I. Preface

This report is submitted in partial fulfilment of the requirements for the award of an MSc degree in the further-education program: Railway. The thesis was carried out during the spring semester of 2019, at the same time I had full-time job in Multiconsult.

The master thesis came as a result of an idea between Per Schjølberg and the undersigned. We discussed two alternatives for the master's thesis. These two were:

- Smart maintenance railway infrastructure in China
- Smart maintenance railway infrastructure in Norway

I was inspired to pursue this project topic in the course of commuted. I lived in Jessheim and my office is in Skøyen in Oslo, which has 50 kilometer distance between. I commuted between home and office by train daily. Delayed train or cancelled train was always big issuer for the people who commuted in Oslo area in the last years. The reason for delayed train or cancelled train was often due to railway infrastructure which means the infrastructure needs immediate corrective maintenance. What is maintenance strategy in Bane NOR and how it is affected the punctuality was very interesting to me. Then I decide to do some research and find out.

I would like to thank Multiconsult, former Heat of Railway Unit Tone Manum and Heat of Railway Unit Håkon Bratlien for giving me this opportunity to take this master's degree in railway engineering. The Master's program has given me many new impulses and a lot of professional refills.

I would also like to thank Per Schjølberg (SINTEF and NTNU) and external supervisor Anna Gjerstad (Bane NOR) for very good guidance. I would also like to thank Hogne Dufseth (Muticonsult) who released me from many assignments and that gave me the opportunity to write my master's thesis.

Finally, I would like to thank my family in particular, they have been my biggest motivators and supported me throughout this three and half year period that Master's program.

Oslo, 14.October.2019

Huihong Zhu

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V. Definitions

BaneData: Bane NOR`s infrastructure base for all infrastructure information and maintenance management tools.

Degradation: Detrimental change in physical condition, with time, use or external cause.

Dependability: The collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance.

Down time: Time interval throughout which an item is in a down state.

Failure: Termination of the ability of an item to perform a required function.

Failure cause: Circumstances during specification, design, manufacture, installation, use or maintenance that result in failure.

Failure mode: Manner in which the inability of an item to perform a required function occurs.

Failure mechanism: The physical, chemical or other process which has led to a failure.

Fault: State of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources.

Industry 4.0: Fourth industrial revolution.

IoT (Internet of Things): Is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

Life cycle: Series of stages through which an item goes, from its conception to disposal.

LCC (Life cycle cost): All of the costs generated during the life cycle of the item.

Machine learning: Is the scientific study of algorithms and statistical models that computer systems use to perform a specific task without using explicit instructions, relying on patterns and inference instead.

Maintenance: Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function.

Maintenance ability: The ability of a maintenance organization, under given conditions, to plan, organize, perform and control its maintenance tasks.

Maintenance engineering: engineering discipline developing and applying methods, tools and techniques to influence design and to assure that an item is in a state in which it can perform required functions in a safe, sustainable and cost-effective manner.

Maintenance level: Maintenance task categorization by complexity.

Maintenance management: All activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics.

Maintenance objective: Target assigned and accepted for the maintenance activities.

Maintenance strategy: Management method used in order to achieve the maintenance objectives.

OEE: **O**riginal **E**quipment **E**ffectiveness.

On time: For short-distance trains arrival at the terminal station within a margin of three minutes and 59 seconds. For long-distance trains and freight train, this margin is five minutes and 59 seconds.

Punctuality: The number of train on time at the terminal station.

RAMS: **R**eliability, **A**vailability, **M**aintainability and **S**afety.

RCM: **R**eliability **C**entered **M**aintenance.

Reliability: The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.

Required function: A function or a combination of functions of an item which is considered necessary to provide a given service.

Switch (turnout or points): Is a mechanical installation enabling railway trains to be guided from one track to another.

Switch motor (point machine): Is an electric, hydraulic or pneumatic mechanism that aligns the points with one of the possible routes.

Turnover: Is the net turnover of a company or a plant including deliveries for other plants of the company and production for own use.

WCM: **W**orld **C**lass **M**aintenance.

1. Summary

Railway infrastructure maintenance is complicated to organize and has numerous challenging planning problems and consumes very large budgets. The European countries are reported to allocate 25 billion EUR annually on maintenance and renewals for a railway system (Figure 1 and 2). There is however an inherent conflict in deciding how to assign maintenance work slots and train operation paths since these activities are mutually exclusive. This planning conflict becomes crucial on lines with high traffic density and especially when network traffic demand and maintenance needs are increasing.

The Norwegian government's vision for an active industrial policy is: Norway will be a leading industrial and technology nation. This means that we must invest greener, smarter and more innovative to provide future growth, jobs and tax revenues. The Government will facilitate growth in both existing and new companies and promote Norway as an attractive location for industrial activity. Stable economic development and a weak krone are important for new growth in competitive business, and this is taken into account by the government in the formulation of economic policy. (Meld.St (2017))

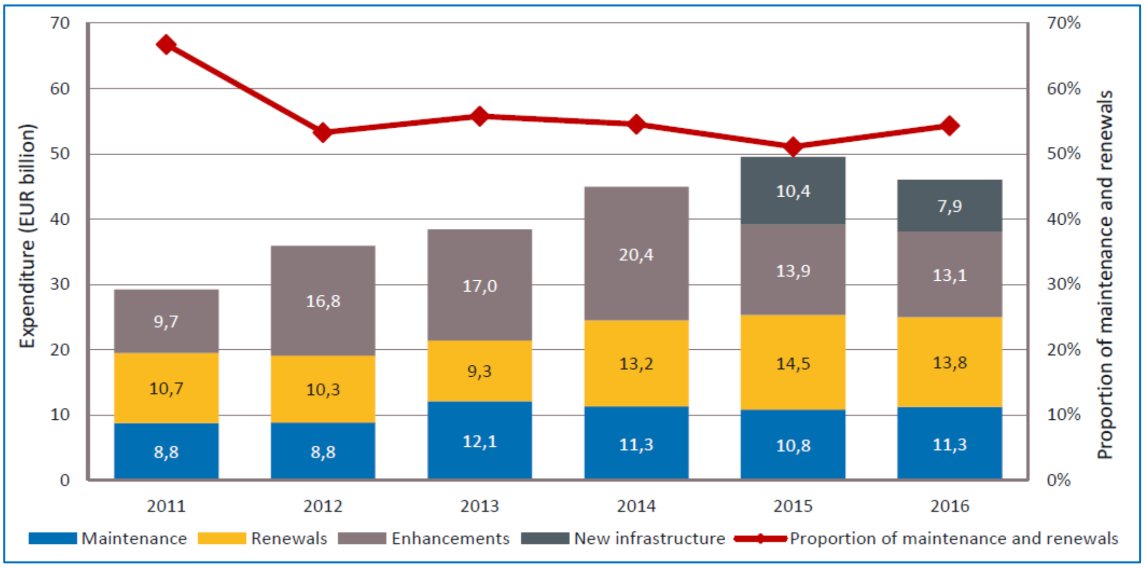

Figure 1: Expenditure on infrastructure and proportion on maintenance and renewals, 2011-2016. (Source: European Commission (2019))

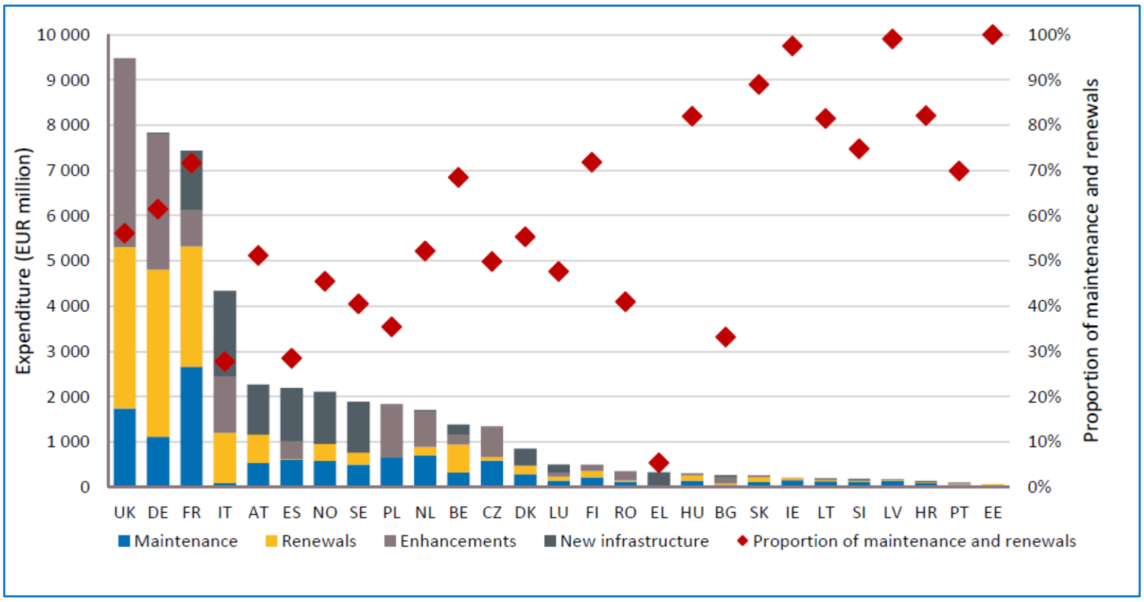

Figure 2: Expenditure on infrastructure and proportion on maintenance and renewals per country, 2016. (Source: *European Commission (2019)*)

Sensor technology

Smart use of sensor technology can also reduce machine downtime, increase maintenance efficiency, and save energy. The digital factory can shorten the planning time and enable seamless integration between design, product development and production - even without the various activities having to be co-located.

The industrial concept also includes assembly of parts for finished products, waste recycling, specialized maintenance and repair of products, industrial machinery and installation of industrial machinery and equipment.

With the development of sensor technologies, the maintenances for many complex systems involve more and more condition-based and preventive activities to reduce maintenance costs on one hand, and improve their performance on the other hand. (Liu et al. (2017)).

Keywords: Smart maintenance, predictive maintenance, maintenance strategy, switch monitoring and punctuality.

2. Introduction

Railway infrastructure maintenance and renewal is fundamentally important for passengers and freight carriers to experience a more punctual and reliable railway infrastructure. As we approach the 4th industrial revolution, the situation becomes more challenges.

2.1 Background

The railway is a widely recognized mode of transport, particularly in the Oslo area, and is a key component of integrated transport system today and in future. The transportation capacity of railways has lagged behind the growth of transportation demand for a long time, and the long delay in railway infrastructure maintenance is a very big challenge for railway systems. The scientific management of infrastructure maintenance and repair can guarantee transportation safety and economic interests. Establishing a reasonable maintenance plan is an effective way to solve the contradiction between transportation and maintenance and save costs.

The main railway network consists of 4,200 km of lines, which 2,622 km is electrified and 270 km is double track, 60 km high-speed rail in Norway (Figure 3). The Norwegian Railway Directorate manages the railway network in Norway on behalf the Ministry of Transport and Communications. Bane NOR is a state enterprise which builds and maintains all railway tracks.

Figure 3: The national rail network in Norway (Source: Banenor.no (2019))

Oslo Central Station (Oslo S) is the main railway station in Oslo, and the largest railway station in Norway. Railways in the Oslo area were built over several line and over a long period of time. The Trunk Line (Hovedbanen: between Oslo S and Eidsvoll) was opened in 1854 and rebuilt double track in 1902. The Drammen Line (Drammenbanen: between Oslo and Drammen) was opened in 1872 and has double track today. The Østfold Line (Østfoldbanen, runs from Oslo through the western parts of Follo and Østfold to Kornsjø) was opened in 1879 and the northern half is double track. The Gjøvik Line (Gjøvikbanen: between Oslo and Gjøvik) was opened in 1902 and only single track. The Gardermonen Line (Gardermobanen: between Oslo and Eidsvoll) was opened in 1998 and is a high-speed railway line. (Figure 4)

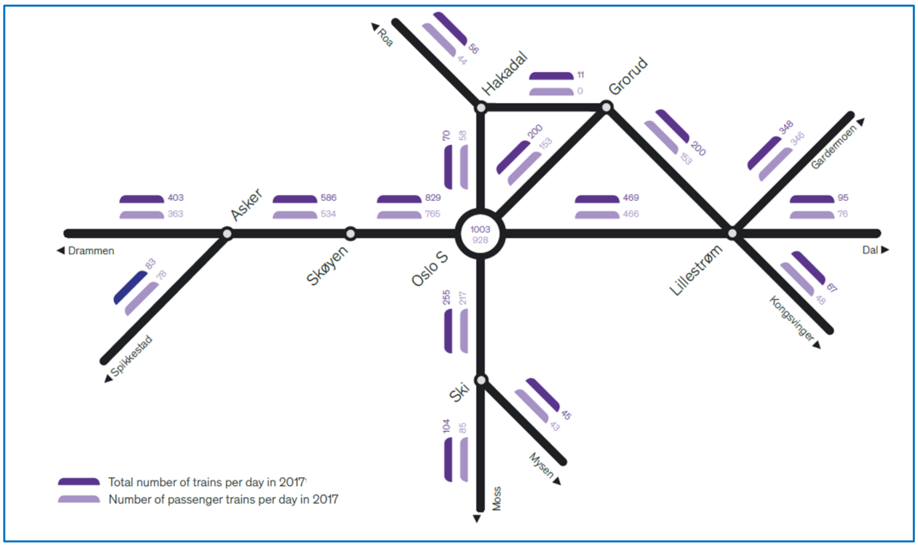

Figure 4: Railway infrastructure system in Oslo area. (Source: Railway Statistics (2017))

Railway infrastructure maintenance is crucial importance in order to obtain a well-functioning transportation system. Railway infrastructure require a wide range of equipment and special facilities for storage and maintenance, which on their side need regular maintenance interventions as well. The actual maintenance work consists of a large amount of different activities, requiring considerable resources and large budgets. Some of the equipment include superstructure, substructure, drainage, tunnel, bridge, overhead wire, railway power generation, power transmission and signal (Figure 5).

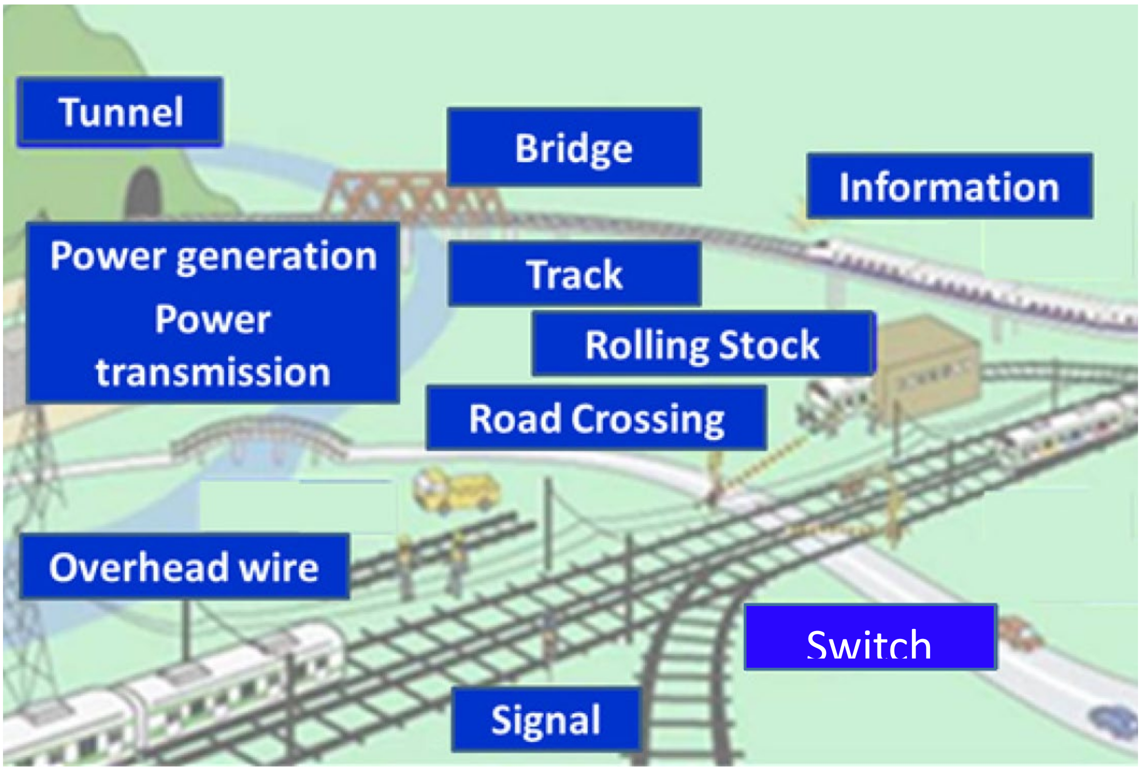

Figure 5: Railway facilities. (Source: Atsushi Yokoyamaa (2015))

The challenge is the trains run at few minutes intervals from early in morning to late at night, especially we have lots of single track out of Oslo region and weather condition is a big issue in winter season. And the time between each train is reduced to a minimum. All maintenance must be done at night. That make difficult to operate and manage the maintenance activity efficiently without interrupting train service. Predictive maintenance of railway infrastructure is a god way to solve the problem.

Predictive maintenance of infrastructure" tackling the challenge of infrastructure managers" cost reductions, it will rely on the digitalization of control, supervision and management of infrastructure components (switch points, Point heating, track field, rolling stock, train detection systems…) via a large scale adoption of remote wireless connected sensors (IoT) for detecting temperatures, pressures, vibrations, security alerts in critical points and in real-time, automatic collection and organization of all those trackside sensors' data, immediate analysis by automatic systems based on Artificial Intelligence(AI).

2.2 Objectives

The main objective of this master thesis is to present maintenance strategy and how predictive maintenance has been used today in Bane NOR.

The main objective is achieved by performing the following tasks which form part of the thesis sub-objectives:

1. Identify and clarify the main maintenance philosophies applied to Railway infrastructure.
2. Identify and clarify the maintenance organization, strategy and process in Bane NOR.
3. Provide a case study to justify the utilization of condition monitoring on critical assets as a means to contribute increase punctuality.
4. Identify and present possible approaches and the benefits to achieve smart maintenance.

2.3 Approach

The following methods are used to chart, document and systematize the task, with the intention of trying to come up with a good maintenance strategy.

2.3.1 Interview

Interview of head of "Smart Maintenance" unit Anna Gjerstad in Bane NOR has been carried out ongoing project by smart maintenance, organization of project and cooperation in Bane NOR.

2.3.2 Literature search

Literature searches have been carried out in many documents. These are documents that deals with maintenance planning, requirements for carrying out maintenance and governing documents for railway operations in Norway. These documents are Railway Statistics (2017), The manual for maintenance (STY-601058 (2011) in Bane NOR and presentation of Punctuality Seminar. In addition, internet, "NTNU Oria" and "Google Scholar" have been extensively used, see also the reference list page IX.

The Smart maintenance is a new and evolving paradigm, literature in the area was scarce and hard to find. Documentary "China's Mega Project" and "Chinese High speed Railway" from CCTV are also used.

2.4 Structure Of The Report

The report is organized as follows:

1. Summary: Overview of thesis.
2. Introduction: Presentation of the background for the thesis and description of research questions, objectives and approach of the assignment.
3. Theory: Description and presentation of the various theories. Presentation and review of the various theories has been used in Bane NOR.
4. Method: Description of maintenance, strategy, process in Bane NOR and case study.
5. Discussion and conclusion: Conclusion of results and discussions in the thesis.
6. Further Work: Description how the conclusions of this thesis can be implemented in future work.

3. Theory

This chapter provides an overview of theories used in this thesis on the topics of maintenance. This includes definition of maintenance, definition of maintenance in Bane NOR, and including advantages and disadvantages of difference maintenance.

3.1 Industry 4.0

Industry 4.0 connects embedded system production technologies and smart production processes to pave the way to a new technological age which will radically transform industry and production value chains and business models." (Germany Trade and Invest)

Industry 4.0 refers to a forth industrial revolution after the invention of the steam machine and the mechanization of manual work in the 18th, the emergence of mass production in the 19th and manufacturing automation through computer technology in the 20th century.

Figure 6 shows four industrial revolution.

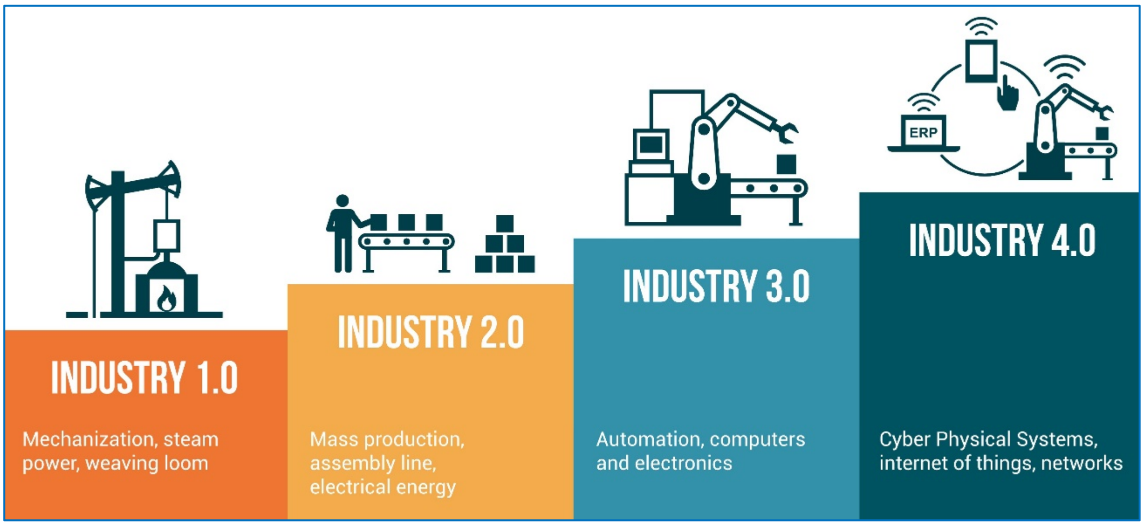

Figure 6: Industry 4.0 as fourth industrial revolution. (Source: Elenabsl, "Industrial revolution stages from steam power to cyber physical systems, automation and internet of things").

Industry 4.0 is an indication of the effects of the 4th industrial revolution in industry, production and value chains, where digitalization and integration are key concepts.

The first industrial revolution was about using mechanics, steam and other things to streamline work processes. The second industrial revolution was about increasing productivity in the form of electricity, mass production etc. The third industrial revolution was primarily about automating individual processes using mechanical installations and more computing power.

This concept first appeared in Germany, officially launched at the Hannover Messe in 2011 whose core purpose is to improve the competitiveness of German industry, taking the lead in the new round of industrial revolution. Subsequently, the German government listed one of the ten future projects proposed in the German 2020 High Technology Strategy. The project is jointly funded by the German Federal Ministry of Education and Research and the Federal Ministry of Economics and Technology, with an estimated investment of 200 million euros. Designed to enhance the intelligence of manufacturing, build smart factories with adaptability, resource efficiency and genetic engineering, and integrate customers and business partners in business processes and value processes. Its technical basis is the network entity system and the Internet of Things.

The so-called industry 4.0 in Germany refers to the use of the Cyber-Physical System (CPS) to digitize, intelligentize, and ultimately supply to manufacturing, sell production information, finally achieve fast, efficient and personalized product supply.

Industry 4.0 represents more of an evolution than a revolution and represents a next step for businesses that have already extracted major impacts through lean, continuous improvement etc. Through digitalization of products and services, as well as technological integration both horizontally and vertically in the value chain to bring out the next level of cost-effectiveness and increased productivity, as well as create new business models and customer platforms.

Fourth industrial revolution has emerged in the past few decades, known as Industry 4.0. Industry 4.0 takes the emphasis on digital technology from recent decades to a whole new level with the help of interconnectivity through the Internet of Things (IoT), access to real time data, and the introduction of cyber-physical systems. Industry 4.0 offers a more comprehensive, interlinked, and holistic approach to manufacturing. It connects physical with digital, and allows for better collaboration and access across departments, partners, vendors, product, and people. Industry 4.0 empowers business owners to better control and understand every aspect of their operation, and allows them to leverage instant data to boost productivity, improve processes, and drive growth.

Industry 4.0 solutions give businesses greater insight, control, and data visibility across their entire supply chain. By leveraging supply chain management capabilities, companies can deliver products and services to market faster, cheaper, and with better quality to gain an advantage over less-efficient competitors.

Industry 4.0 solutions give manufacturers the ability to predict when potential problems are going to arise before they actually happen. Preventive maintenance happens based on routine or time Without IoT systems. In other words, it’s a manual task. With IoT systems in place, preventive maintenance is much more automated and streamlined. Systems can sense when problems are arising or machinery needs to be fixed, and can empower you to solve potential issues before they become bigger problems. Predictive maintenance analytics allow companies to not just ask reactive questions. Figure 7 shows typical questions from predictive maintenance analytic. This analytics can enable manufacturers to pivot from preventive maintenance to predictive maintenance.

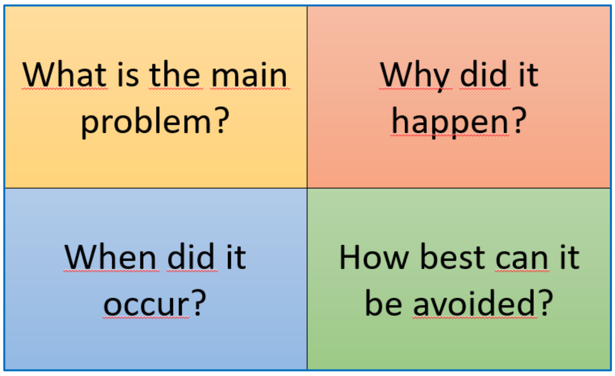

Figure 7: Predictive maintenance analytics.

Figure 8 shows technologies for industry 4.0.

Figure 8: Technologies for industry 4.0. (Source: adobe Stock)

The cooperation between Germany "Industry 4.0" and "Made in China 2025"has been long-standing.

Made in China 2025: is a strategic plan of China issued by Chinese Premier Li Keqiang and his cabinet in May 2015.

China aims to move away from being the world's "factory" (producing cheap, low quality goods due to lower labour costs) and move to producing higher value products and services. It is in essence a blueprint to upgrade the manufacturing capabilities of Chinese industries. (www.miit.gov.cn and http://www.gov.cn/zhuanti/2016/MadeinChina2025-plan/mobile.htm)

The plan lists 10 key industry sector:

- Information Technology
- Robotics
- Green energy and green vehicles
- Green energy and green vehicles
- Ocean engineering and high tech ships
- Railway equipment
- Power equipment
- New materials
- Medicine and medical devices
- Agriculture machinery

3.2 Big data

In 2001, industry analyst Doug Laney articulated the mainstream definition of big data as the three Vs of big data: volume, velocity and variety. (Figure 9)

Volume: The quantity of generated and stored data. The size of the data determines the value and potential insight, and whether it can be considered big data or not.

Velocity: In this context, the speed at which the data is generated and processed to meet the demands and challenges that lie in the path of growth and development. Big data is often available in real-time. Compared to small data, big data are produced more continually. Two kinds of velocity related to big data are the frequency of generation and the frequency of handling, recording, and publishing.

Variety: The type and nature of the data. This helps people who analyze it to effectively use the resulting insight. Big data draws from text, images, audio, video; plus it completes missing pieces through data fusion.

Big data can be described by the following additional characteristics:

Variability: It refers to data whose value or other characteristics are shifting in relation to the context they are being generated.

Value: Rational use of big data to create high value at low cost.

Veracity: The quality of the data.

Complexity: A huge amount of data, source multiple channels.

Figure 9: Illustration of Big Data. (Source: Data Science)

3.3 Definition Of Maintenance

Maintenances are described as ensuring that the equipment achieves the desired functionality with current international standards. A combination of all technical and management activities taken to maintain, restore, and improve equipment status throughout the lifecycle.

The maintenance terminology standard (EN-13306 (2010)) defines maintenance as "combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function". Maintenance is about preserving the functions of physical assets. (Figure 10)

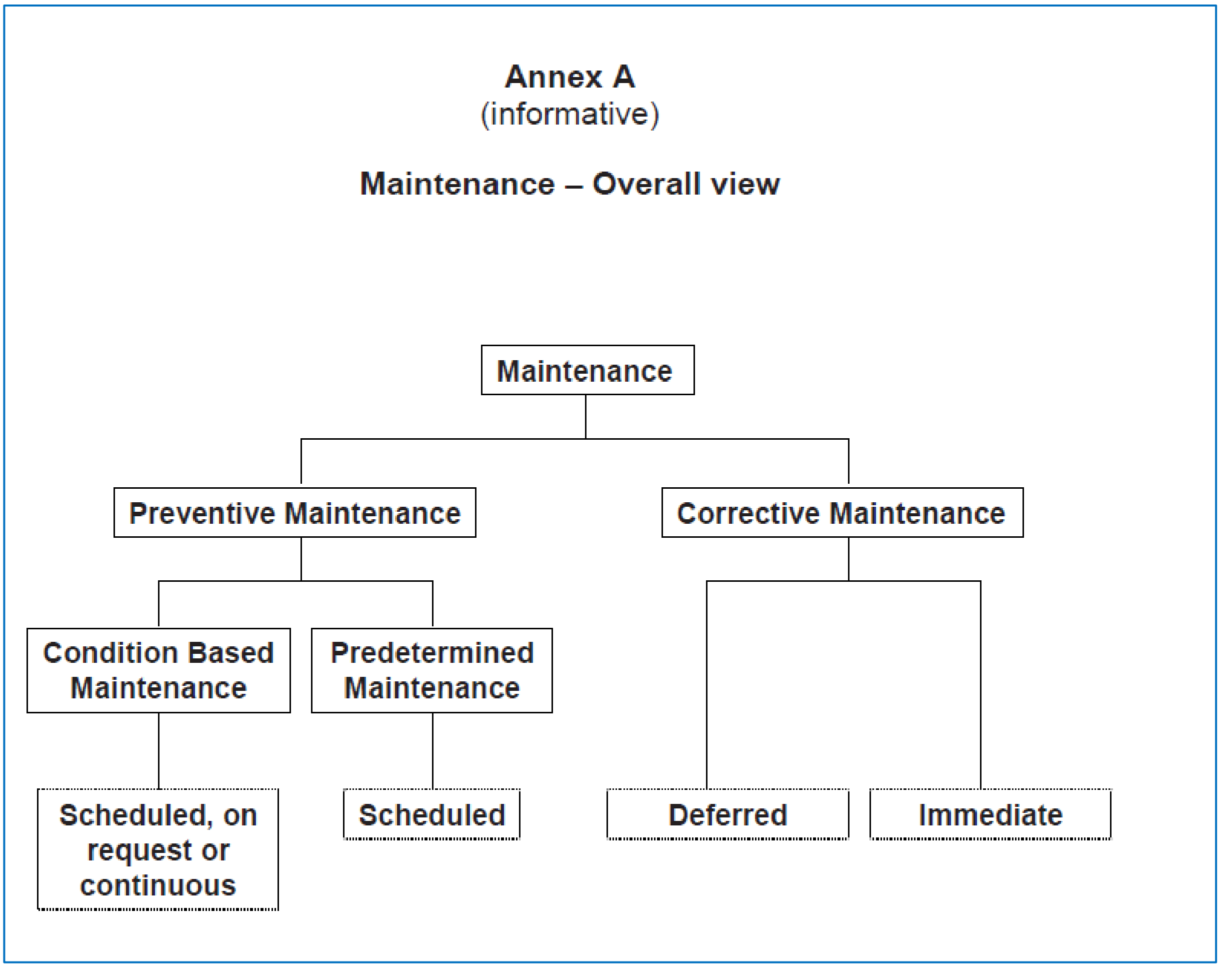

Figure 10: Maintenance overview. (Source: EN-13306 (2010))

Mobley summarized the maintenance into three main types in his work: Corrective Maintenance, Preventive Maintenance and Improvement maintenance. And summarized Preventive maintenance into Reactive Maintenance and Condition Monitoring Maintenance. (A Keith Mobley, (2011))

Smith and Hinchcliffe summarized the maintenance into two main types: Corrective Maintenance and Preventive Maintenance. And summarized Preventive maintenance into Time-Directed Maintenance, Condition-Directed Maintenance, Failure-Finding Maintenance and Run-To-Failure Maintenance. (Smith A M, Hinchcliffe G R, (2003)) Although the classification of the above maintenance is slightly different, it fundamentally reflects the gradual improvement and development process of the maintenance method, from reactive maintenance to preventive maintenance. Different types of preventive maintenance have been derived with the advancement of production management levels and equipment status detection methods. With the emergence of Industry 4.0, an intelligent maintenance system enhances the performance of predictive maintenance systems by utilizing the advancements in computer science, electronics and information technology.

3.3.1 Corrective Maintenance (CM)

The standards (EN-13306 (2010)) defines corrective maintenance as "Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function". The philosophy is "fix things when they break" and it is reactive maintenance.

Examples of corrective maintenance are:

- Due to equipment failure
- Compliance maintenance repair of upgrade
- Repair or upgrade of equipment due to inadequate operation of the equipment
- Due to safety concerns

The steps of corrective maintenance are:

- Following failure and diagnosis
- Elimination of the part and causing the failure
- Ordering the replacement
- Replacement of the part

Test of function and finally the continuation of use Corrective maintenance can be subdivided into "immediate corrective maintenance" and "deferred corrective maintenance.

Immediate Corrective Maintenance

The standards (EN-13306 (2010)) defines immediate corrective maintenance as "Corrective maintenance that is carried out without delay after a fault has been detected to avoid unacceptable consequences". The philosophy is "work starts immediately after a failure".

Deferred Corrective Maintenance

The standards (EN-13306 (2010)) defines deferred corrective maintenance as "Corrective maintenance which is not immediately carried out after a fault detection but is delayed in accordance with given rules".

The decision to choose corrective maintenance as a method of maintenance is a decision depending on several factors as the cost of downtime, reliability characteristics and redundancy of assets. (Christer Stenström, Per Norrbin, Aditya Parida, Uday Kumar, (2016))

3.3.2 Preventive Maintenance (PM)

The standard (EN-13306 (2010)) defines preventive maintenance as "Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item". The main goal of PM is noticing small problems and fixing them before major problems develop. Ideally, nothing breaks down. The main objective are enhance capital equipment productive life, reduce critical equipment breakdown and minimize production loss due to equipment failures.

Preventive maintenance can be subdivided into "Condition-based maintenance" and "Predetermined maintenance. And in addition predictive replacement which means replacement of an item that is still functioning properly.

Condition-based Maintenance (CBM)

The standard (EN-13306 (2010)) defines Condition-based maintenance as "preventive maintenance which include a combination of condition monitoring and/or inspection and/or testing, analysis and the ensuing maintenance actions".

Predetermined maintenance (PtM)

The standard (EN-13306 (2010)) defines predetermined maintenance as "Preventive maintenance carried out in accordance with established intervals of time or number of units of use but without previous condition investigation".

In addition, **Predictive replacement** that means replacement of an item that is still functioning properly.

3.3.3 Predictive Maintenance (PdM)

The standards (EN-13306 (2010)) defines Predictive maintenance as " condition based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the significant parameters of the degradation of the item".

3.3.4 Difference between preventive and predictive maintenance

Manufacturers have been using different forms of preventive and predictive maintenance for years. Understanding the difference between them is critical with the emergence of Industry 4.0.

Preventive maintenance depends on visual inspections, followed by routine asset monitoring that provide limited, objective information about the condition of the machine or system. In this process, manufacturers regularly maintain and repair a machine to prevent failure.

Predictive maintenance is data-driven and relies on analytics insights for maintenance and repairs ahead of disruptions in production.

3.3.5 Objectives of maintenance

The specific objectives of maintenance can be summarized as:

- Increase the availability of equipment and increase production with low cost, high reliability and safety
- Minimize equipment failures and emergencies
- Maximize the allocation and utilization of production resources
- Reduce production downtime due to failure
- Improve inventory management of system equipment
- Improve equipment efficiency and reduce scrap rate
- Minimize the use of related energy in production
- Optimize the life of your equipment
- Provide reliable and cost-effective budget control

- Achieve a reduction in production costs.

3.3.6 The advantages and disadvantages of difference maintenance

	Advantages	Disadvantages
Corrective maintenance	Lower short-term costs	Higher long-term costs
	Minimal planning required	Unpredictability
	System and equipment will not be overhauled	Paused operations
	Simpler process	Equipment not maximized
		High risk of a second failure
		Excessive maintenance staff
Preventive maintenance	Improved system reliability	High installation costs, for minor equipment items often more than the value of the equipment
	Decreased maintenance costs	Unpredictable maintenance periods cause costs to be divided unequally
	Decreased number of maintenance operations causes a reduction of human error influences	Increased number of parts that need maintenance and checking
	Decreased risk factor	Reduction of output
	Follows a schedule	Faster deterioration
	Longer equipment/building life	Unplanned downtime can't be excluded
	Decreased energy wasting	Unneeded maintenance of some component
	Decreased disruptions	Increased chances of accidents and less safety to both workers and machines
	Timely, routine repairs circumvent fewer large-scale repairs	
	Improved safety and quality conditions for everyone	

Table 1: Overview of advantages and disadvantages of various maintenance mode.

Manufacturers and their customers get a range of business benefits from predictive maintenance. The advantages of PdM include:

- Reduced maintenance time
- Increased efficiency
- Competitive advantage

3.4 Maintenance strategy

Traditional components of a maintenance program often fall into four categories (Figure 11):

- Reactive maintenance
- Planned maintenance
- Proactive maintenance
- Predictive maintenance

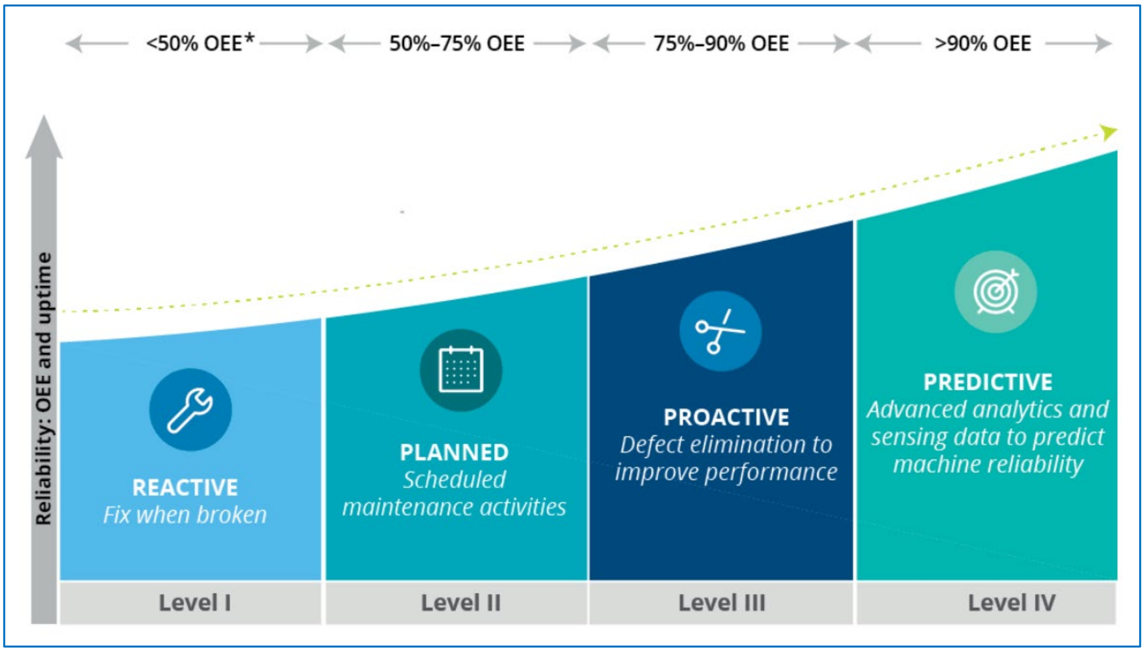

Figure 11: Original equipment effectiveness. (Source: Deloitte analysis)

Predictive (PdM) has become possible using smart, connected technologies that unite digital and physical assets. A large amount of technology investment is required to process the massive amounts of data required, usually only deployed to the largest organizations.

Today, the high availability and low cost of digital technology, coupled with the rise of digital supply networks (DSNs), allows PdM to scale up across facilities and organizations of all sizes.
This combination of operations and information technology allows for deeper analysis of data from the physical world and drives further intelligent action.

Figure 12 shows the predictive maintenance process.

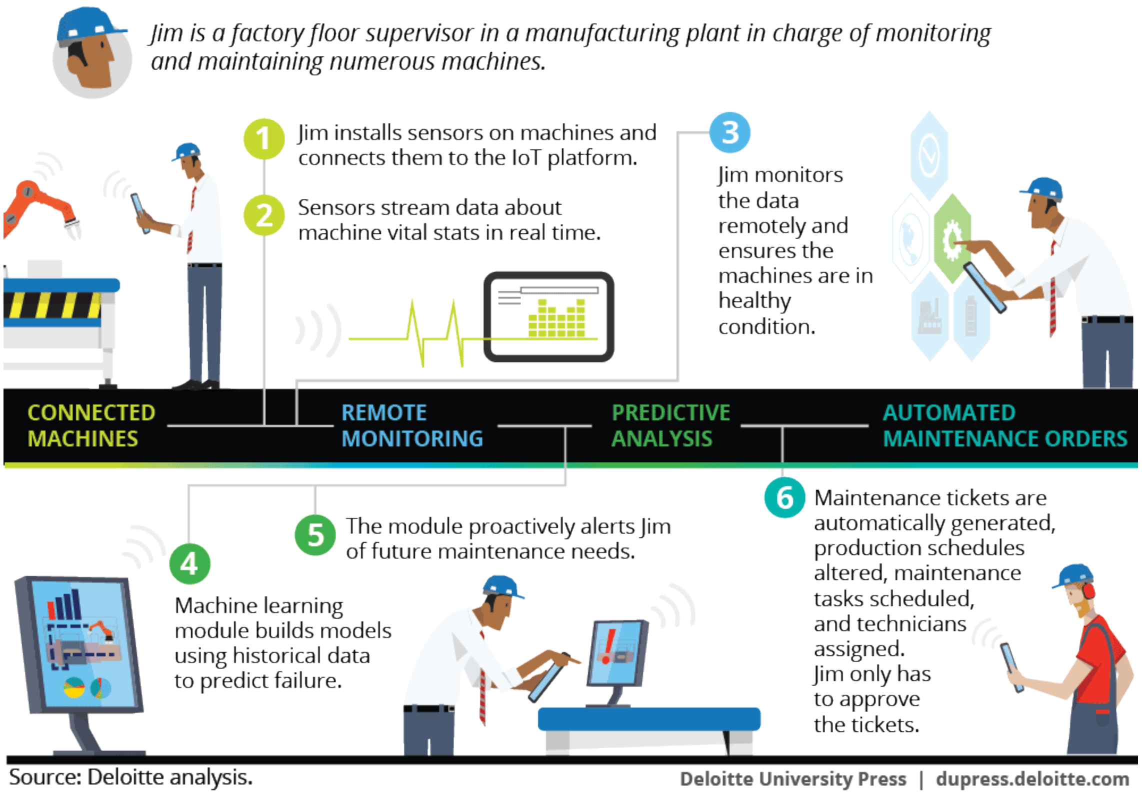

Figure 12: The predictive maintenance process. (Source: Deloitte analysis)

3.5 Definition Of Maintenance In Bane NOR

The manual for maintenance (STY-601058 (2011)) defines maintenance as "Combination of all technical and administrative activities, including management activities intended to maintain or recover a condition that enables a unit to perform the required function".

Bane NOR divides the maintenance into "Preventive maintenance" and "Correcti10ve maintenance" in accordance with NS-EN 13306 and "Renewal".

Bane NOR's model for maintenance is shown in Figure 13

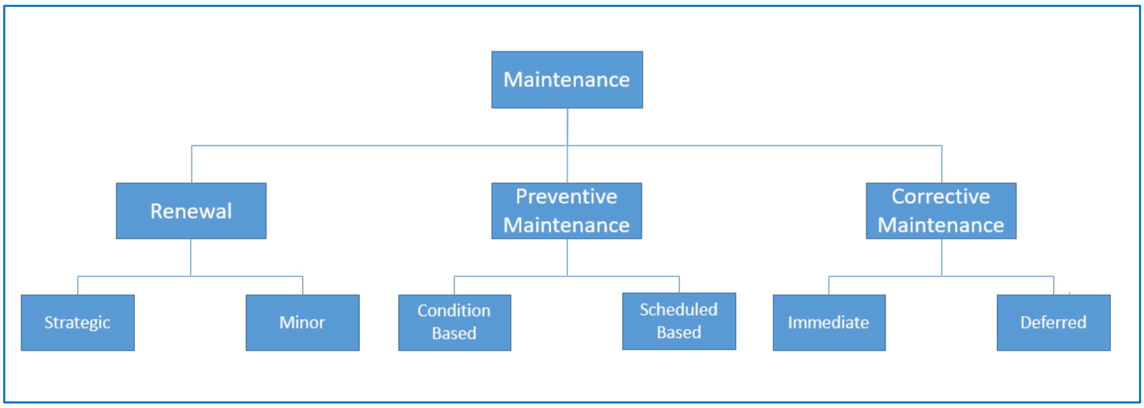

Figure 13: Bane NOR`s model for maintenance. (Source: STY-601058 (2011))

3.5.1 Corrective Maintenance (CM)

The manual for maintenance (STY-601058 (2011)) defines corrective maintenance as “Maintenance performed after failure is detected and intended to return a device to a condition that allows a required function to be performed”.

Immediate Corrective Maintenance (ICM) means the fault which must be corrected immediately to maintain safe train delivery and to avoid delays.

Deferred Corrective Maintenance (DCM) means the maintenance does not start immediately after fault condition is identified.

3.5.2 Preventive Maintenance (PM)

The manual for maintenance (STY-601058 (2011)) defines preventive maintenance as “Maintenance performed at predetermined intervals or according to predetermined criteria, intended to extend lifespan and reduce the likelihood of failure or disability”.

Preventive maintenance is planned and managed using Bane NOR`s tools BaneData.

Condition Based Maintenance (CBM) means activities that are performed to detect state changes and extend lifetimes. CBM for railway transportation is one of the most challenging Streaming Data Analysis problems, consisting of the implementation of a predictive maintenance system for evaluating the future status of the monitored assets in order to reduce risks related to failures and to avoid service disruptions. The challenge is to collect and analyze all the data streams that come from the numerous on-board sensors monitoring the assets.

Scheduled Based Maintenance (SBM) means Maintenance performed at predetermined intervals and intended to extend lifespan and reduce the likelihood of failure or functional impairment (degradation).

Preventive maintenance in Bane NOR should be optimized with the help of **R**eliability **C**entered **M**aintenance (RCM). This means that all “Maintenance Critical Functions” must be followed up through preventative maintenance, all other functions can be taken care of by corrective maintenance, it means after malfunction and preventive maintenance is designed to optimize the life of the components. For installations that do not have high technology dependence, optimal lifetime will usually mean maximum lifetime.

The main rule is that "Preventive maintenance" is performed on components that are important for safety, punctuality, value assurance, comfort and environment.

3.5.3 Renewal Maintenance

The manual for maintenance (STY-601058 (2011)) defines Renewal as “Replacement of systems where it is no longer economical or possible to maintain a required function by means of “Preventive or Corrective Maintenance”, or the repair of larger components to avoid accelerated degradation”.

Minor renewal

The manual for maintenance (STY-601058 (2011)) defines minor renewal as “Renewal Activities carried out to safeguard security and achieve controlled degradation. Budget funds for minor renewals are allocated as a framework to the units”.

Strategic renewal

The manual for maintenance (STY-601058 (2011)) defines strategic renewal as “Major sectional / systemic renewals that result in an improvement of the condition in the direction of "Good infrastructure". Budget funds for strategic renewal are allocated per project based on a nationwide priority.

3.6 Smart Maintenance

Smart maintenance is about machines that can send condition data in real time, and through software algorithms, predict and prevent malfunctions before they happen. Smart maintenance is about tying many data sources together such as machine condition data, machine criticality, service levels, spare part supply, and availability of service engineers, travel time, traffic or weather conditions and more. It`s about being able to pull all this data together and to visualize, automate and optimize decision alternatives through software systems.

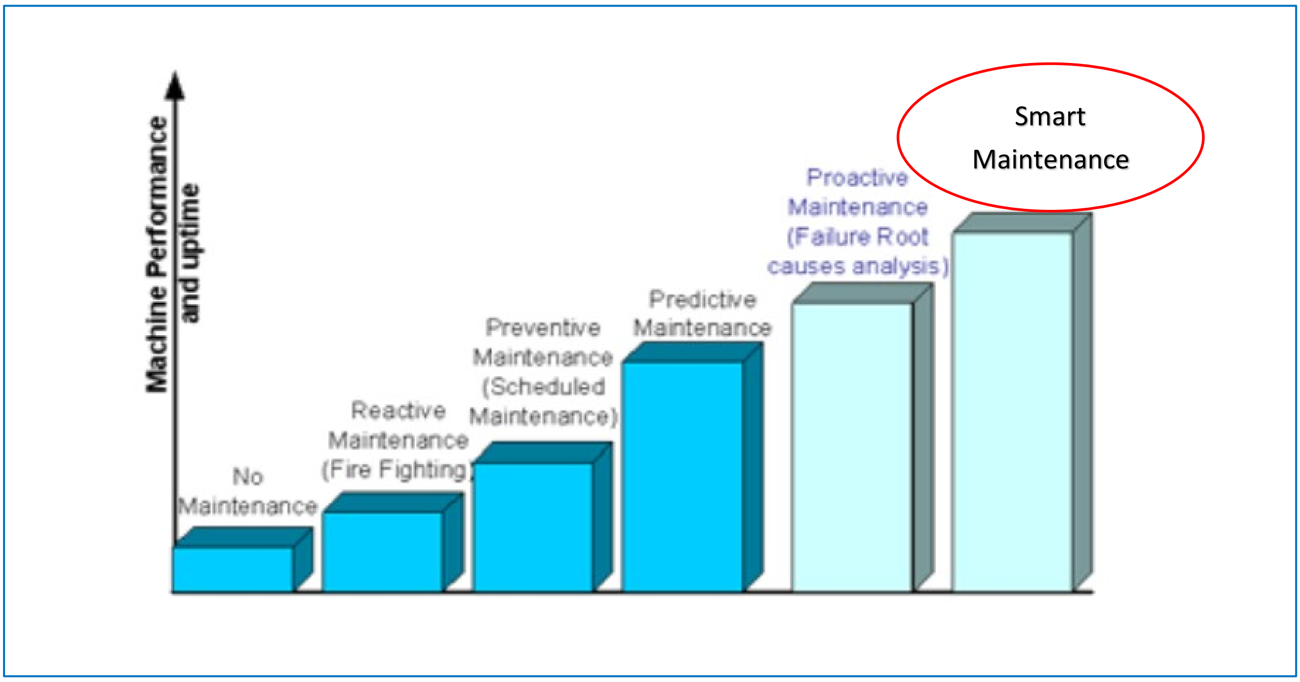

Figure 14: Overview of maintenance strategy. (Source: Schjølberg)

Predictive maintenance industry 4.0 is a method of preventing asset failure by analyzing production data to identify patterns and predict issues before they happen.

Maintenance managers and staffs carried out scheduled maintenance and regularly repaired machine parts to prevent downtime. In addition to consuming unnecessary resources and driving productivity losses, half of all preventive maintenance activities are ineffective.

Not a surprise that predictive maintenance has quickly emerged as a leading Industry 4.0 use case for manufacturers and asset managers. Implementing industrial IoT technologies to monitor asset health, optimize maintenance schedules, and gaining real-time alerts to operational risks, allows manufacturers to lower service costs, maximize uptime, and improve production throughput.

Bane NOR has its own Smart Maintenance program that implements state monitoring of infrastructure components. It will help reduce delay times by seeing errors and acting in advance before the error becomes critical and affects train performance. (Figure 14)

3.7 Maintenance Costs

Railway infrastructure maintenance consumes very large budgets, is complicated to organize and has numerous challenging planning problems. The actual maintenance work consists of a large amount of different activities, requiring considerable resources and large budgets. In 2019 is reported to allocate 2.6 billion Norwegian kroner annually for operation and 6.2 billion Norwegian kroner on maintenance and renewals for railway system. That is including 1.4 billion for the ERTEM project which will replace today's signal systems and is important for improving punctuality and capacity in train traffic. Priority for maintenance and renewal is fundamentally important for passengers and freight carriers to experience a more punctual and reliable railway.

The definition of Maintenance costs was approved by EFNMS Council in May 2001 in Copenhagen. Maintenance costs means:

- Direct wages for direct maintenance staff (first line maintenance)
- Salaries for managerial and support maintenance staff
- Payroll added costs for the above mentioned persons (taxes, insurance, legislative contributions)
- Spares and material for direct use in maintenance
- Spares purchased for inventory
- Consumable charged to maintenance
- Tools and equipment for maintenance purposes
- Contractor costs
- Costs for consultancy services in maintenance
- Administration costs for maintenance
- Costs for education of maintenance staff
- Costs for maintenance carried out by production staff
- Overtime for maintenance staff
- Costs for transportation, hotels, etc
- Costs for documentation, CMMS and planning systems

Exclusions:

- Depreciation of maintenance equipment
- Costs for product changeover or transaction time
- Down time costs

4. Method

This chapter provides an overview of organization and maintenance strategy in Bane NOR.

4.1 Organization

4.1.1 Bane NOR`s organization

Bane NOR is a 100 percent state-owned company and subjects by the Ministry of Transport and communication, which has responsibility for the national railway infrastructure. (Figure 15)

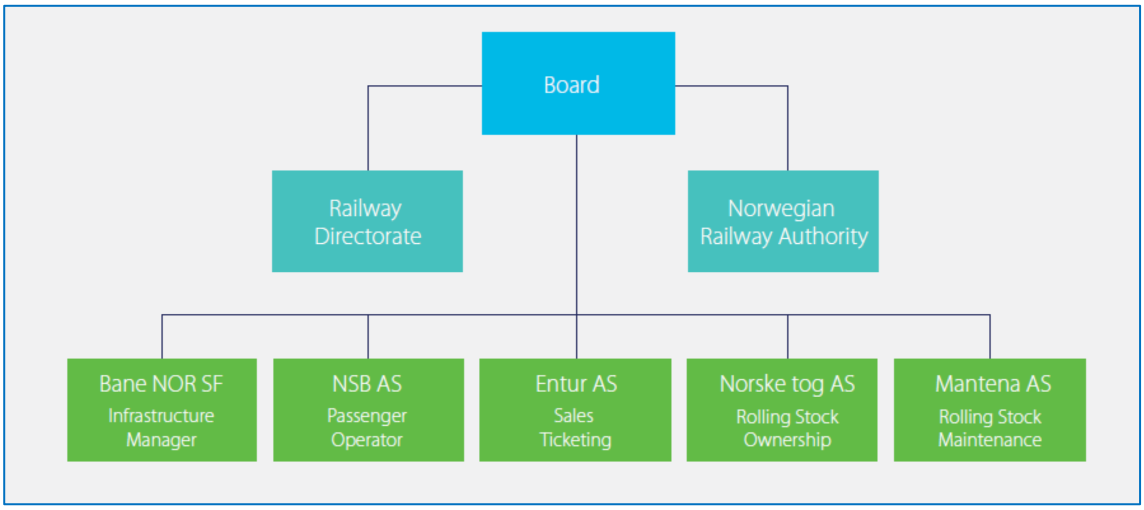

Figure 15: Organizational chart of ownership structure in the railway transport sector. (Source: Banenor.no (2019))

Bane NOR's mission is to provide accessible railway infrastructure and efficient and user-friendly services, including hubs and freight terminal development.

Bane NOR is responsible for the planning, development, administration, operation and maintenance of the national railway network, traffic management and administration and development of railway property. Bane NOR has operational coordination responsibility for safety work and operational responsibility for the coordination of emergency preparedness and crisis management.

Bane NOR has approximately 4,500 employees and the head office is based in Oslo.

Figure 16 shows organizational in Bane NOR.

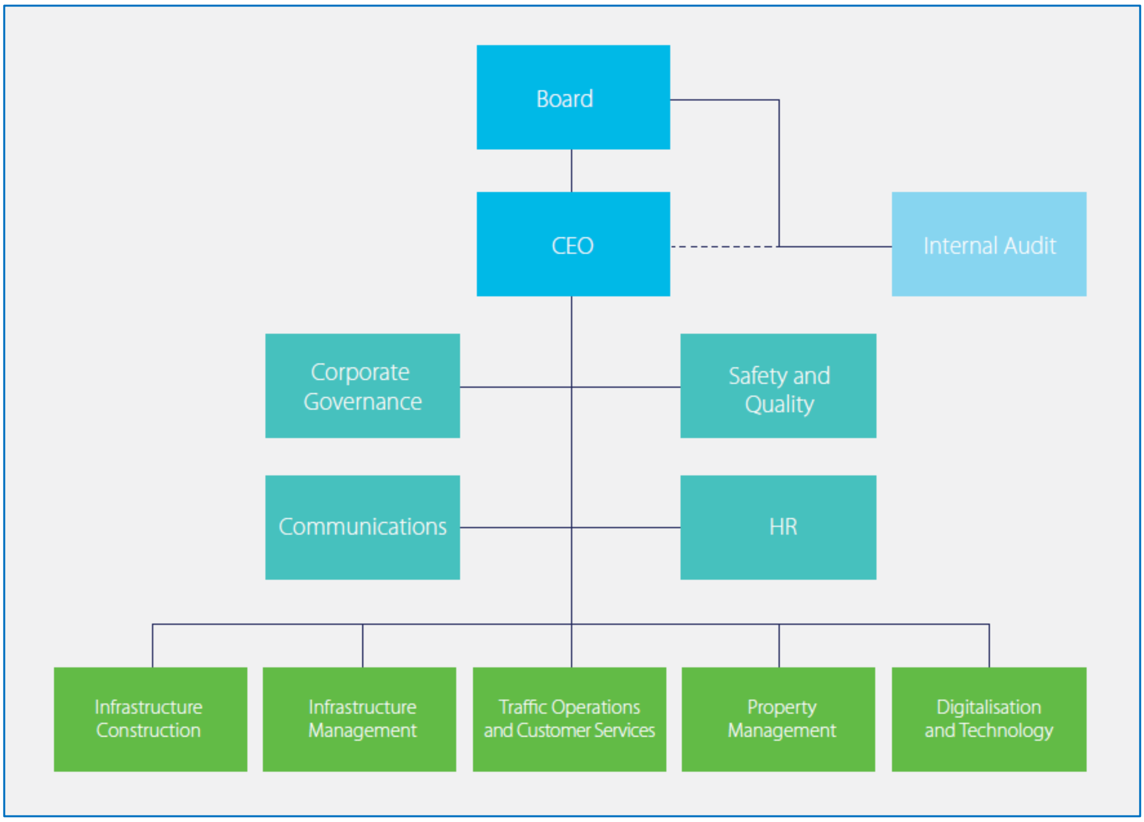

Figure 16: Organizational chart of Bane NOR. (Source: Banenor.no (2019))

Bane NOR is organized into five divisions with responsibility for each of their areas of work and four groups with professional responsibility across the divisions.

- Infrastructure Construction is responsible for planning and implementing projects related to new infrastructure.
- Infrastructure Management is responsible for management, operation and maintenance, as well as investment projects related to the improvement of existing infrastructure.
- Traffic Operations and Customer Services is responsible for operational traffic management, operational itinerary, agreements with train operators and information for travelers.
- Property Management is responsible for managing and developing the properties in the enterprise.
- Digitalization and Technology is responsible for the development and deliveries of digitization and technology to the entire enterprise.

4.1.2 Digitalization and Technology division

Digitalization and technology division develops and uses smart solutions and the technology of the future. This gives travelers and train companies a safe, modern, customer-friendly and cost-effective railway.

Figure 17 shows organizational of digitalization and technology division in Bane NOR.

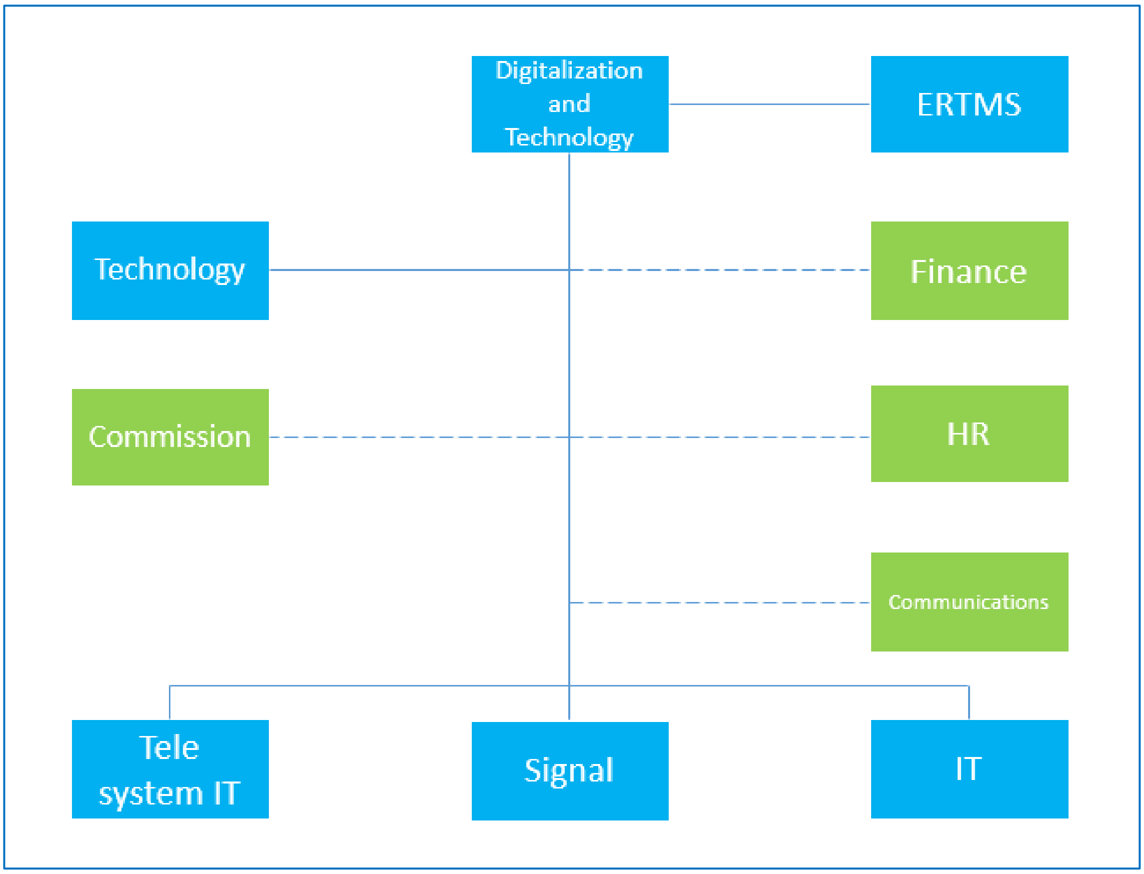

Figure 17: Organizational chart of digitalization and technology division. (Source: Banenor.no (2019))

The division has five units: ERTMS, Signal, Tele system IT, Technology, development and innovation and IT, which has the following main tasks:

ERTMS unit is leading Norway's largest digitization project currently. The railway will be renewed with a digital common European signal system, the European Rail Traffic Management System (ERTMS). For travelers, this means a more stable railway with better punctuality, increased safety and in the longer term more capacity. The unit has about 240 employees.

Signal unit in Bane NOR has Norway largest competence environment in the signal industry combined. The unit is delivering signal expertise to Bane NOR's large and small development projects. The unit is responsible for research, planning and build and execute tasks based on the Signal Process in the Management System. The unit has about 210 employees.

The Tele system IT unit will ensure that Bane NOR has stable information technology services with high availability to support all train performance in Norway. The unit is responsible for transmission, radio, audience information, software-based signaling in a lifecycle perspective. The unit has a 24-hour operations center and is operationally responsible for cyber security in Bane NOR. The unit has about 220 employees.

The Technology, development and Innovation unit is responsible for Bane NOR`s digital strategy that contributes to user-friendly and effective digital solutions. With digital innovation, we will, among other things, develop predictive and modern maintenance through innovative use of technology, data collection and machine learning. The unit provides services and expertise in technical information and documentation, including information models. The unit also prepares regulations for the subjects Signal and Tele, and work to standardize the solutions, manage and develop work processes and tools for the same subjects. The unit has about 45 employees.

IT unit is responsible for developing and operating Bane NOR's administrative IT systems, including applications, enterprise architecture and the company's digital infrastructure. The IT unit also manages the project and portfolio processes for all IT investment projects in Bane NOR and is responsible for managing the company's total IT architecture. The unit has about 50 employees in three departments; IT applications, IT operations and IT management and innovation.

4.1.3 Target system

Bane NOR has an ambition to become a leader in Europe in the maintenance of railway infrastructure. To achieve this, among other things, World Class Maintenance principles are used. Maintenance in Bane NOR is an investment that safeguards Bane NOR`s values, and actively contributes to making important strategic decisions that enable Bane NOR to deliver high availability, reliability, punctuality and regularity, low environmental impact and high security.

The railway are already using many computerized solutions. Many tasks relating to route allocation, maintenance and customer information are currently executed using PCs or tablets.

Sensors along the train routes issue alerts when the railway infrastructure requires inspection.

Bane NOR can continuously monitor the condition of its railways by using sensors and monitoring the power consumption of track components. This allows us to rectify technical faults before they affect rail services. Such systems are already used on several railway lines, between Oslo and Drammen, for instance. This will become the standard for the entire rail network in Norway in a few years. We call this "smart maintenance", because staying one step ahead is generally a pretty smart thing to do.

Bane NOR`s digital initiative is facilitating better utilization of existing resources and expertise in a number of specialist fields, providing more and better railway for the money invested. The digital railway is becoming increasingly apparent in three areas:

- Signal renewal
- Condition monitoring
- ICT security

Signal renewal

The renewal involves introducing both ERTMS and Thales system (also computerized). Bane Nor`s objective is to renew its signaling systems on all railway lines by 2030.

Condition monitoring

Monitoring the condition of the railway gives us the opportunity to remedy technical faults that may lead delayed services. Power consumption and sensors provide alerts when the railway requires inspection.

ICT security

A digital railway is a vulnerable railway. Bane NOR is carefully monitoring potential threats in an increasingly computerized world. We have to protect the railway infrastructure from deliberate actions that may affect rail services, people or assets.

4.2 Maintenance Strategy

The maintenance terminology standard (EN-13306 (2010)) defines maintenance strategy "management method used in order to achieve the maintenance objectives".

It is the responsibility of any maintenance management to define its maintenance strategy according to the following main objectives:

- To ensure the availability of the item to function as required by optimum costs
- To consider the safety and any other mandatory requirements associated with the item;
- To consider any impact on the environment
- To uphold the durability of the item and/or the quality of the product or service provided considering costs where necessary

4.2.1 Bane NOR maintenance strategy

Railway infrastructure maintenance in Bane NOR must be cost-effective and ensure optimal utilization of the infrastructure, while safeguarding personal safety, material values and the environment by:

- Maintain functional requirements
- Increase the quality of the plants with regard to error rates and track quality to achieve reduced non-conforming costs
- Work for optimal lifetime of installation

The maintenance strategy in Bane NOR will help achieve long-term goals for the development of the infrastructure and ensure uniform thinking and awareness of what function the maintenance should have. Important elements of Bane NORs maintenance strategy are:

- Long-term and comprehensive planning
- Competence and interaction
- Minimization of maintenance costs

Long-term and comprehensive planning

With the long lifetime that components of railway infrastructure have, it is a requirement that the owner of the infrastructure has a long-term view of all planning and thinking around maintenance.
The goal is to achieve "Good infrastructure". It means reliable facilities that do not cause large time losses with delays, which result in low maintenance costs and little need for corrective maintenance.

Competence and interaction

Bane NOR`s knowledge view is based on the fact that competence consists of both so-called "silent knowledge" and skills acquired through practical work, as well as theoretical knowledge that can be put into words or articulated.

Important expertise is often experience-based, embedded in what we do, and is based on a knowledge we cannot express. High maintenance ability requires both theoretical and experiential knowledge, both individually and collectively.

Theoretical knowledge is not a sufficient prerequisite for mastering a subject area. Practical knowledge must always be there.

There are different practice communities in Bane NOR. By community of practice is meant the understanding of reality and competence that arises between people in a group who have a common interest and experience from a certain type of tasks.

Important work processes often run across different practice communities. To ensure that we as an organization make good decisions, it is important to ensure that the right expertise is made available and applied in important (critical) processes. It is therefore planned that certain types of personnel interact, for example in connection with RAMS work and in the preparation of maintenance plans.

Minimization of implementation costs

In general, the greatest impact on implementation costs during the planning phase.
Important activities within preventive maintenance (PM), corrective maintenance (CM) and renewal (FO), respectively, to minimize costs are: RAMS (Reliability, Availability, Maintenance, Safety).

Figure 18 shows steps from today`s maintenance program to modern maintenance.

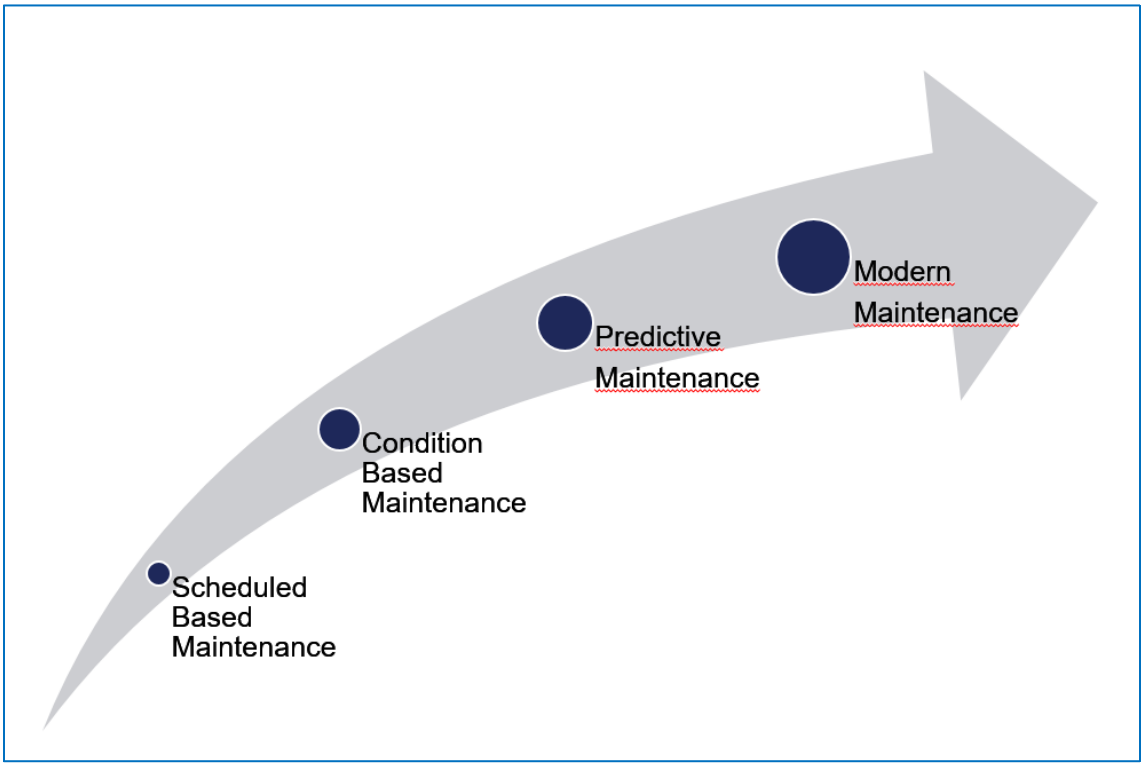

Figure 18: From today's maintenance program to modern maintenance.

4.3 Maintenance Process In Bane NOR

The Infrastructure Operation and Maintenance process consists of the following 3 sub-processes in Bane NOR:

- Long-Term Planning
- Operational planning
- Implementation

4.3.1 Maintenance Planning

The plan for maintenance is based on the results of the response and the means of implementation.

Maintenance planning is based on upcoming maintenance activities and it is the specific arrangement of various maintenance activities under the established maintenance method.
The contents of the maintenance plan:

- What? Maintenance task and order
- Why? Reason of maintenance
- Who? Maintenance staff
- Where? Location
- When? Scheduled, time, deadline
- How? Activities, method

4.3.2 Long-Term Planning

Important prerequisites for the Infrastructure Management Division to succeed in its overall decision-making processes in connection with long-term planning are:

- Leadership focus and involvement of knowledge in the organization so that can make the best possible decisions across responsibilities
- Highlighting functions and responsibilities in connection with important decisions
- Guidelines for how decision-making processes for the distribution of operating and maintenance assets should be carried out

4.3.3 Operational planning

The main activities within the part process operational planning are:

- Plan internal and external tasks. (Work plans) The basis for the preparation of work plans will be route plans from the main process Capacity allocation
- Risk analysis and coordinated resources and capacity utilization
- Contracts formation

4.3.4 Implementation

The main activities within sub process execution are:

- Accomplish planned activities
- Accomplish unplanned activities

4.4 Maintenance Management

The standards (EN-13306 (2010)) defines maintenance management as "all activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics.

4.5 Maintenance Management Model in Bane NOR

The model for maintenance management is intended to illustrate how Bane NOR should have control over maintenance. (Figure 19)

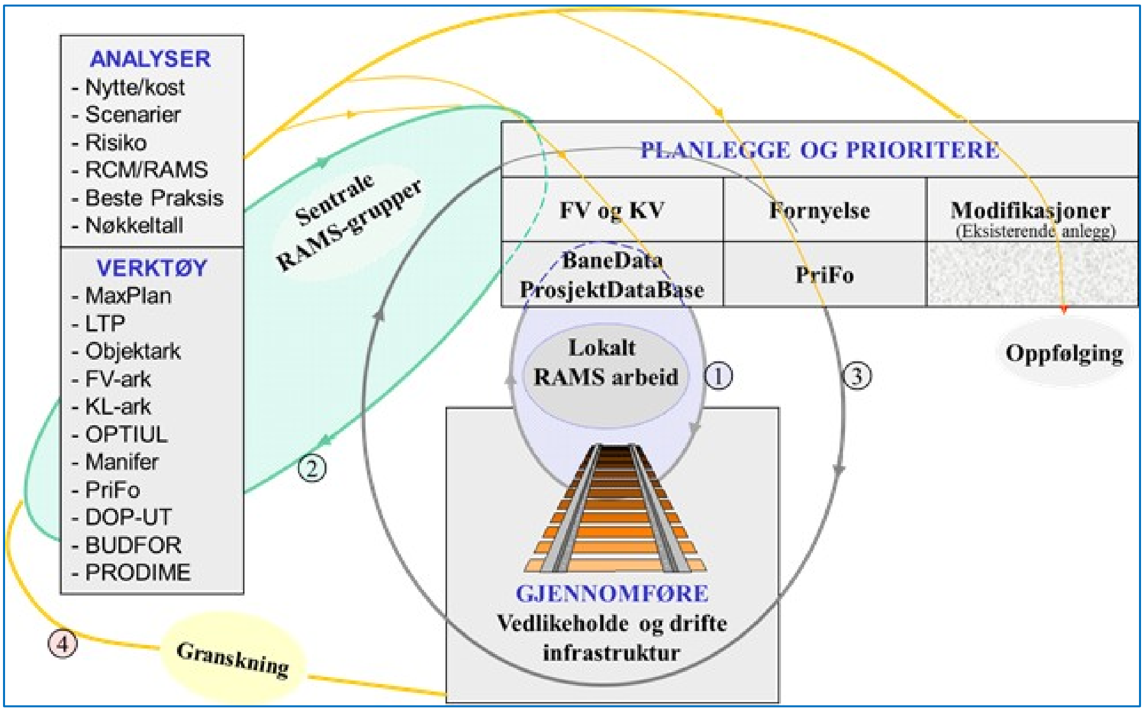

Figure 19: The control model consists of the following four control loops. (Source: STY-601058 (2011))

- Daily management and implementation of preventive maintenance, corrective maintenance and operational measures
- Continual improvement
- Planning and implementation of renewal
- Handling undesirable incident

4.6 Case study: Track Switch Monitoring Systems

The purpose of this section is to discussed an ongoing project in Bane NOR, and what was result of been used predictive maintenance.

4.6.1 History about project

Smart maintenance unit in Bane NOR spent the last four years working on the system they have tested between Oslo and Asker. Track switch monitoring started in August 2016 on the new double track between Sandvika and Asker. 1500 switch motors are currently being monitored in switches on national basis.

The project started by find out which components contribute most to the delays and decided to test the state monitoring of the most vulnerable components. The signal failures was on the top and the worst by statistic, and within that category it was clear that the big switch and track fields were the biggest problem areas. The condition monitoring that was implemented was to set sensors that measure current and time on these drives. It started by looking at the simple curves of power and time. It is developing the tool to see more and more failures and could be better at predicting failures.

The monitoring system has been developed in collaboration between Bane NOR and Microsoft.

A track switch consists of one or more switch motor, which perform the work of overlaying the rails in the switch. Power sensors read off the power the motor uses to make this work. Monitoring of switch motor can aid in detecting early symptoms of degradation prior to failure. There are often wrong connection with track switches that delay or stop the train. From January to April in 2019, almost 200 failures in track switches were rectified in time by using sensors.

The sensors is being installed, especially on Oslo S. (Figure 20)

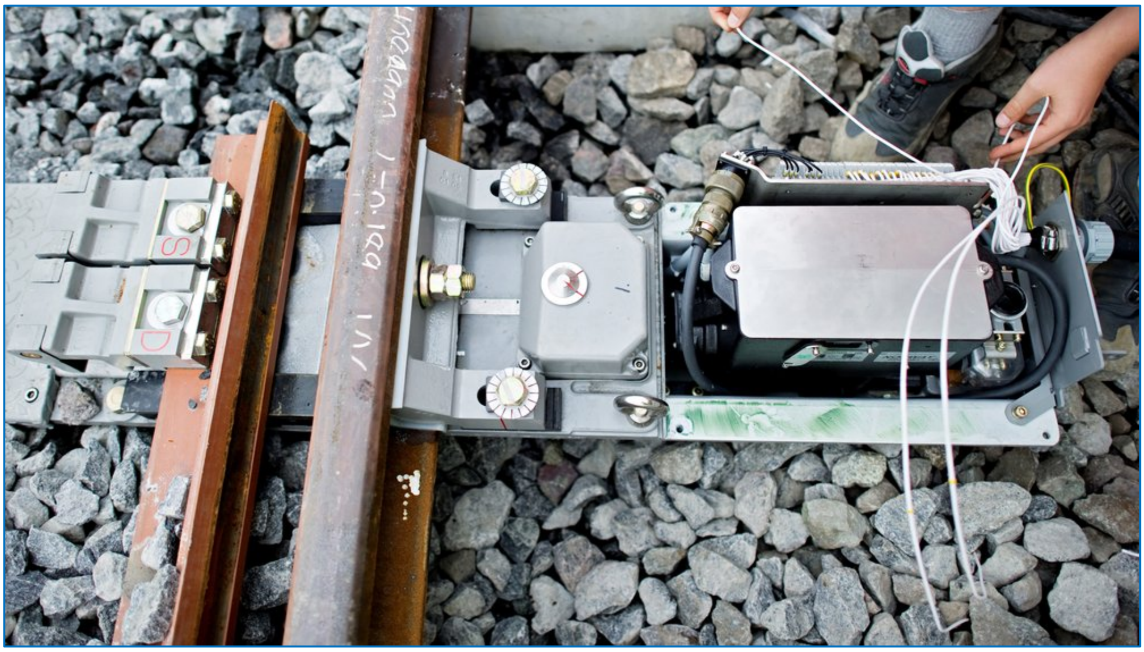

Figure 20: Switch monitoring. (Source: Banenor.no (2019))

Figure 21 shows various maintenance concepts for switch.

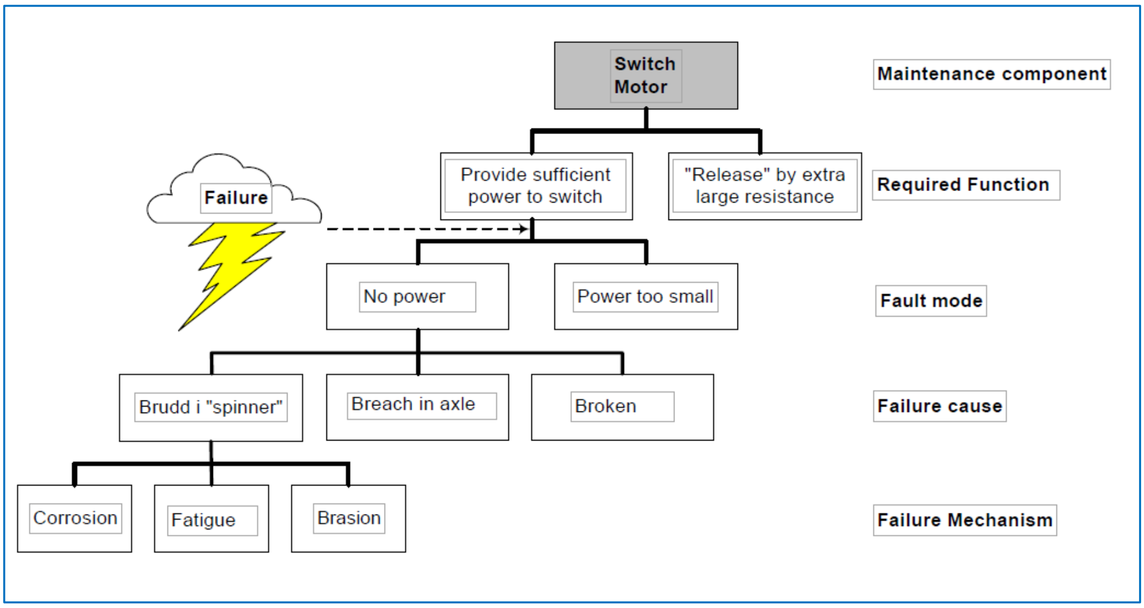

Figure 21: Illustration of various maintenance concepts. (Source: STY-601058 (2011))

4.6.2 Objectives of project

Main objectives for installation of track switch monitoring are:

- Reduce the number of Immediate Corrective Maintenance by 20%
- Increase punctuality - min. 65 reduced delay hours
- From comfort to pain relief to root cause
- Better integration of the state monitoring operation organization
- Interdisciplinary working methodology
- Changed generic work routines
- Improve switch`s lifetime

4.6.3 Track Switch Monitoring Systems

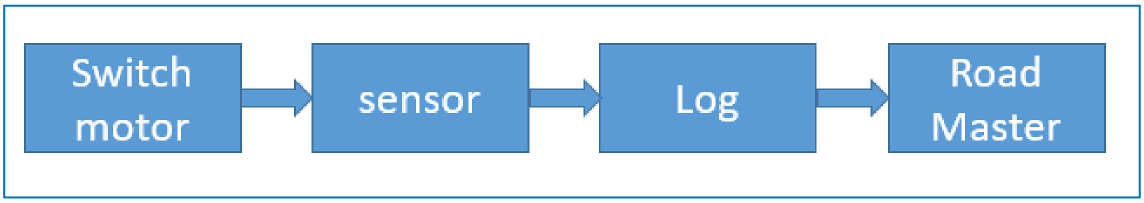

Figure 22: Monitoring system.

A switch motor functional means that all the necessary equipment to carry out a successful reorganization, which consists of unlocking, control of unloading and control of position of the interchangeable point.

An online program "RoadMaster" provided by Voestalpine is used to monitor switches today. The program detects failures based on deviations between a simple reference curve and an actual power curve, as well as simple "failure types" using threshold values, but has no indication of the remaining life of the switch. In several of the cases, the failures are picked up only when the exchange has a critical short time before failure, which in the worst case becomes train stop. (Figure 22)

It is crucial for Bane NOR with expert monitoring personnel with today's monitoring system, who must be able to conclude when sending maintenance personnel in advance to correct a switch. The job of sending maintenance staffs at the optimal time, so that resources are prioritized correctly to avoid train stops, is therefore a challenging manual task. The manual monitor of the switches is comprehensive and resource intensive.

“RoadMaster” measures power and time per conversion, "small" fields in the “RoadMaster” curve have been picket out and follow this backwards in time.

4.6.4 Output from "RoadMaster"

Figure 23 shows login "RoadMaster" website.

Figure 23: "RoadMaster" webside

Output from "RoadMaster":

- Power id
- Deviations through changed power curve
- Which switch motor, which rearrangement and which phase
- Some root cause
- Signal or track must correct the failure
- Maintenance / installation is done correctly

Figures 24 and 25 are showing output from "Roadmaster".

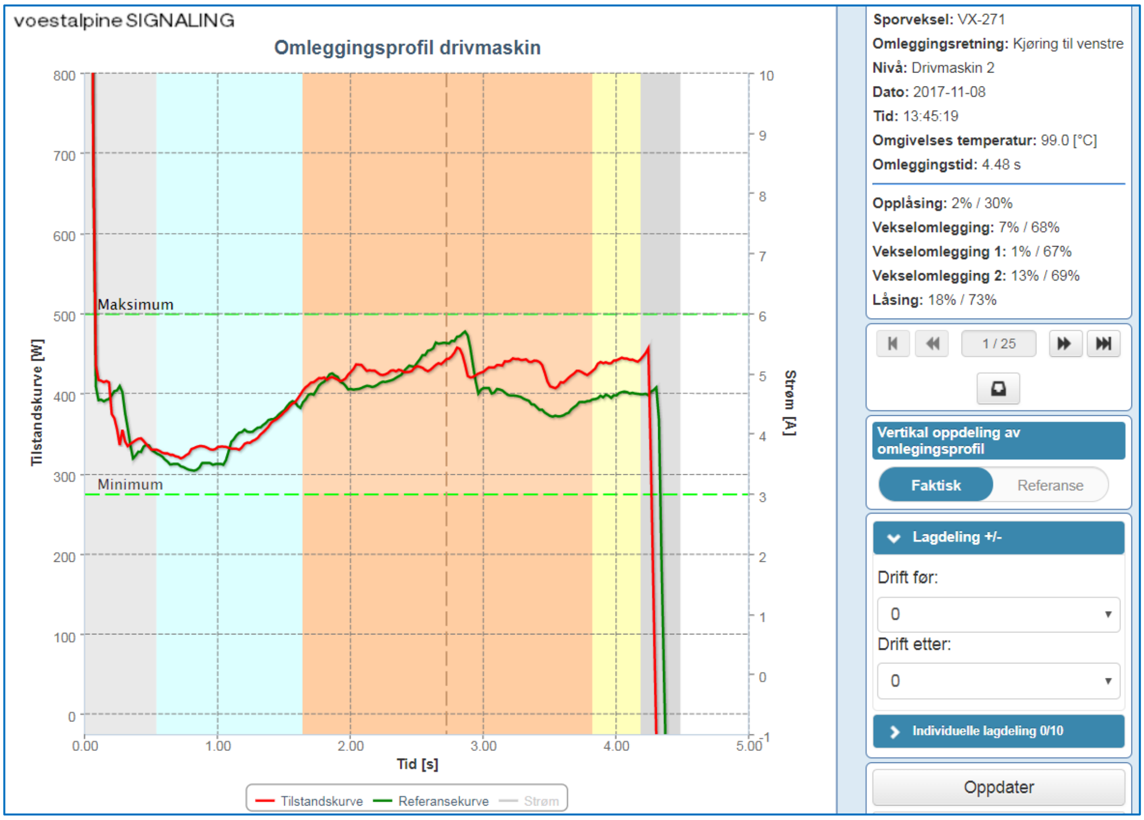

Figure 24: Condition monitoring by using "RoadMaster". (Banenor.no (2019))

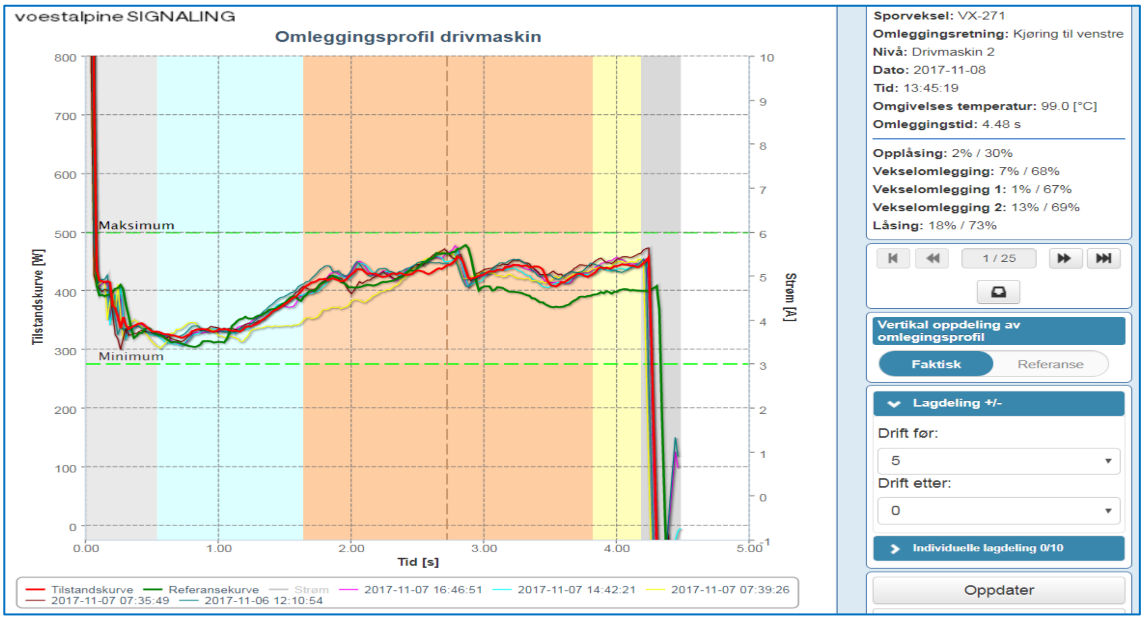

Figure 25: Data handling - Need for efficiency to see trend development in "RoadMaster". (Banenor.no (2019))

4.6.5 Working process "RoadMaster"

Figure 26 shows working process Switch Monitoring Systems

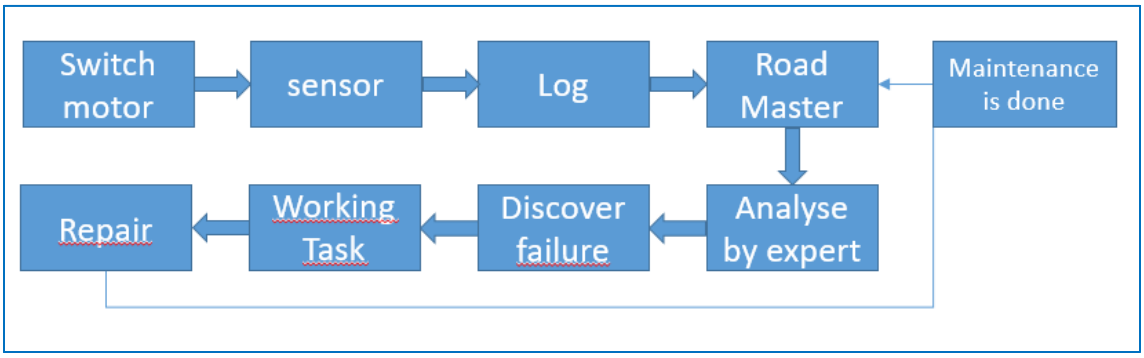

Figure 26: Working process Switch Monitoring Systems.

Figure 27-32 are showing output from "Roadmaster" due to different failures.

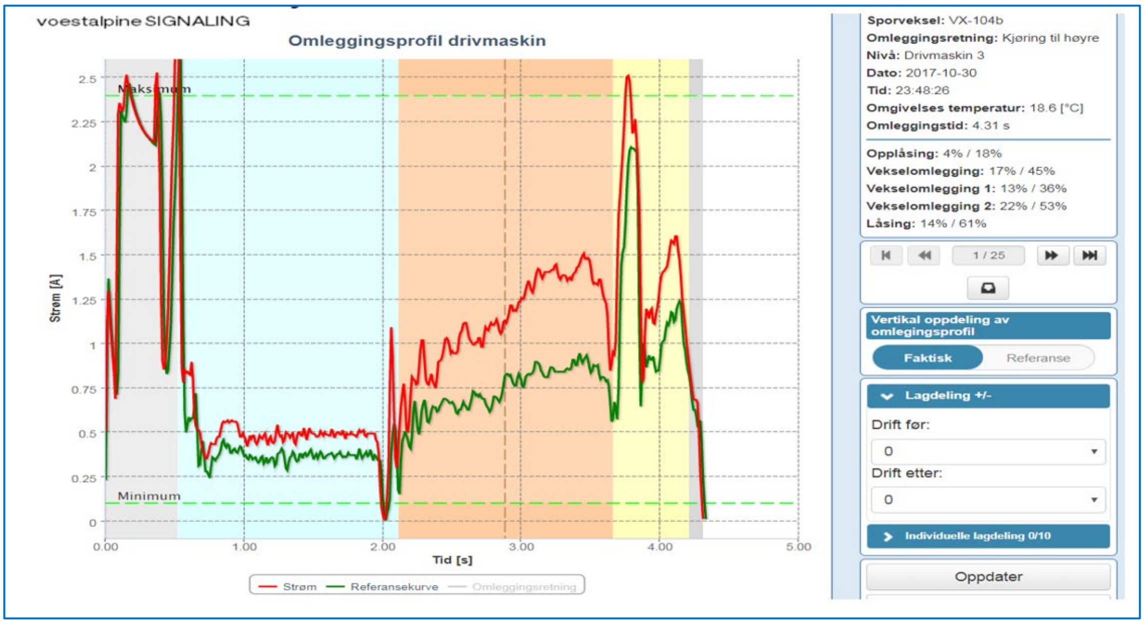

Figure 27: Failure due to Switch motor. (Banenor.no (2019))

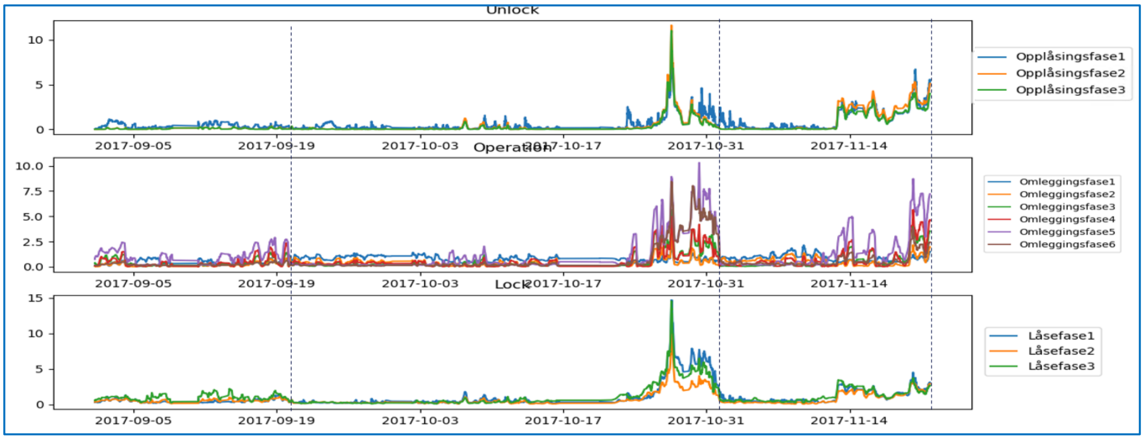

Figure 28: Failure due to Switch motor. (Banenor.no (2019))

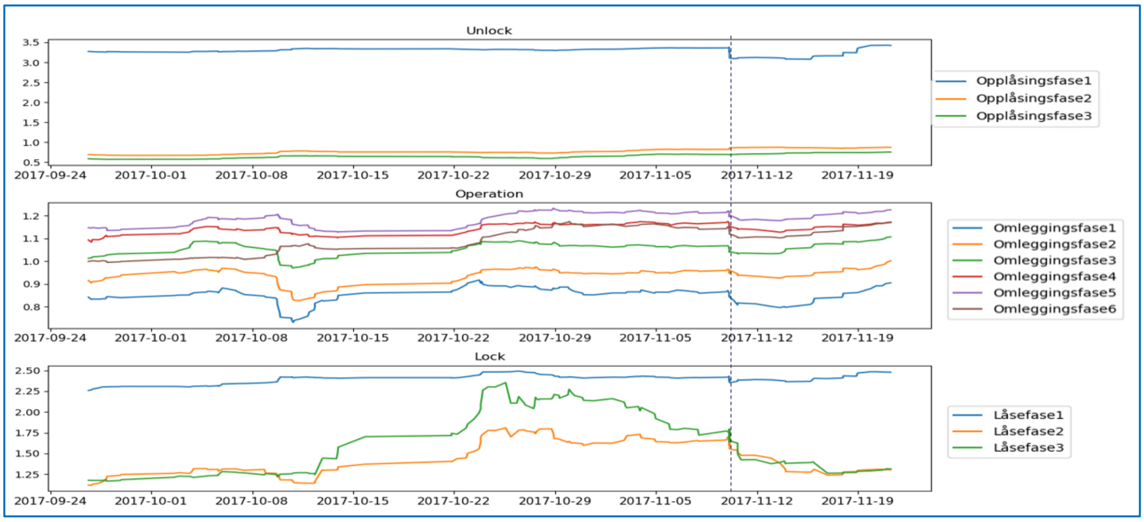

Figure 29: Failure when switch is unlocking. (Banenor.no (2019))

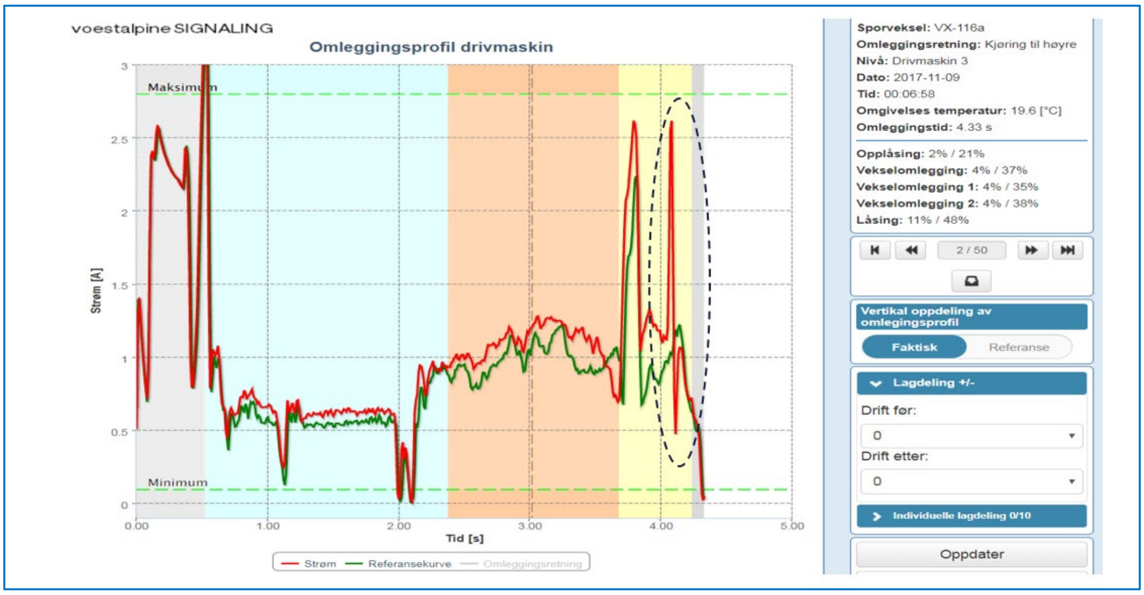

Figure 30: Failure when switch is unlocking. (Banenor.no (2019))

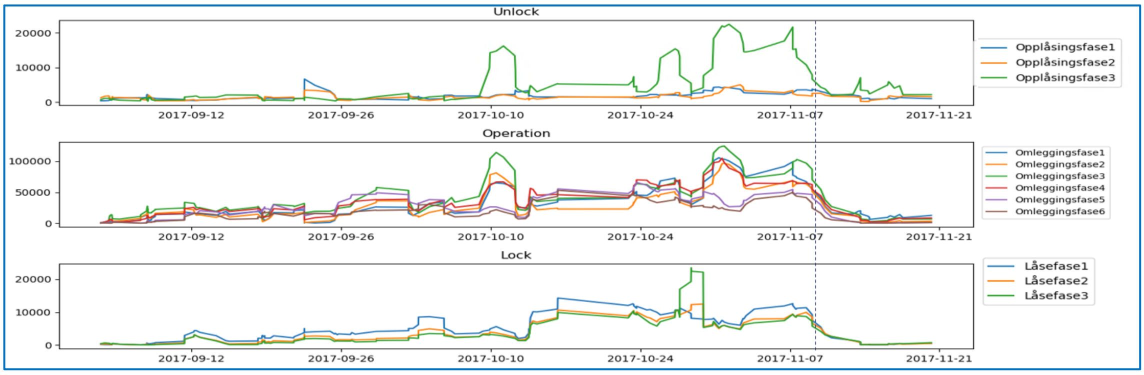

Figure 31: Friction failure during the restructuring phase. (Banenor.no (2019))

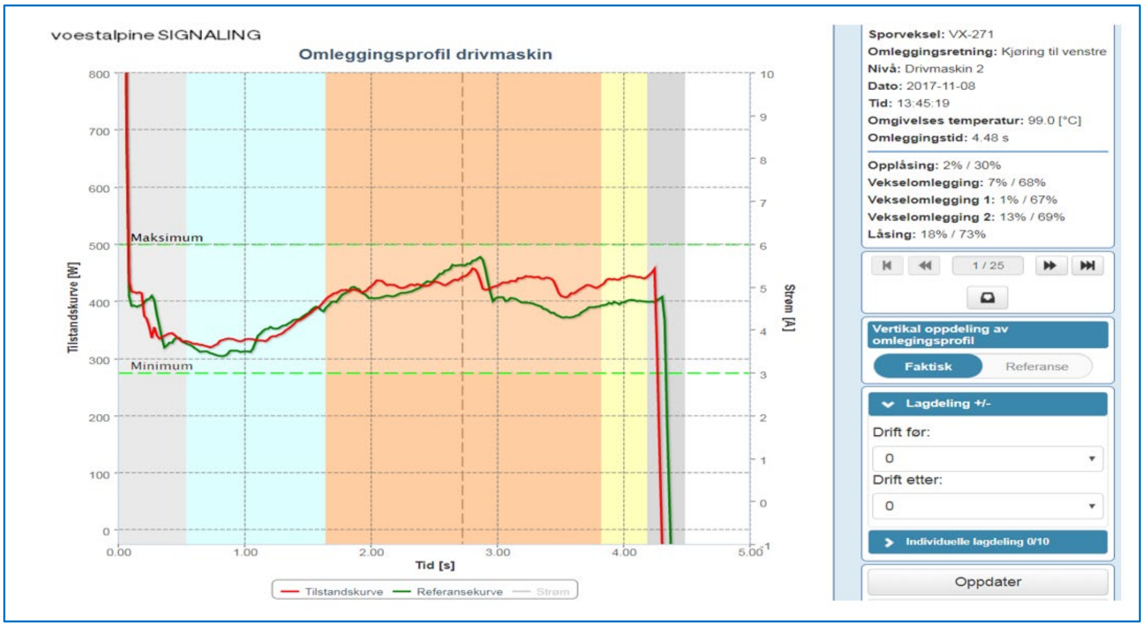

Figure 32: Friction failure during the restructuring phase. (Banenor.no (2019))

Figure 33 shows switch solution tools mobile/Ipad.

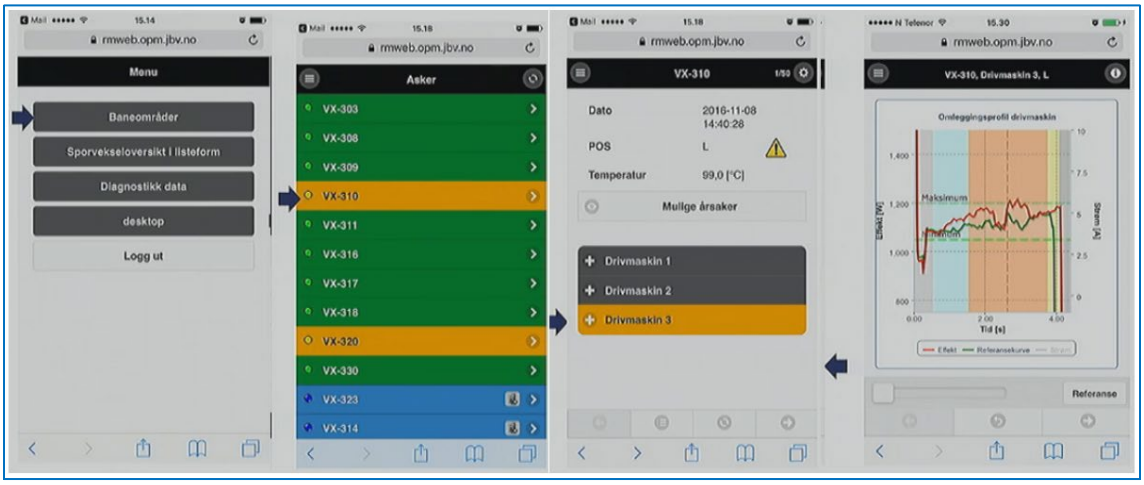

Figure 33: Mobile/Ipad switch solutions. (Banenor.no (2019))

Figure 34 shows Collaborate IT - standardized IT architecture in Bane NOR.

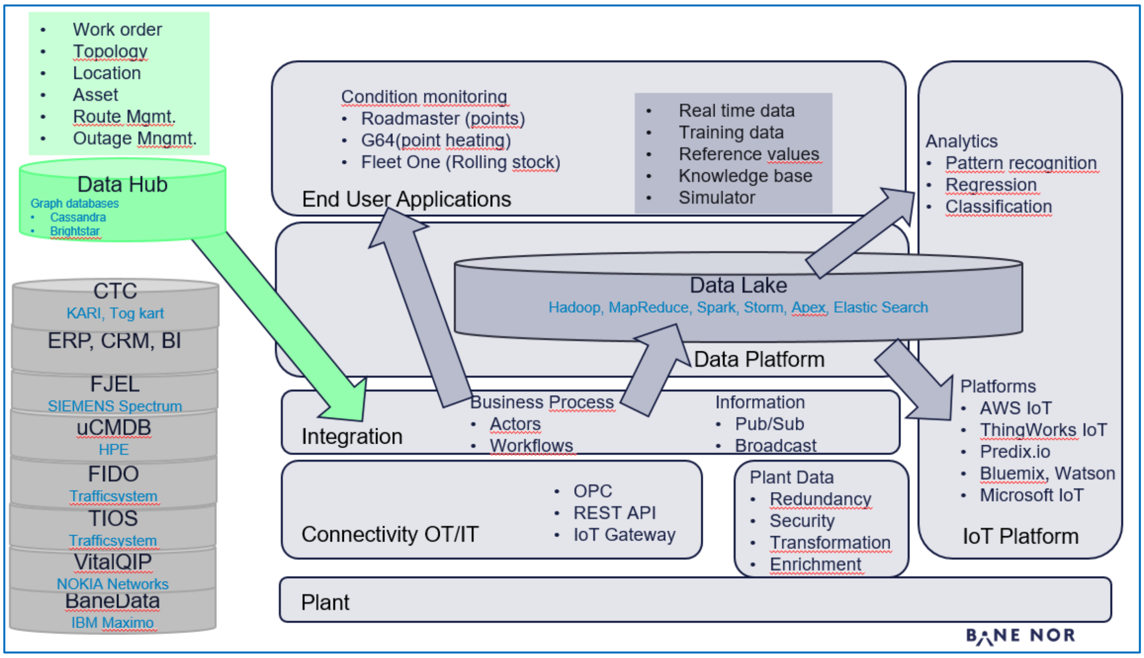

Figure 34: Collaborate IT - standardized IT architecture (Banenor.no (2019))

Expert analyses and sends maintenance task to maintenance staff, they operate with 3 deadlines to correct failures: 1, 3 and 7 days.

Changing from TBM to CBM means a fundamental change in justification for decision-making for the priority matter in maintenance of “when to maintenance and what kinds of maintenance”. The effects of repairs will also greatly improve by being able to obtain track irregularity data on a daily basis. The more data is accumulated, the smarter the important decision-making process in maintenance is.

4.7 Result Of Using Switch Monitoring Systems

In Bane NOR defines a short-distance train is considered on route if it arrives at the terminal within 3:59 minutes of the specified time. For long-distance trains, this margin is 5:59 minutes.

Figure 35 shows working task Oslo S and Asker line. The number of discovered failures by traffic/operation has been reduced between Oslo S and Ask by using monitoring system.

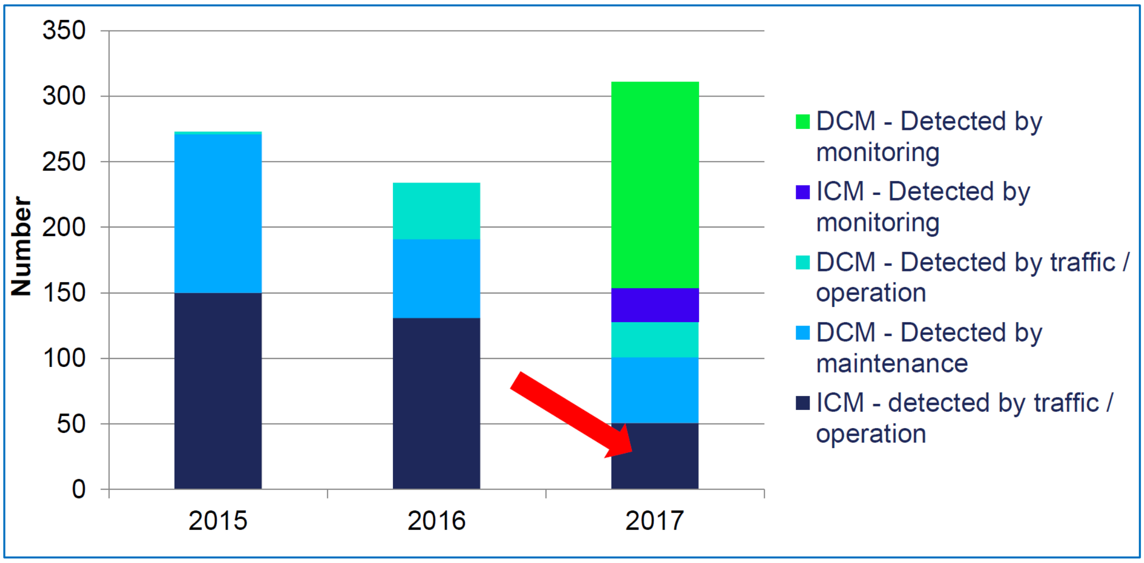

Figure 35: Working task Oslo S and Asker line. (Banenor.no (2019))

Table 2 shows delays and cancelled train related to switch failure reduced 30% and 61% from 2016 to 2017 between Oslo S and Asker.

		land Base	Asker - Oslo-S
2015	Delay hour	510	134
	Cancelled	858	237
2016	Delay hour	572	219
	Cancelled	758	444
2017	Delay hour	610	153
	Cancelled	389	170

Table 2: Delays and cancelled train related to switch failure from 2015-2017. (Source: Bane NOR (2019))

Figure 36 shows Punctuality trends 2007-2017.

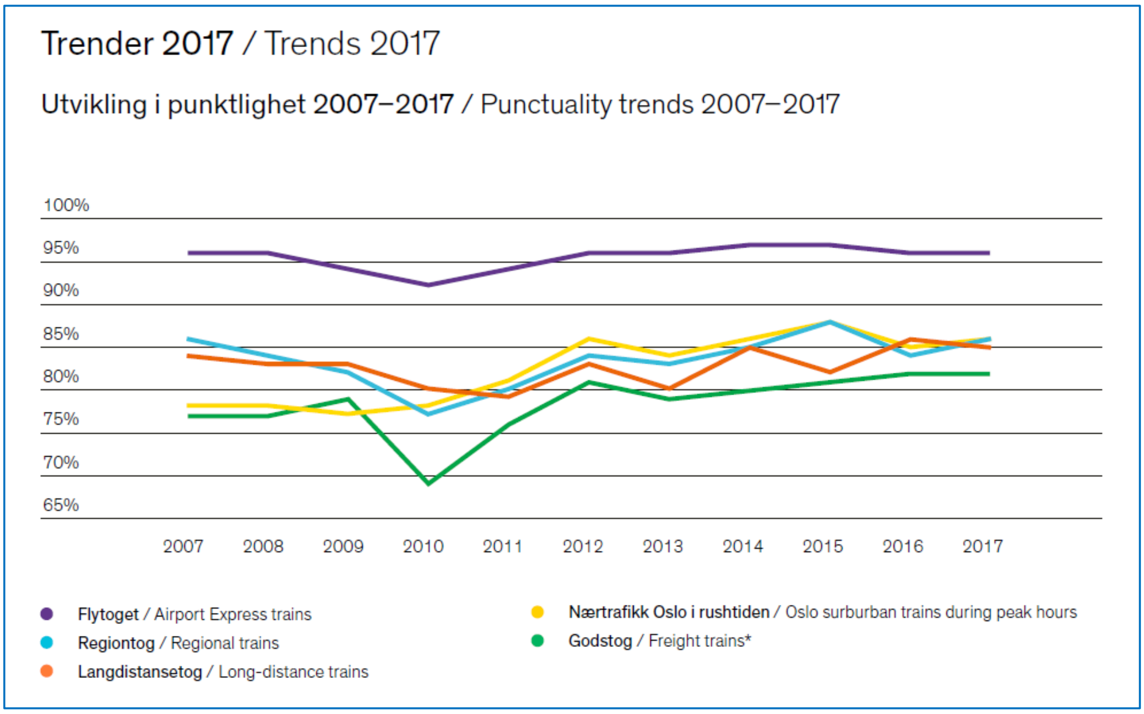

Figure 36: Punctuality trends 2007-2017. Railway Statistics 2017. (Source: Railway statistics (2017))

Figure 37 shows Punctuality trends 2007-2017.

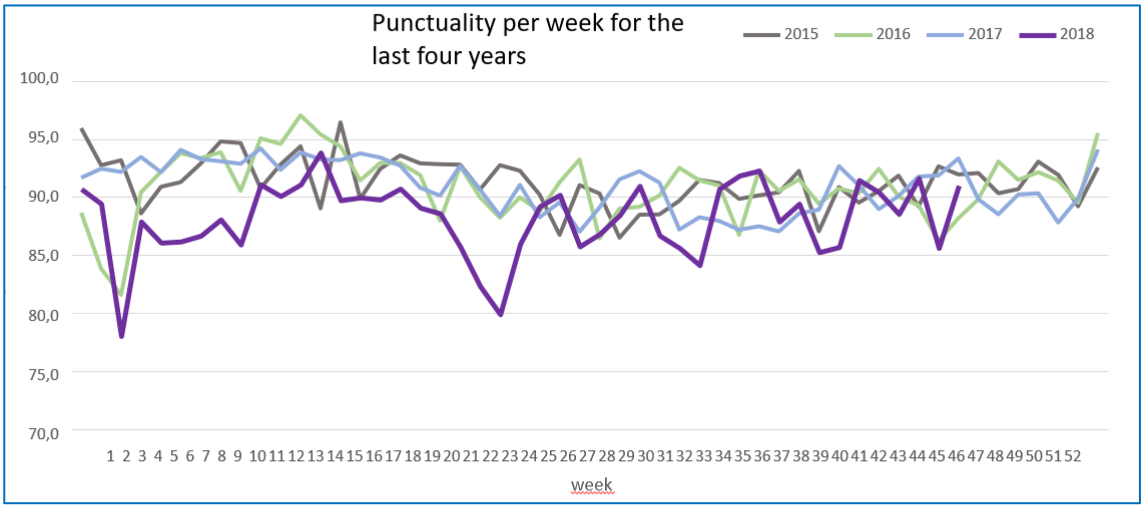

Figure 37: Punctuality per week for 2015-2018. (Source: Bane NOR (2019))

So far, we can see the punctuality in 2018 was the worst year in the last years. In 2018, it faced major weather challenges early in the year and it became difficult to catch up on punctuality again. That indicate old components on the railway infrastructure cannot withstand the stresses of weather and heavy train traffic as well as new components.

4.8 Smart Maintenance Tools

4.8.1 OPTI UL

OPTI UL is a program for optimizing the frequency of ultrasound runs. The program optimizes the frequency for both ultrasonic trains and ultrasonic trolleys. These are used as a supplement to one another based on, for example, concentration of errors. The ultrasonic trolley is a good complement to the ultrasonic train if crack initiation is concentrated to shorter parts of a line.

4.8.2 Bane Data

Bane Data is Bane NOR`S "asset management system" with computer program for object information and maintenance. Here can find object information for all components, performed and planned maintenance, as well as failure correction on the component for the entire railway infrastructure for several years back in time. Data from Bane Data is considered to be a reliable source, due to the database operated by Bane NOR itself.

The problem is that Path Data relies on manual input, which results in a human factor in reporting, and constantly insufficient information at the component level.

The report generator from BaneData also gives an overview of the backlog with the possibility of special focus on safety-related issues.

4.8.3 Maximo

Maximo is an asset management system from IBM. IBM Maximo combined with IoT data from people, sensors and devices to provide warning signals from assets to reduce unplanned downtime and increase operational efficiency. It also provides near real-time visibility into asset usage across multiple sites, extends the useful life of equipment, improves return on assets and helps you defer new purchases. (Figure 38 and 39)

Figure 38: Maximo. (Source: Bane NOR (2019))

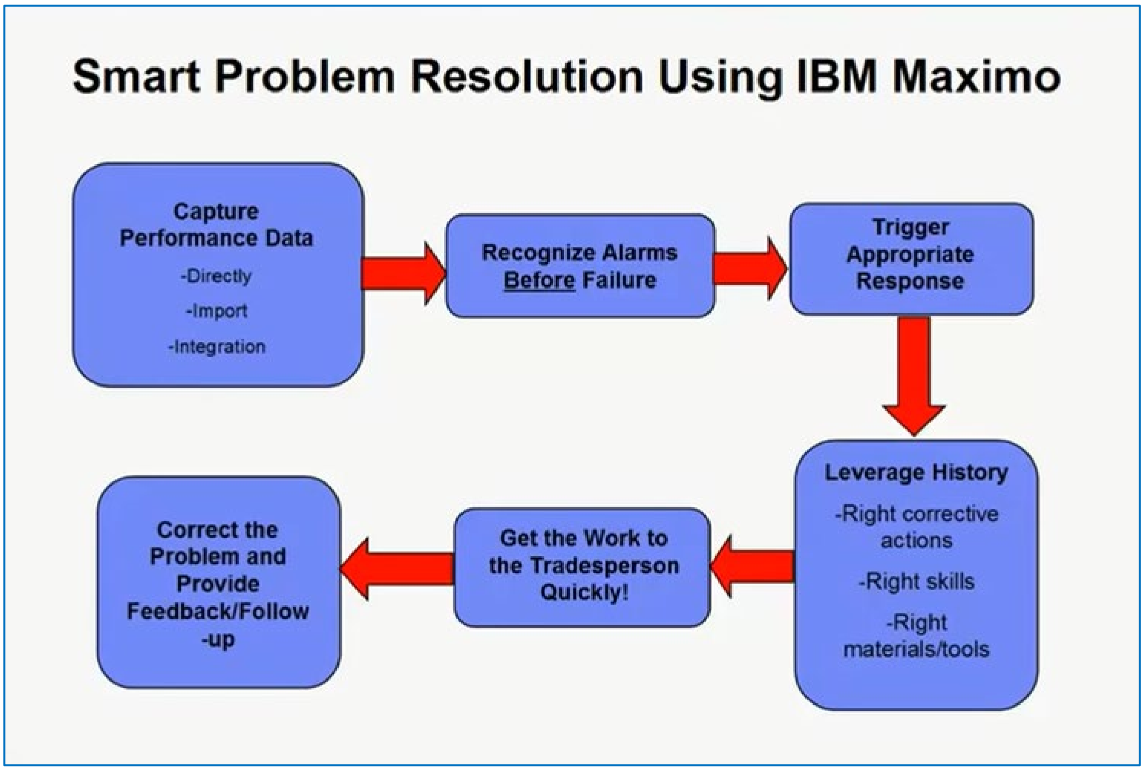

Figure 39: Resolution by using Maximo. (Source: Bane NOR (2019))

4.8.4 Other tools

OPTIRCM: Decision tool to optimize maintenance intervals for preventive maintenance identified in RCM analysis.

OPTIUL: Decision tool for Optimizing Intervals for Ultrasound Measurements.

PriFo: Decision tool for priority renewal.

PRODIME: Tools to calculate productivity.

4.9 Smart Maintenance Management Challenge

Challenges to be successful in improving equipment reliability and maintenance management:

- Maintenance cost must be reduced quickly
- Knowledge about best practices
- Lack of leadership and good management
- People don't like change
- Comfort zone for people
- Reorganization brings unsafe to staff
- People are our biggest asset
- Having more maintenance people on shift reduces downtime
- New computer software will improve reliability and maintenance performance
- Equipment criticality decides inspection frequency
- Communication

Turnover

From Bane NOR was established in 2017 and up to August 2019, a total of 134 people have joined the digitization and technology division. 4 Of the 134 people have been laid off, 13 have been hired temporarily, while 19 have retired. Digitalization and technology division develops and uses smart solutions and the technology of the future.

4.10 Continuous Improvement

A basic prerequisite for continuous improvement is the systematic collection and analysis of experience data and the use of good professional judgment. The most important elements of the improvement work include:

- Root cause analyzes of frequent and /or critical failures types to detect weaknesses in Preventative maintenance, Instructions or designs
- Mapping, disseminating and implementing good practice
- Find the optimal time for renewal or quality enhancement with increasing costs related to poor quality
- Interval optimization (Interval optimization) for preventive maintenance by continually updating reliability parameters, and cost figures related to maintenance costs and consequences of errors

Ongoing smart maintenance activities in Bane NOR:

- Point heating monitoring
- Track field monitoring
- Rolling stock monitoring
- Overhead wire monitoring

- Lubricating switch by drone

Planning smart maintenance activities in Bane NOR

- Development IT system
- Linking data from different sources
- Machine learning, correlating data to see relationships, automating

The sensors should install whole country, line by line.

Figure 34 shows vision of future maintenance switch in Bane NOR.

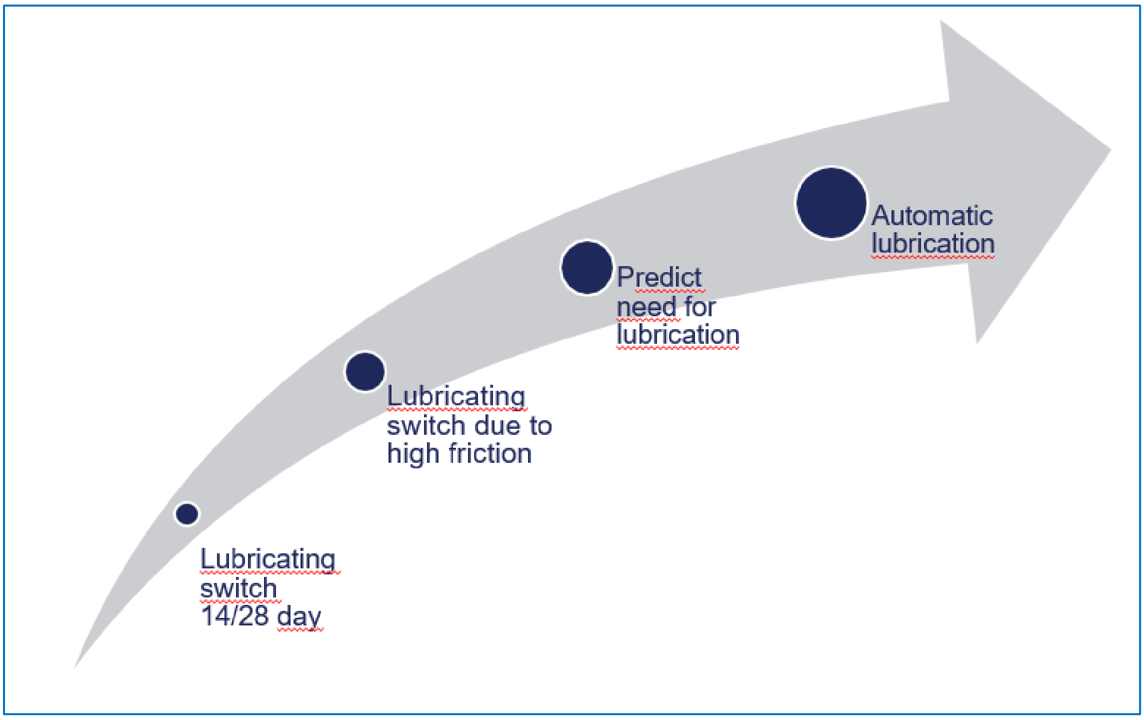

Figure 40: Maintenance switch.

5. Discussion And Conclusion

5.1 Smart maintenance railway in other countries

5.1.1 China

Rolling stock

Researchers from Operation and Maintenance Engineering at Luleå Railway Research Center, Luleå University of Technology have initiated projects to develop a maintenance and technology framework for Prognosis and Health Management (PHM) for high-speed trains in China. The system will make the high-speed railway system more robust and reliable by the use of state of the art predictive and prescriptive technologies and solutions.

Chinese CRRC is the world's largest rail and high-speed train manufacturer and 60 percent of the world's high-speed rail system is being manufactured in China, and there are more than 22,000 km of railways for high-speed rail. The fastest now-rolling train in China runs 350 km / h (design service speed is 400 km / h).

Railway Research Center can provide robust and reliable Prognostic and Health Management (PHM) solutions for high speed trains and it will be based on so-called intelligent cloud services. The CRRC - LTU centered is exclusively focused on focus on maintenance technology. One of the more common technical problems on high-speed trains is axle bearings so it will be one of the areas where the new system will detect and prevent problems prior to functional failure. The system will also provide a forecast of when and how the problem has to be addressed.

The researchers at the Division of Operation and Maintenance Engineering at Luleå University of Technology consisting of more than 40 researchers are globally recognized for their capability and competence and plays an important and leading role when it comes to research in the field railway maintenance.

That project will facilitate development of not only reliable and cost effective train but also it will make significant contributions towards making these train sets failure free facilitating high level of safety in operation. It is in the field of operation and maintenance that we primarily discuss research collaboration.

The project Prognostic and Health Management for Rail Transportation Equipment – Application studies on maintenance strategies of EMU axle bearing and collaborative maintenance management technologies is being carried out in cooperation with the Chinese company CRRC Sifang - China South Locomotive and Rolling Stock Industry Corporation - and will last until 2019. This project is divided into two sub-projects, the other part is about maintenance strategies and prognostic of axle bearings. (Source: Luleå University of Technology (2019))

5.1.2 Japan

JR East

The Research and Development Center of JR East Group has proposed the Smart Maintenance Initiative as 21st century innovation in maintenance of railway equipment. The Smart Maintenance Initiative goes beyond the aspects of simply improving methods of repair work.

The Smart Maintenance Initiative is composed of 4 key parts, which include bellows:

- Achieving CBM
- Introduction of Asset Management

- Maintenance Work Support by AI
- Integrated Database

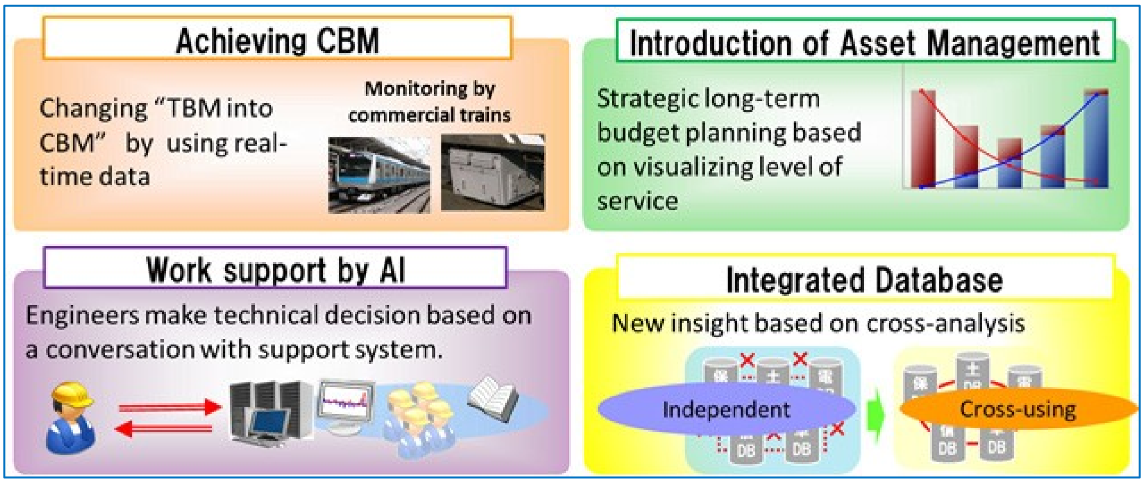

Figure 41: Figure Smart Maintenance Initiative. (Source: Atsushi Yokoyamaa (2015))

First is changing the basis of maintenance from Time Based Maintenance (TBM) to Condition Based Maintenance (CBM).This entails a major change in the philosophy of maintenance. By achieving the change, much more streamlined maintenance than now will be possible. Changing from TBM to CBM means a fundamental change in justification for decision-making for the priority matter in maintenance of "when to conduct what sort of repairs". (Source: Atsushi Yokoyamaa (2015))

Innovation Japan

Atsushi Yokoyama, Executive Officer in Technology Planning Department in JR East Group presented "Smart maintenance is contributing to safer rail systems around the world".

Each week, 34 million people ride the Yamanote Line, which encircles Tokyo (Figure 42). As the trains run at 2-3 minutes intervals from early in morning till late at night, it is difficult to operate and manage the maintenance activity efficiently without interrupting train service. However, the introduction of smart maintenance using IoT technology allows the collection and analysis of enormous amounts of data from trains and rails in real time, making it possible to detect minor changes and to predict failures well in advance. As the issue of aging transport infrastructure attracts a new level of attention around the world, smart maintenance will offer a novel solution to keep infrastructure in safe condition.

Japanese railways are renowned worldwide for their high levels of reliability and safety. The Yamanote Line, a loop line around central Tokyo, which is also the world's largest transport infrastructure used by 34 million passengers a week, is supported by the Smart Maintenance.

Figure 42: Yamanote Line map showing all the stations and interchanges. (Source: https://www.jrailpass.com)

It collect daily data while our trains are running, using sensors attached to the railcars currently.

As an example, monitor the status of rails and power lines in real time, together with railcar equipment such as the mechanisms used to operate the doors. Analyzing the large volume of data captured enables a much more rational approach to maintenance than was previously possible.

Improving transport quality and carrying out high-quality maintenance embodied in the smart maintenance approach, will fundamentally transform railway maintenance.

A smart maintenance system are trialing on the Yamanote Line known as CBM, or Condition Based Maintenance, which uses the Internet of Things (IoT) technology to enable the high-frequency collection and analysis of equipment and railcar status data. It helps identify equipment weaknesses, forecast railcar failures, and efficiently carry out repairs, to make safe, reliable railway operation possible. (Figure 43)

This approach enables us to provide safe, consistent rail service more efficiently.

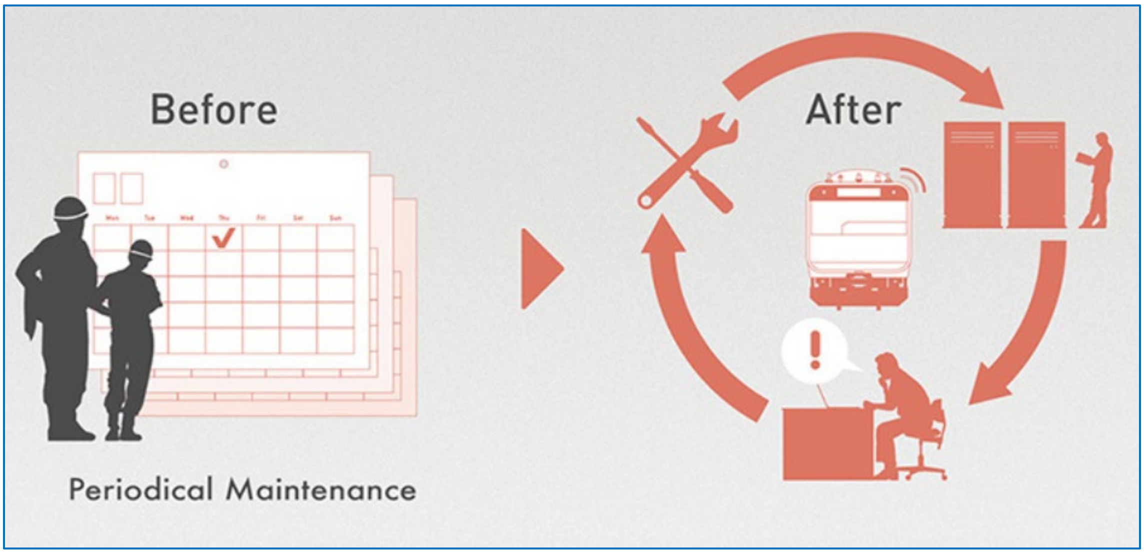

Figure 43: Maintenance before and after JR East. (Source: Innovation Japan)

5.1.3 South Korea

Korea Airport Railway Corporation

It has reached an agreement between Hyundai Rotem and the Korea Airport Railway Corporation on the joint development of intelligent maintenance systems to develop "intelligent railway maintenance" technology for railway vehicles. "Intelligent Railway Maintenance" technology is a technology that uses a variety of sensors and Internet of Things (IoT) technology to remotely monitor the main train equipment in real time. It analyzes sudden faults and optimizes vehicle maintenance cycles by analyzing big data such as status information and history.

Hyundai Rotem plans to build a "smart railway maintenance" technology system next year to accommodate the growing global rail vehicle maintenance market. Through the agreement, Hyundai Rotem will develop a cloud platform based on big data analytics, develop maintenance plans for airport railways, and use vehicle development and installation systems to collect vehicle support and technology development data to reduce maintenance costs and improve train availability and safety.

It is reported that after the completion of the system, it can reduce the maintenance cost of high-speed railway vehicles by 25%-30%, reduce the spare parts inventory by 20-30%, and improve the equipment life by 20-40%.

5.2 Conclusion

To sum up, it is clear to that the environment is changing surrounding railways, such as the increase in population, progress of globalization, and rapid advancements in ICT. In this situation, Bane NOR must further development railways as a representative infrastructure.

For that reason, it is important to go beyond the boundaries of railway technologies and innovation as the key to that.

Bane NOR must continuously to make maintenance work smarter based on “Smart Maintenance”.

6. Further work

This master's thesis has made some recommendations to the Bane NOR for further work on establishing and audit a good maintenance strategy.

- **Training:** Training and use of Bane Data is essential in order to be able to plan maintenance thoroughly and well in the future.
- **Revision of The manual for maintenance (STY-601058)**: Smart maintenance should be added into Bane NOR.
- **Standardization**: Working process and tools.
- **IC project:** In this thesis doesn`t mention InterCity project, but I think LLC analysis must including smart maintenance.
- **Machine learning.**
- **Data Security.**

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