamental improvements to the industrial processes involved in manufacturing, engineering, material usage and supply chain and life cycle management. The smart factories that are already beginning to appear employ a completely new approach to production. Smart products are uniquely identifiable, may be located at all times and know

their own history, current status, and alternative routes to achieving their target state.

2.2 Key components of Industry 4.0

To introduce Industry 4.0 in a value chain, there are some concepts that are essential for the transition. Application is highly dependent on the domain and the environment. Here is a brief description of these key components [2].

2.2.1 Cyber Physical Systems (CPS)

A cyber physical system is a system where there is cooperation between a computer system and physical machines [fig 2]. The computer system controls the machine, and in return gets sensor data or other status back.

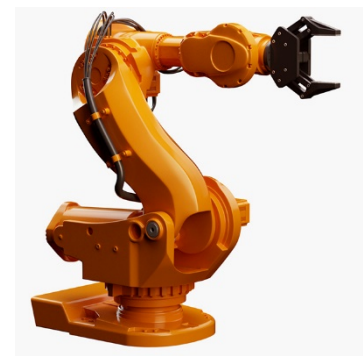


Figure 2 - Example of an industrial robot arm [6]

2.2.2 Internet of Things (IoT)

Internet of Things encapsulates the idea that even the smallest object shall have circuits that allow the sending and receiving of messages over the internet. The introduction of IPv6 protocol in the mid-90s gave opportunities for an “infinite” number of devices to be connected to the internet. This is relevant to industry because far more and smaller units can be embedded in the components of the production systems. This provides accessibility advantages giving systems access to new types of data. This data is not only associated with the production flow, but also information about the environment during production.

2.2.3 Internet of Services (IoS)

Online forecasts of the weather by reputed meteorologists is just one example of a service provided through the internet. The idea behind “Internet of Services” is that a system should be able to go online to use services that are useful in its domain. This requires that services are

developed with a focus on interoperability, i.e. that the service is structured in a way that it can easily be used by other systems. It also requires that the services are open to all, or at least set up with an access system that allows qualified users to use them.

In short, the Internet of Services and Internet of Things are two basic concepts that should be implemented in factories as a precondition for the smart factory of the future [fig 3].

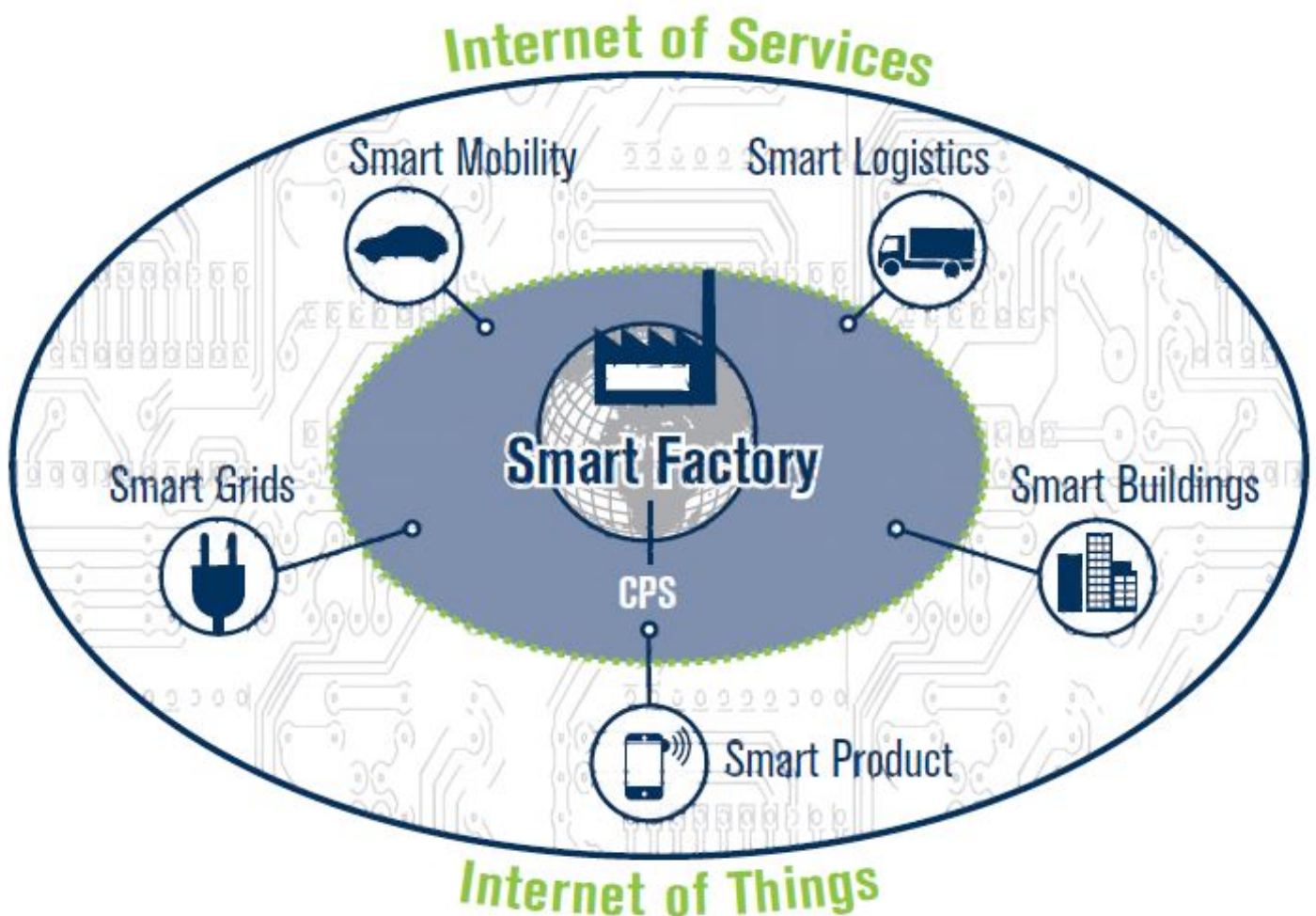


Figure 3 - Smart factory overview [1]

2.2.4 Smart Factory / Factory of the Future

“Smart” factories are one of the goals of Industry 4.0. In today’s industry, IT systems that control production by having control of where products are at all times and starting machines based on the status of the production process are common [fig 4]. One goal of Industry 4.0 is production that is more flexible, for example it will no longer be necessary to produce in large batch sizes to avoid changeover times.

Today

Rigidly sequenced car manufacture on a production line

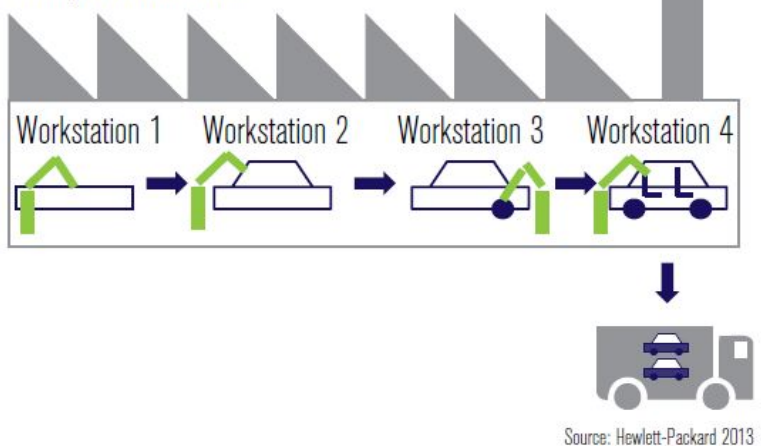


Figure 4 - Illustration of assembly line [1]

The plant will have several workstations [fig 5] and the production system will have control over the status for each product constantly. This will mean that the result of each product does not need to be determined before the final stage of the process. In turn, this can lead to a customer decoupling point as late as possible, and more precise production planning. This strategy can be integrated into the entire resource planning system of a company such that the time from when a customer clicks “order” until the product is

Tomorrow

Decoupled, fully flexible and highly integrated manufacturing systems

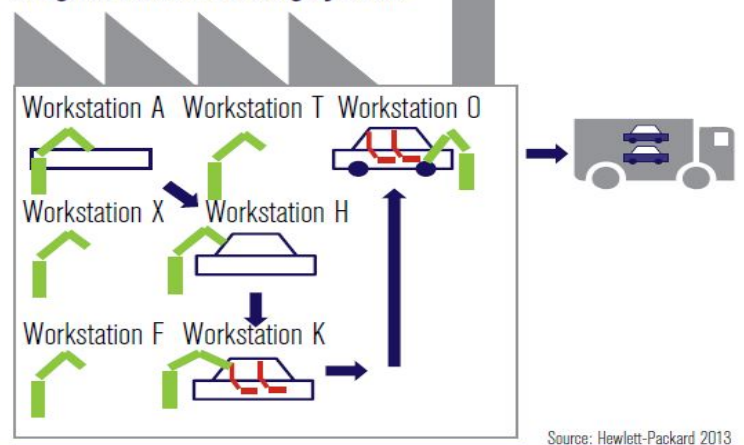


Figure 5 - Assembly line of tomorrow [1]

sent, can be shortened.

2.3 Cyber security

Since more and more components will be connected to the internet and it will be possible to control a machine from anywhere, the risk arises that networked systems are vulnerable to a cyber-security breach [3]. With today's computer systems, it is not enough to have an advanced password to keep people out. Companies should be aware of the consequences and prepare as follows: 1) protection of privacy, 2) protection/integrity of information, and 3) protection of systems/assets. Cyber security experts advise in favor of a system architecture that "hides" vital parts of the system away from the internet. For instance, it can be impossible to access information about a machine from outside the factory, but not necessarily the physical devices themselves. Computers with internet visibility need to have much higher security solutions.

It might be confusing, but internet access to a robot arm is not required when using IoT solutions. IoT mostly emphasizes cheaper and smaller connections to a network. Connection to a local network is sufficient to realize the benefits of Industry 4.0.

3 History of maintenance

Machines in production will always be subject to wear and the need for maintenance [fig 6]. Waiting until a machine stopped or was damaged before initiating a process to find the parts that were damaged and then replace them is called corrective maintenance. Many of the parts that lead to a breakdown are consumables that wear naturally by applied strains. Because of that, it is possible to say something about how long these components last and introduce fixed maintenance intervals.

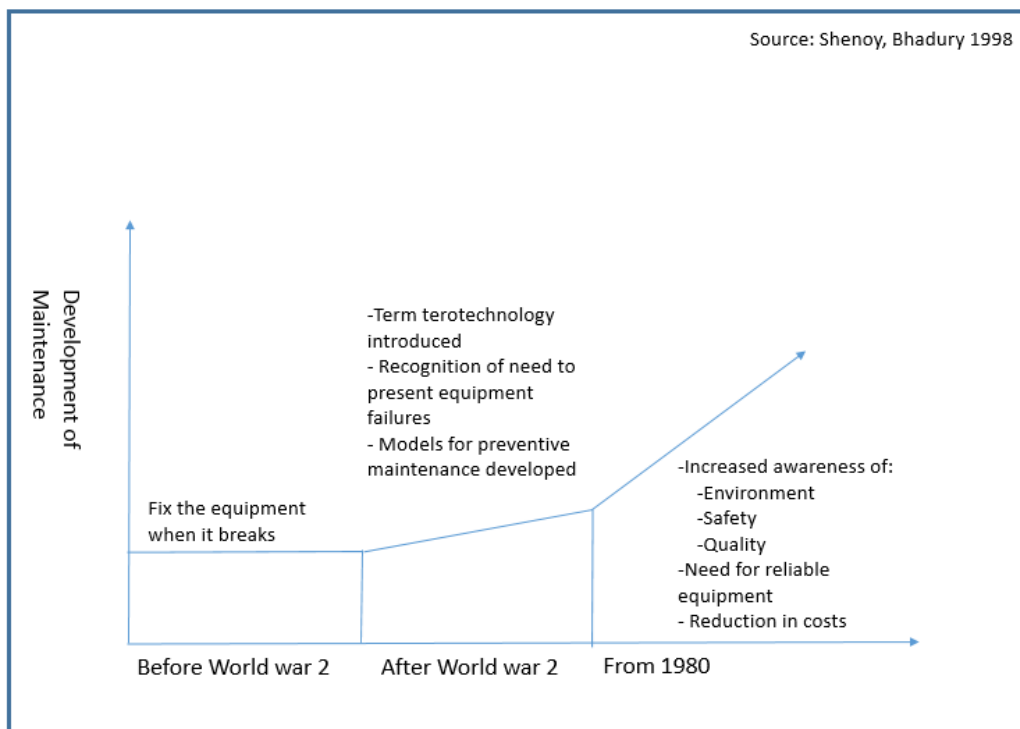


Figure 6 - Graph of trends in maintenance in 20th century

As production in the industry depends on a greater degree of availability to deliver orders on time, it is desirable that machines do not breakdown. At the same time, too much maintenance means extra expenses, resources, and lost production. The aim in recent years has been to introduce a maintenance strategy that can calculate the need for maintenance before a breakdown. Condition based maintenance is such a method, based on measuring the condition of components with technology; for example, use a thermal camera to inspect the effectiveness of a heat sink.

3.1 Computerized maintenance management system - CMMS

Today, it is common to use specialized software to plan a maintenance schedule. This software is called "Computerized Maintenance Management Software" or CMMS. The purpose of this software is to understand how the machines in the factory are set up, and then generate schedules for preventive maintenance. The installation of this software is usually based on recommendations from the manufactures

and experience gained from maintenance logs. CMMS is very useful if a company has many machines to track, but there is the potential to do smarter maintenance planning.

3.2 Condition monitoring

One of the benefits from new technologies is that it is now possible to read the status of a consumable component, such as a gear. Condition monitoring is the process of monitoring a parameter in machinery to identify a significant change that can be interpreted as a sign of a developing fault.

If we combine condition monitoring with CMMS, it gives the computer software more data to make a more accurate plan. One of the new concepts introduced by Industry 4.0 is called Cyber Physical Maintenance Systems. It has the same purpose as CMMS (to plan maintenance operations), but the software will be cyber-connected to the machines so that they can gather sensor data during production and then “sense” the need for maintenance and schedule it.

CMMS solutions today are connected to condition sensors such that the system can request maintenance based on the real status of the components [fig 7]. There are also systems that log conditions from manual condition inspections, but systems connected to sensors can save a lot of human effort and may be more reliable.

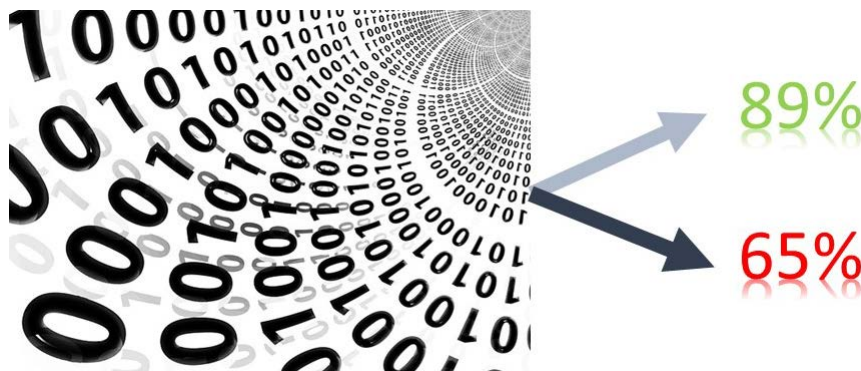


Figure 7 - Analyzing data into meaningful small data

4 Maintenance management challenges

Balancing maintenance management with the production schedule and quality is the biggest challenge. Today, it is estimated that firms are doing one-third too much maintenance [4]. While there are some justifications for doing early maintenance, more often the maintenance operation can be postponed with more precise information about the component.

Alongside technological updates, the factory of the future will require companies to **restructure their organizations** away from disparate silos of production and maintenance and see the respective operations as two sides of the same goal to achieve profitable sustainable manufacturing.

Big data has been described as the next frontier for innovation, competition, and productivity. Technological advances have supported the indiscriminate collection of data without prior consideration of its relevance or usefulness. As an example of this, a process plant that stores a parameter every second (perhaps more often) to control the process generates 31.536.000 values from just one sensor in one year. While there is little benefit in looking at every value individually, **patterns and trends** may emerge from analysis of these figures that may be useful for several applications.

Production systems already collect data from machines used to control the processes in the production. This data may be used in real-time, and then archived. **Data mining and other analysis methods** can access this data such that it can be used to develop indicators for maintenance software, or give smarter feedback to the production workers.

The potential of the internet of things and access to more data from production systems introduces the possibility of more intelligent maintenance scheduling combined with zero-defect manufacturing.

5 Factors for decision-making

If the primary goal regarding maintenance is that neither too much nor too little maintenance should be performed, at the same time, the middle road is very hard to find. This raises questions regarding how Industry 4.0 will help to optimize maintenance planning.

Industry 4.0 is very extensive and includes measurements that span the entire value chain for a product, from the IoT at the factory floor level to smart industries at the top. These changes will not occur overnight!

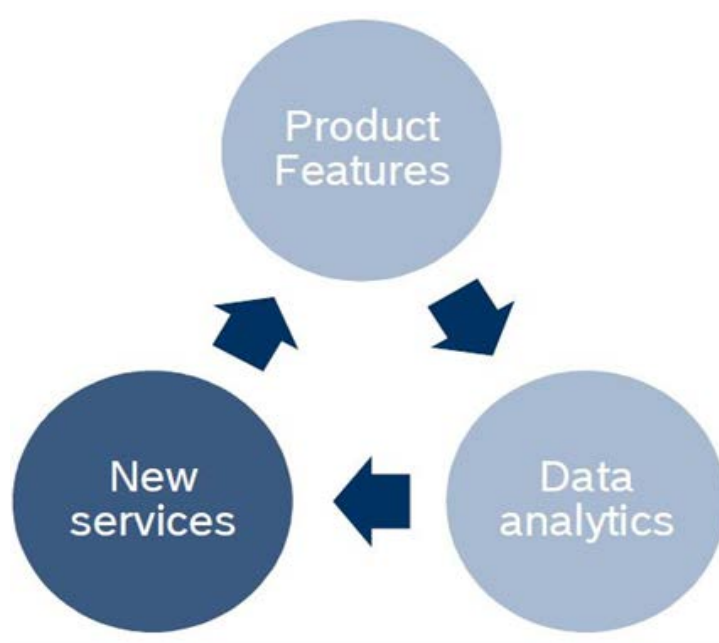


Figure 8 - Innovation cycle [4]

5.1 The Industry 4.0 innovation cycle

For most companies, the challenge will be to look at what they already have and then, make adjustments to take advantage of these concepts. One way to do this by using the Industry 4.0 Innovation Cycle from Bosch Software Innovations [5] [fig 8].

Product features phase: The purpose of this phase is to equip the products (machines and components) with Industry 4.0 features such that the product itself is able to generate data relating to its status and

operation, to process this data on a product level, and to take any necessary action.

Data analytics phase: The purpose of this phase is to glean new insights from the accumulated data by applying data analytics on the data stream that is created by all the connected items. This provides a useful basis to assist in developing new services.

New services phase: The goal of this phase is to introduce new, useful services. The knowledge acquired in the previous phase can be used to derive new services for customers. This can for instance be a live KPI monitor to give workers or management useful insight. The service can also provide vital data to other machine processes that previously needed that data from a human worker.

5.2 Small data

Smarter systems are needed to be able to use all the new information collected from the network of systems. There is a great unrealized potential to use some of the data that is just stored, but could contribute to the creation of meaningful dashboards and other views. These smarter systems will be a cyber physical computer system, because they will have more information on the physical status in the production environment.

When collecting large amounts of data, it is also very important to use the data in a way that returns useful information in the form of graphs or dashboards with colored numbers. The ultimate goal here is to convert big data into small data.

Some companies have already worked to achieve systems that provide meaningful dashboards for the human decision maker. In the context of maintenance planning, one very useful attribute is remaining useful life. This can be shown as remaining useful cycles and then the software can give much more accurate recommendation on when to perform maintenance.

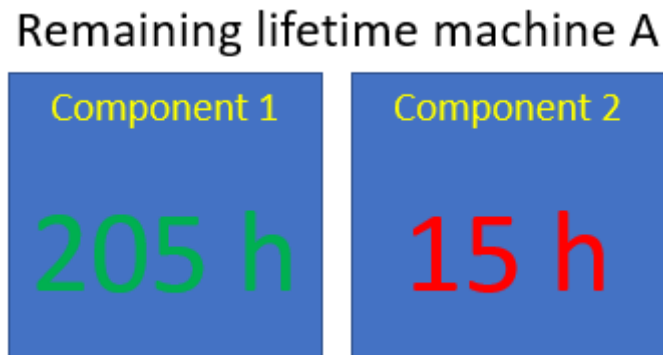


Figure 9 - Visual view of health

This is an example [fig 9] of part of a dashboard with simple and clear texts, big fonts and a color that indicates the urgency of the number. Many calculations are done behind the scenes and reduced to these two numbers that can provide valuable input to the maintenance crew as they plan the maintenance operations.

5.3 New business models

Implementing Industry 4.0 creates the possibility for new services and new business models. Bosch Software Innovations took a deeper look into how predictive maintenance can create new business models by implementing IoT into machines [5] [fig 10] and visualized the assessment in the “Magic triangle”. This model describes four different aspects of predictive maintenance; who, what, how and revenue.

What is predictive maintenance? It is a strategy for determining exactly when maintenance is needed, so we do not perform too much or too little maintenance. This leads to minimized downtime, minimized resource consumption and optimized maintenance services.

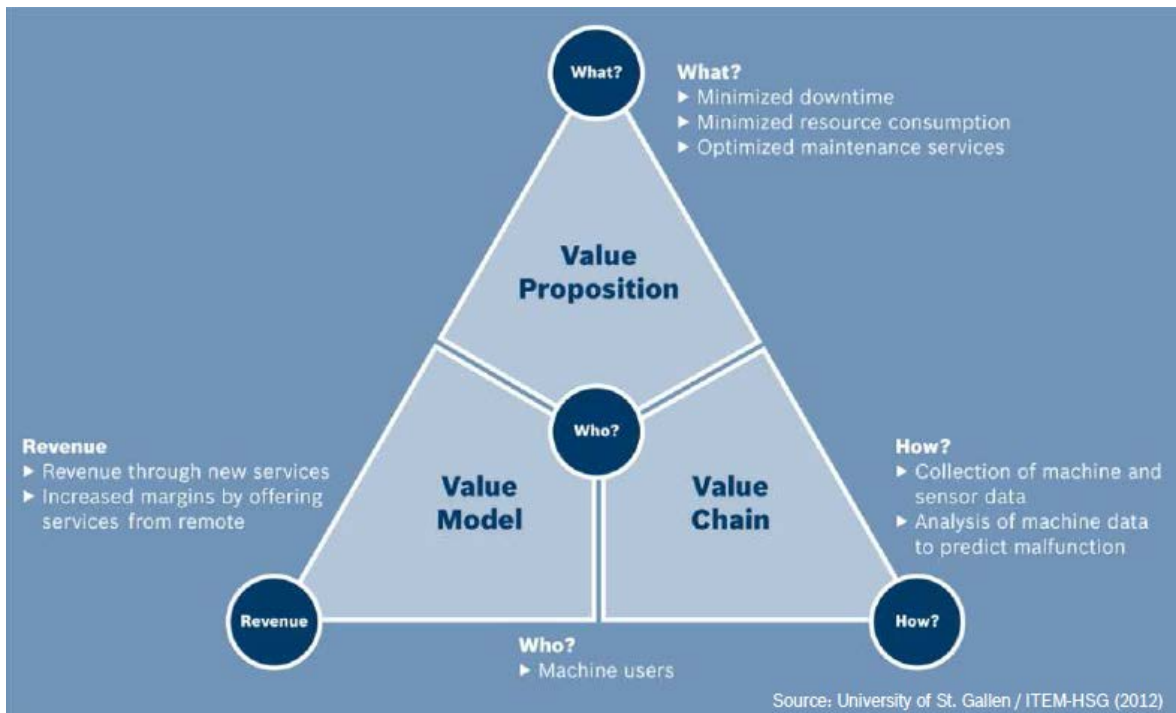


Figure 10 - Magic triangle illustration of Predictive maintenance implementation

How is it done? Predictive maintenance is complex, but when we attach sensors to the right places in the machine, we can log and analyze condition data, make a suitable model and then predict malfunction.

What is the **revenue** of this strategy? The implementation requires some investments at the start, but less downtime and maintenance at the right time saves money in the long run. The machine manufacturer can also offer this maintenance insight as a new service, which gives their product more value by saving some effort for the users.

Who is using this strategy? This affects mostly machine users and the maintenance crew, but if the machine manufacturer has the responsibility to collect and analyze the data, they will also be responsible for managing the maintenance activities.

6 Summary

In a time with hard competition in the different industries, it is very important to have as effective and efficient production as possible. The maintenance management is very important to avoid unexpected downtime and late deliveries. When working towards Industry 4.0, we start by implementing more sensors, which provides valuable data. This data can be analyzed to provide insights that can be a basis for better maintenance planning. Data analysis can also spot deviations in production, which can prevent the release of defective products in an early stage.

For established companies, it will be expensive to change the whole infrastructure, but they can also benefit from having a trade study of their current systems, to check what can be improved. For new factories, it will be obvious to take Industry 4.0 seriously from the start.

7 References

- [1] H. Kagermann, W. Wahlster and J. Helbig, "Recommendations for implementing the strategic initiative INDUSTRIE 4.0," Forschungsunion, acatech, 2013.
- [2] M. Hernabb, T. Pentek and B. Otto , "Design Principles for Industrie 4.0 Scenarios: A Literature Review," *Working Paper*, 2015.
- [3] B. y. T. K. Hans-Christian Pfohl, "The impact of industry 4.0 on the supply chain," *Innovations and strategies for logistics and supply chain*, 2015.
- [4] P. Schjøberg, "NFV," 8 January 2016. [Online]. Available: http://www.nfv.no/fileadmin/Filer_kursdokumentasjon/2016/Moderne_Vedlikehold/1_-_Moderne_Vedlikehold_2016.pdf. [Accessed 23 January 2016].
- [5] Bosch Software Innovations, "Industrial Internet: Putting the vision into practice," 2015.
- [6] "behanche.net," [Online]. Available: https://mir-s3-cdn-cf.behance.net/project_modules/disp/076b9f12309585.562664aec2543.jpg. [Accessed 23 January 2016].



Postboks 73

N - 1325 Lysaker

Telefon: +47 67 52 60 10

www.nfv.no