Rijkswaterstaat
Ministry of Infrastructure
and Water Management

Possibilities of performance and condition monitoring at Rijkswaterstaat

Internship report

S.K. de Haan (s1486225)
MSc Mechanical Engineering
s.k.dehaan@student.utwente.nl
Faculty of Engineering Technology
Department of Design, Production & Management

16-4-2018 till 9-7-2018

Rijkswaterstaat Eastern-Netherlands East
Brugginksweg 6
7555 PB Hengelo
The Netherlands

Supervisor Rijkswaterstaat:
Dinant Schippers
Advisor Asset Management
dinant.schipper@rws.nl

Academic supervisors:
Jan Braaksma:
Assistant Professor in Maintenance Engineering
a.j.j.braaksma@utwente.nl
Sukon Wu:
PhD candidate maintenance engineering
s.k.wu@utwente.nl

University of Twente
PO Box 217
7500 AE Enschede
The Netherlands

UNIVERSITY OF TWENTE.

Preface and acknowledgement

For 12 weeks from April 2018 till July 2018, I did an internship at Rijkswaterstaat, a public company with the responsibilities for the infrastructure and water management of the Netherlands. Rijkswaterstaat's core business involves the main infrastructure and the water management of the Netherlands. A division can be made between the three main systems of Rijkswaterstaat, namely the main highways, the main water systems and the main waterways. Figure 1 gives an overview of the location of these systems in the Netherlands. Rijkswaterstaat is the executive body of the Dutch Ministry of Infrastructure and Water Management. This internship is part of my 2-year master program Mechanical Engineering, which I conduct at the University of Twente, the Netherlands.

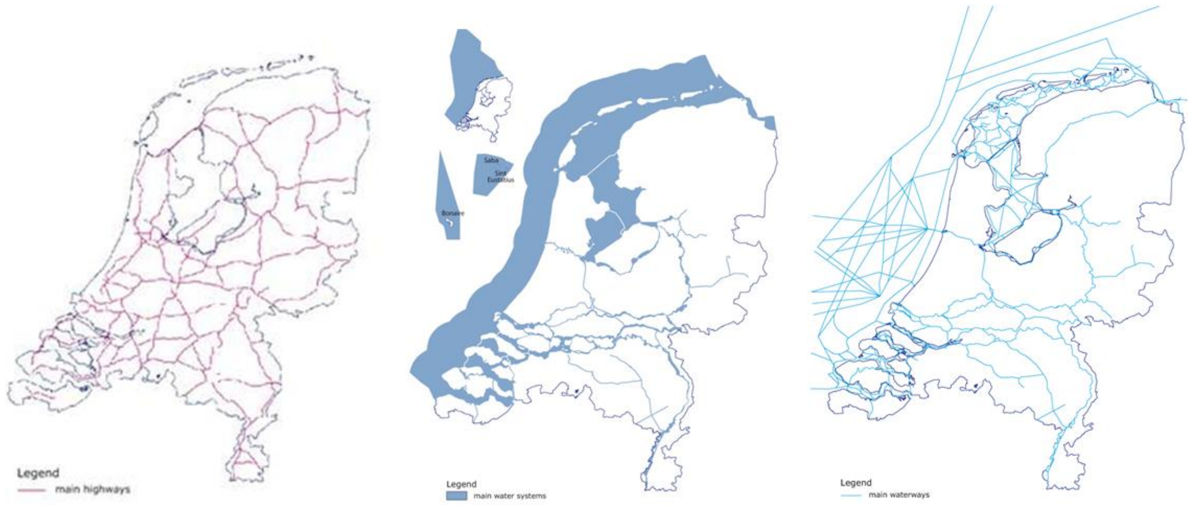


Figure 1: Overview of the main network of Rijkswaterstaat [1]

During mine internship I was located at Rijkswaterstaat Eastern Netherlands, District East. At this location I worked on an assignment project to look into the added value of performance and condition monitoring in the work process of the Asset Managers. The main content of the assignment is to generate the global overview of all the data and information flows in the organisation of Rijkswaterstaat. Furthermore, the possibilities of performance and condition monitoring are investigated and evaluated in order to determine the added value of monitoring in relation to the work process of Rijkswaterstaat and the Asset Managers.
Besides the fact that I gained a lot of practical experience and knowledge, I also got a great opportunity to look into the different provisions of Rijkswaterstaat and their working processes, tasks and responsibilities. Furthermore, I improved mine soft skills, such as communication skills and representing skills in a real setting.

I am very thankful to Dinant Schippers, my supervisor at Rijkswaterstaat, for giving me this great opportunity to work on this assignment at Rijkswaterstaat. Dinant guided me during my internship and took me to a lot of aspects of the normal working structure of the company, such as meetings, working visits of the assets, setting-up inspections, team organisation etc. It gave me a good overview of the working structure and entire working culture of Rijkswaterstaat.
Furthermore, I am Helma van de Voort very thankful for letting me visit other teams within Rijkswaterstaat and visiting organised creative and organisational sessions. It gave me a very good overview and impression of the work which is done at Rijkswaterstaat and the working culture and processes of Rijkswaterstaat. It gave me a lot in insight in all the potential working possibilities for me at Rijkswaterstaat.
I would also like to express my gratitude to Jan Braaksma and Sukon Wu, my enthusiastic academic supervisors for letting me do this assignment at Rijkswaterstaat.

Furthermore, I would like to thanks all the employees of Rijkswaterstaat that I have met during my internship for all their enthusiasm and interest in the company, their work, mine assignment and their knowledge of Rijkswaterstaat. Wherever I came, it always felt warm and open.
Finally, I would like to thank Rijkswaterstaat and the University of Twente to let me do this assignment at Rijkswaterstaat and gaining a lot of knowledge and working experience in a public company on an asset management level. During mine assignment, I got the opportunity to use the theoretical knowledge gained during my courses at the university. And vice versa, I gained a lot of practical knowledge about the implementation of a new working process and all the needed support and substantiation of theoretical knowledge in a practical manner.

Rijkswaterstaat
Ministry of Infrastructure and Water Management

Table of content

1 Summary

This report is written as part of the internship of Sven de Haan at Rijkswaterstaat Eastern-Netherland East. This internship is an part of the master program Mechanical Engineering at the university of Twente. The main goal of the assignment was to investigated the possibilities of performance and condition monitoring within Rijkswaterstaat and the working processes of the Asset Managers.

This report will first describe the organisation structure of Rijkswaterstaat. When the overall scope of the company is given, the normal working processes and methodologies of the Asset Managers are given. The stake- and shareholders related to a monitoring system are derived and the future information flows between the different stake/shareholders is visualized.

Later, the trends of monitoring within the industry are derived for performance and condition monitoring. Based on this literature research, the possibilities of monitoring within the organisation of Rijkswaterstaat and within the working processes of the Asset Managers are described. The goals related to the performance of the networks, the vision and targets of the upcoming years of Rijkswaterstaat and the wishes of the Asset Managers are compared to the possibilities of monitoring of the assets. Later on, the tasks and changing in the working processes related to monitoring are explained and related to the different phases of the life cycle of an asset of Rijkswaterstaat. At the end of chapter 4, a resume is given about the possibilities of monitoring within Rijkswaterstaat. The conclusions and further tasks chapter 5.

2 Introduction

In the industry, the performance and uptime of machinery is important. When systems are not operating, they create no added value for the company. So, it is important that the systems are functioning at the right minimum desired level. In the industry, there are certain Key Performance Indicators (KPIs) set which should be met during operating. This can be very different for each kind of product. Also, different participant can think different over how a system should operate. When analysing the performance of the system, the performance should be met to the KPIs in order to say something about the real level of performance of an asset (system/machine/product etc.). This could be in a quantitative (on time, lost time, quality control etc.) or qualitative (safety, motivation etc.) measurements [2]. The outcome of the comparison of the functional behaviour and the KPIs can say something about the overall performance of an asset.

The selection of the KPIs can be done in the design phase of a system (in order to come to a good design), but could also later be created during the operational phase of an asset (in order to meet customer requirements and wishes and the functional behaviour). In relation to the public sector, the KPIs will be mainly focused on the operational aspect of the system. If we take for example the infrastructure of a country, the different kind of transportation must be accessible and in a proper condition. Everybody wants a road that is always open and in a good state, but it is to the owner to maintain the road in such a way that the expectations of the drivers is (almost) always met.

According to [3], the traditional measurements of construction stakeholders (client, consultants and contractors) are shifting from the iron triangle (on-time, under-budget and according to specifications) to other performance indicators such as safety, effectiveness, satisfaction of stakeholders and reduced conflicts. In other words, the industry is departing form the traditional quantitative performance measurements to a rather mix of both quantitative and qualitative performance measurements on large-scale public sector projects. [3]

In relation to the performance of a system, the maintenance plan and strategy plays an important role in the performance of a system. Maintenance is done in order to repair the system or to prevent the system from failing. When a proper maintenance plan and strategy are pre-described and executed, the system should be in such a state that the performance will met the desired functional behaviour.

Large companies normally have a well-derived maintenance concept plan in order to keep their system at a certain required performance level. An important factor in deriving the maintenance concept plan, are the applied maintenance strategies. According to J. Fernández and A. Márquiz, there are five different maintenance strategies: Corrective maintenance, preventive maintenance, predictive maintenance, proactive maintenance and perfective maintenance, or called "Design-out Maintenance". [4]

There is a different goal behind each of these strategy:

- Corrective maintenance: A run-to-failure strategy. When a component of the system is broken, is will be replaced/repaired. This is doable for components that are less critical for the system or have less/no impact to the functional behaviour of the system;
- Preventive maintenance: A set of planned routines in order to maintain the system in such a way that it can always operate in the optimum level of performance;
- Predictive maintenance: By applying a set of analyses which can determine an reduction in function, or predict when failures will occur in order to maintain the system at the right time with optimal usage of the remaining useful life of the components;
- Proactive maintenance: A next step in the maintenance strategy is proactive maintenance. This strategy aims its actions at the root causes of the failures and not the failure symptoms. By looking at the root cause of failures, the configuration might slightly change (lubricant, redesign of parts) in order to improve the performance and extend the remaining useful life of the system [5];
- Perfective maintenance: This strategy is an improvement of the proactive maintenance strategy, whereby the services required for the maintenance tasks are improved as well, which could for example lead to the right amount of spare parts at the right desired location [4].

With the upcoming technology, the industry is now implementing digitization and intelligentization is a rapid speed. The term that is used in the industry with relation to the upcoming technology is "Industry 4.0". The central objective of Industry 4.0 is the need to fulfil the individual customer needs, while areas as management, research, development and utilisation of the assets are taken into account. This will have an effect of both the influences of the machinery and technology, as well as the human role in the entire production environment. [6] Industry 4.0 tries to convert ordinary systems in "smart" systems that are improving their overall performance and maintenance management in relation to its environment. With the introduction of an open and smart platform, it is possible to have an industrial-networked information system. The main needs for a system in the Industry 4.0 are being able to monitor real time data, tracking status of assets/subsystems and control the operational processes of an asset. [6, 7, 8, 9] Figure 2 visualise the most interesting topics in the industry 4.0.

It can be stated that the industry is shifting from an inspection oriented analysing system, towards a system wherein sensors are placed on the installed components in order to monitor certain parameters. Normally, inspection are done in order to determine the state of the art of an asset/component. This will be the input in the decision making process for determining the maintenance strategy and tasks. Nowadays, sensors are added to the system in order to make them smart. The sensor can measure parameters over a certain period of time. When the data is analysed and evaluated correctly, the maintenance tasks can be done at the right moment in time, which will result into the fact that the negative influences (unplanned downtime, extra damage) of the performance of an asset are kept as low as possible.

Figure 2: Industry 4.0

2.1 Problem statement

Since a few years, Rijkswaterstaat is implementing the concept of Asset Management into its organisation. The reason why the Asset Managers are added to the organisation is to find the optimal balance between the performance, risks and costs of the systems over the entire life cycle of these assets. Since there are certain performance requirements set by the management, there is not really insightful in how the performance of the assets are related to these requirements. At this moment, the level of performance of the network is mainly evaluated in reports which are done monthly or four-monthly. Since the report are only evaluating the performance of the main aspects of the networks, the reports are very global and some relevant information for the Asset Managers could be lost in the process. The missing information can be insightful for the Asset Managers of Rijkswaterstaat in order to have an increasing in the level of knowledge and knowhow of the assets under their supervision. The missing information can be related to specific performances of lower level (sub)systems of the asset under supervision.

Furthermore, a lot of data is collected on the lower levels of the assets, but this data is not much monitored or even evaluated. It is thought that the collected data might be helpful in order to increase the level of knowledge and knowhow of the performance and current condition of the assets/installed components. There might thus be some room for improvements of data monitoring and evaluating.

Rijkswaterstaat is also always improving their working methods and working processes. In the working processes of the Asset Managers, the Reliability Centred Maintenance (RCM) philosophy is adapted. The RCM methodology is used in order to have a better information about the assets, which can be used for contract of the maintenance tasks and activities. At this moment, the information about the assets is mainly based on regular or planned inspections. But, the information out of the inspections is not always specific enough. It is

thought that the usage of data can help the Asset Managers in order to improve their level of knowledge and knowhow of the current condition of the assets. [10]
Monitoring of performance parameters and condition parameters can thus assist the Asset Managers to increase their level of knowledge about the real time performance of the assets under supervision. Since monitoring is not adopted in the working methods and processes yet, and the sentiment is that it might be beneficial to use, the following problem statement is derived:

"To investigate the possibilities added value of performance and/or condition monitoring in the work processes of the Asset Managers of Rijkswaterstaat"

2.2 Organisation of this report

In order to determine a well-supported answer to this research topic, different tasks will be executed and evaluated. First of all, the organisation-processes, data-flows and information-flows will be created in order to give some overview of how Rijkswaterstaat works according to a top-down company analysis. This to determine how the company is organised and what the working methodologies and working processes of the Asset Managers are within Rijkswaterstaat. This is an important step, in order to have a clear overview of the entire company, how the information is shared and how different provisions are related to each other. Due to the fact that this assignment is focused around the organisational processes of the Asset Managers, this forms the baseline from where to start. Since it is possible that this becomes very wide, the main focus of this will be in the direction of the working methods and processes of the Asset Managers of Rijkswaterstaat. An extended stakeholders analysis will be used to investigate the different stakeholders and their focus of interests and tasks/responsibilities in relation to monitoring of the assets of Rijkswaterstaat.
Furthermore, a literature research will be performed about setting up and implement of a monitoring system for both condition, as well as performance monitoring and what the lessons learned are from literature on the topic of monitoring. When this is known, the translation from the required performance level (Rijkswaterstaat use the term SLA-PINS (see further information in chapter 3)) in relation to the performance parameters of the assets will be investigated. In this part, the possibilities for condition monitoring will be derived as well. The next step is how the implementation of monitoring will affect the working methods and processes of the Asset Managers. When this is known, the added value of performance and condition monitoring can be evaluated. The added value will firstly be described on a global process level and later be investigated in more in-depth added value of the work processes and work tasks of the Asset Managers.
Finally, the conclusion and future work are stated, followed by the references and the appendices.

Since this research is mainly focused on the organisational process of Rijkswaterstaat. The waterway system will be mainly used as a reference for the entire monitoring processes, this is done in order to specify the scope of the assignment. The lock complex Eefde will be used in order to make some aspects more specific and insightful in order to clarify aspects of the maintenance methodology and processes. Lock complex Eefde is used, because of the complex contain a lot of different installed installations (canal lock, pumping station, operating and control system etc.). Furthermore, a second canal lock is built by Lock2Twente, which will be a "smart" canal lock. Due to the this, the lock complex Eefde is part of a program ("Vitale Assets"), which focused on making the assets of Rijkswaterstaat easier to maintain by using all kind of data and data analysis. [11]

3 Rijkswaterstaat

3.1 Overview of the company

Rijkswaterstaat is an old organisation with a long history. Rijkswaterstaat finds its origin back in 1798, when the organisation "*Bureau voor den Waterstaat*" is founded, which is in 1848 renamed to "Rijkswaterstaat". The most important tasks are the construction, management and maintenance of rivers, canals, flood defences, dams and draining. Over this period of time, Rijkswaterstaat gained a lot of knowledge about the water management, new materials and technologies. This eventually resulted in the main infrastructure which lays in the Netherlands. One of the biggest disasters, the big flood of 1953, resulted in maybe the biggest achievement of Rijkswaterstaat nowadays: the Delta Works. The American Society of Civil Engineers declared the Delta Works to one of the seven modern wonders of the world.

Rijkswaterstaat is part of the Dutch Ministry of Infrastructure and Water Management and responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands. This includes the following networks:

- The main road network;
- The main waterway network;
- The main water systems [12].

> "Our road inspectors, traffic centers, lock masters and water management center Netherlands are working 24 hours a day in order to keep the water management reliable and safe and to travel fast from A to B on the road and on water for all users. We act as fast as possible on accidents and go in action at calamities and crisis's as a result of extreme weather."
> **Karin Visser**
> Hoofdingenieur-directeur Verkeers- en Watermanagement [76]

An overview of the three network systems is given in Figure 1. Rijkswaterstaat is the executive agency of the Ministry of Infrastructure and Water Management dedicated to promoting safety, mobility and the quality of life in the Netherlands. Besides the tasks of involving executing project in the roads and waterways, Rijkswaterstaat must also balancing the interest of the economy, the environment and the quality of life. Therefore, Rijkswaterstaat is working together with citizens in creating their living environment and works closely with companies, research institutes and water boards for example. Together, they are all working on the task to create sustainable solutions in order to promote safety, mobility and the quality of life in the Netherlands. [13]

Rijkswaterstaat is working hard to keep the Netherlands on the move, which must be done in reliable and available way. This due to the fact that the Dutch economy relies heavily on transportation and logistics. So, for this reason the highway and waterway network must remain accessible and safe over the entire year. This is a great responsibilities, due to the fact that Rijkswaterstaat is responsible for many assets, such as 3.046 km of motorways, 2.749 viaducts, 13 ecoducts, over 6.000 km of rivers and canals and more. Furthermore, Rijkswaterstaat keeps the Netherlands safe by keeping the coast line in a good condition, managing the water level over the entire waterway and water system network and provide sufficient clean water. [14, 15, 16]

In order to make this possible, Rijkswaterstaat has 8700 employees which are working on national, regional or district level. Rijkswaterstaat splits the Netherlands in seven different regions, which all consist of some districts.

On national level of the organisation, the policy and frameworks set by the government and the European Union are translated into a vision, work processes and objectives of Rijkswaterstaat. Rijkswaterstaat on national level is the chain between the different ministries and the work floor of Rijkswaterstaat itself. On national level, the management is accountable for the entire performance of the three network systems. When the goals of the ministry are not met, the management is accountable for the results of the performance. Furthermore, the budget received from the ministry must be divided over the different regions and districts and for new big projects. This division is based on the P*Q-method, where P stands for the price of certain tasks and Q the different objects and their operation and maintenance policies. [17, 18]

At region level of the organisation, the national vision of the management is translated to a more specific vision that can be executed on the district level of the organisation. The region is accountable for the performance of its districts. This contains besides the three network systems also management tasks and goals, such as innovation and improvement projects. Rijkswaterstaat has a lot of assets to manage. The asset owner is the ministry, but the management of the operating and maintenance is done by Rijkswaterstaat. The actual work is normally done by external market companies, which are working according to a contract.
Rijkswaterstaat is working with different contracts in order to do the operation and maintenance management of the different objects which are under control of Rijkswaterstaat. These kind of contracts are: DC (Design and Construct), E&C (Engineering & Construct), PC (performance contract) and DBFM (Design, Build, Finance and Maintain)[1]. The performance contract is made for multiple years and covers the regular and variable maintenance. The E&C contract are small investment and variable maintenance with certain required detail-engineering. The D&C contract are related to the design and construction of new infrastructure. The DBFM contract are big investments where the contractor is responsible for the design, construction, finance and also the maintenance tasks for a certain period of time (normally around 25 years). At this moment, Rijkswaterstaat wants to implement a new form of contract, a p-IHP (prestatiegestuurde instandhoudingsplan, or "performance-driven conservation plan"). This new form of contract must result in a better performance of the assets. Nowadays, the PC contract is focused around the performance of the service provider, while the p-IHP will be focused on the performance of the assets itself. The new contract must stimulate the service provider more, in order to keep the assets available and reliable as much as possible according to the set performance baseline (this will be discussed later). [19, 20]
On district level, the employees are responsible for the performance and condition of the objects within their district. On district level, the interface between the contractor, the industry, the surroundings (both people and environment) and Rijkswaterstaat itself is great. Between all these different stakeholders, many different aspects and motives are important. Rijkswaterstaat plays an important role in order to keep the performance of the objects as high as possible, the risks as low as possible and within its budget. Besides these three parameters, the laws and regulations, policies, requirements and wishes of the ministries, industry and surroundings must be met as good as possible. The district is normally the first contact point for the industry, contractors and surroundings if there are any problems.
Within each district, there are a lot of people working in teams with different expertise's and in-depth knowledge of the objects. At the level of the districts, employees are working on the keeping the information of the entire district up-to-date, are working on different policies such as maintenance plan, operational plan and risk management. This all to keep the assets at a desired level of performance.

Rijkswaterstaat is responsible for the performance of the three network systems. The ministry have an expected desired service level of the performance of the three networks. So, in order to determine the level of performance, the ministry have set certain required level of performances of the three networks. These requirements of the level of performances are called: *Service Level of Agreements (SLA)*. These are the top performance requirements of the three network systems. But, these performance requirements are a little bit abstract. To make this more quantifiable, these SLA requirements are translated into *Performance Indicator (PIN)*. With the PINs, Rijkswaterstaat is able to say something about the level of performance of the network in a more quantifiable way. Appendix 7.1 gives an overview of the set SLA-PINs that are now applicable work Rijkswaterstaat.

---

[1] All the contract of Rijkswaterstaat are according the principle of UAV-GC 2005, see further information at [in Dutch]: http://www.kabu.nl/wp-content/uploads/2016/05/UAVgc-2005.pdf

The SLA-PIN are defined by the ministry. The management of Rijkswaterstaat is translating the SLA-PIN in Management Contract (MC), which is an internal agreement of Rijkswaterstaat (a management contract from the goals and tasks from the management of Rijkswaterstaat towards the work). The level of performance of the assets is normally communicated to the management in two forms. The first one are the SLA monitoring reports (so-called T-reports), which are created three times a year. Once a month, RWS-dashboards are created that gives a small overview of the level of performance of that month. The reports are more a communication from the lower management towards the higher management. The reports and dashboards are more a communication tool, instead of a product to steer and act on. The idea is that the reports and dashboards are a way of supporting the steering process, but in reality, this is not the case. An overview of the agreements and reporting is given in Figure 3.

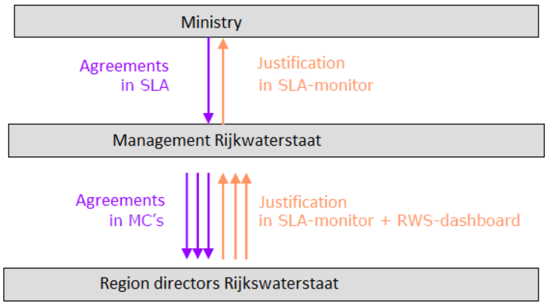


Figure 3: SLA-PIN and MC

3.2 Asset management at Rijkswaterstaat

Within the scope of the assignment, the relation between the work processes of Asset Management is important. Asset Management at Rijkswaterstaat can be expressed as: "Asset Management translate the organisation goals to asset-related decisions, planning and activities based on a risk-controlled approach. Asset Management is about management, methodologies and systems who must ensure that there is an optimal balance between the performance, risks and costs of the networks of Rijkswaterstaat. Connecting the organisation on strategic, tactic and operational level is called the *Line of Sight*. In all processes and organisation divisions there are interfaces with asset management." [21]

Since 2004, Rijkswaterstaat is implementing Asset Management in their working policy and processes. As said before, Rijkswaterstaat is part of the Dutch Ministry of Infrastructure and Water Management and responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands. Rijkswaterstaat is thus the executional organisation of the ministry of Infrastructure and Water Management. Due to this, the following hierarchy can be specified:

- Asset Owner: Ministry of Infrastructure and Water Management ;
- Asset Manager: Rijkswaterstaat ;
- Service Provider: Industry/contractor [22].

The asset managers are divided over different team, covering all the objects of the three main networks. Asset Management within Rijkswaterstaat is built on four pillars:

- All information about the asset must be up-to-date and right;
- Multiple years finance plan related to maintenance;
- Translate maintenance tasks to performance (performance-framework);
- Uniform market activation [20, 23].

The first pillar is about the information of all the assets owns by the ministry of Infrastructure and Water Management. The information must be both quantitative and qualitative. The quantitative information is about the number of asset owns by the ministry and what for (sub)systems are at these asset installed and must thus be maintained. In the quantitative information, the decomposition of the assets is a key factor. For every asset the information must be entered in the system according to the right norm (NEN 2767). The quantitative information of the assets is divided in six levels (example: Level 1: the main network (main water network), level 2: the system (Twentekanaal), level 3: system part (lock complex Eefde), level 4: asset (pumping station), level 5: elements (pump 1) and level 6: components (vacuum pump)) The qualitative information is about the conditions of the assets. When this information is all known, maintenance plans can be set up better in order to have the assets at the desired level of performance, in desired condition, with minimum risks and the costs as low as possible. The information can also be used in written the maintenance policies for the contracts and can be used as input for the financial programming of Rijkswaterstaat. [20, 23]

The second pillar of asset management is related to the financial programming of Rijkswaterstaat. According to the asset information, the maintenance need can be derived, which can be used as input for the new maintenance planning. In combination with the risk analysis of the asset (will be explained later), a financial overview is constructed whereon the budget over several years can be based on. [20, 23]

Fifth pillar: Life Cycle Costing

Besides the four main pillars of Asset Management, Life Cycle Costing (LCC) has an important influence on the decision making of the asset managers.

LCC is a method to determine the influence of the different possible solutions in relation to the costs over the entire life-time of the asset. These costs are related to investment, maintenance and management and possible demolition costs.

The important of LCC is always in relation to the decisions that the asset managers have to make of the asset. LCC is thus always a parallel tool to the process of asset management. [20, 23]

The third pillar is about the performance-framework of Rijkswaterstaat. The ministry sets certain baselines of the performance of the main networks of Rijkswaterstaat. These baselines, norms and framework are all related to the functional aspects of the network. This pillar is used to translate the performance requirements of the ministry to the right maintenance policy, planning and execution. Hereby, the influence of all the different stakeholders are also relevant. The users of the networks also have certain expectations that needs to be met as good as possible, this to prevent image loss of ministry and thus also Rijkswaterstaat. [20, 23]

The fourth pillar is the last chain to the market/ contractors. The asset managers must ensure that the performance framework set by the ministry are properly translated into the contracts. As explained before this can be in the form of one of the four contracts (performance contract, E&C-contract, D&C contract and DBFM contract). [20, 23]

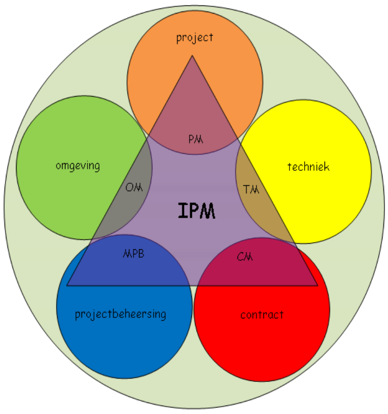


Figure 4: Relations in the IPM

Within the philosophy of asset management in Rijkswaterstaat, a model is created which is called: "*Integraal Projectmanagement Model (IPM)*" (Integral Project management Model). The model must ensure a better efficiency and flexibility of the employees, controlled guidance of projects and to operate according to an uniform and professional manner towards market parties. The IPM-model is visualised in Figure 4 [20]. Table 1 gives an overview of all the roles of the different management parts related to the IPM, which is visualised in Figure 4.

Table 1: roles in the IPM

Abbr.	Dutch	English	Role/tasks
PM	Project manager	Project Manager	Planning and control of the entire project
TM	Technisch manager	Technic Manager	Review of all the execution of all the technical processes
CM	Contract manager	Contract Manager	Everything related to the contract. Marker orientation, market consultancy, reviewing etc.
MPB	Manager project beheersing	Mangers project control	Financial Management, risk management, planning etc.
OM	Omgevings manager	Environment Manager	Internal and external relation management, communication, stakeholder strategy etc.

3.3 Asset management working methodologies

The asset managers at Rijkswaterstaat are working according to a certain working methodology and processes. As said before, the relation between the performance, risks and costs is a very important aspect of the Asset Managers. If one of the parameters is changed, this has a direct influence on the other ones, this result in the triangle of Figure 5 [19], where in the centre the assets/networks are stated. The Asset Managers always have to make decisions that are related to these three aspects. This in contrast to other stakeholders, that are only focused on one of the aspects such as finance or risk management. Furthermore, the Asset Managers must take into account the entire remaining lifetime of the assets, and not only focussing on the best short term solution, an example of this within Rijkswaterstaat can be seen in the highlighted text block "Example: long term decisions".

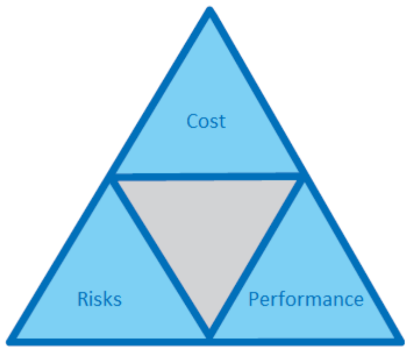


Figure 5: Triangle cost, risks and performance

For the asset managers at Rijkswaterstaat, there are two main methodologies that are important in order to set-up and control the working tasks related to the level of performance. These two methodologies are the ProBO methodology and the RCM method. These two methodologies are mainly focused around the operational phase of an assets, since these methodologies are closely related to the maintenance tasks of the assets. In the design of the assets, the requirements and wishes of for the design must be known and communicated to the design project teams. These are mainly related to the environmental and capacity aspects. The ProBO (Probabilistisch Beheer en Onderhoud, or in English "Probabilistic Management and Maintenance") and the RCM-method (Reliability Centred Maintenance) forms a main part of the working processes/tasks of the Asset Managers. The RCM-method is already partly integrated in the ProBO methodology. These methodologies are explained in more detail below.

"Besides the thee parameters Rijkswaterstaat can tweak (performance, risks and costs), image is also important, and maybe the most important one for Rijkswaterstaat."
Allert Weteringe
Senior Advisor Asset

3.3.1 ProBO methodology

For the asset managers, one methodology that have a relation with a lot of aspects of the asset managers is the ProBO methodology. ProBO can be defined as follows [24]:

"Risks guided manner of management and maintenance of assets, with which it can continuously be demonstrated that the set of RAMS performance requirements are met. "

This methodology has a lot of influence on the working processes of the asset managers at Rijkswaterstaat. Within the ProBO methodology, two key terms are important:

- Continuously control of the level of performance by applying the PDCA-cycle (Plan, Do, Check and Act). A clear overview of the PCDA-cycle is given in Figure 6 [25, 26];
- Focused on different aspects such as: Technic, Organisation (operational, tactical and strategical processes) and Contracts (marketing and finance).

Example: long term decisions
On 3 January 2012, the door of the lock in Eefde has dropped down. This due to a mechanical failure of one of the lifting components. When a new door was placed, the design was slightly changed to better divide the forces over the chains and cables. [79]
The installed new chains only have an expected lifetime of around 5-6 years. But, there was a great renovation planned over eight years. So, when the aspects of the asset managers were taken more into account, maybe another set of chains and cables were selected to cover the entire period till the planned renovation.

These two main concept are very close related to the tasks and goals of the asset managers. They both have also a relation to the triangle of cost, risks and performance. The asset managers are responsible for keeping the level of performance at the required level. This is always an iterative process, since new information, data, changes in laws and regulations and management decisions for changing policies and contracts as well. Besides that, the asset managers are also have sufficient in-depth knowledge about the assets of their acreage.

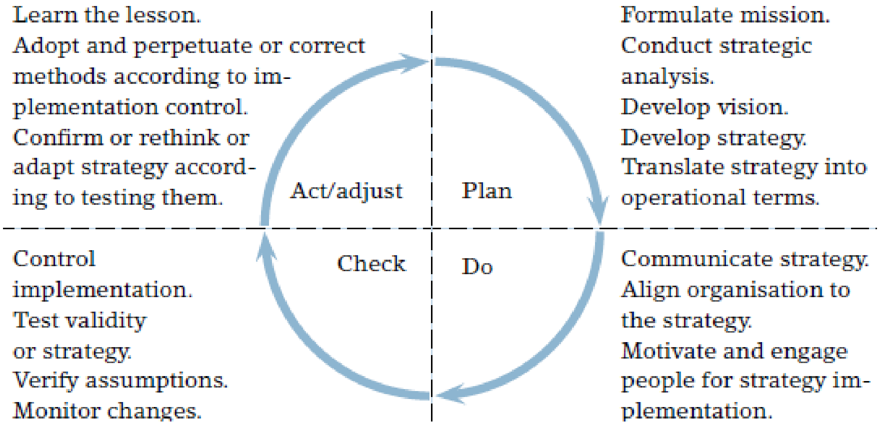


Figure 6: PDCA-cycle [25]

With the usage of the ProBO methodology it is possible to make the level of performance of the assets insightful, transparent and traceable. This is only the case when the ProBO method is fully implemented (At this moment, this is not the case for the entire organisation of Rijkswaterstaat. Normally, a global level of performance is known, but not always the in-depth relations to the assets). When the methodology is fully applied, it is possible to:

- Stay 'in control' over the acreage. No big surprises related to maintenance tasks and costs and safety risks;
- Demonstrably meet the laws and regulations;
- Optimise the costs and revenues related to maintenance;
- Economies of scale due to market (clustering of management and maintenance tasks);
- All roles, tasks and responsibilities are set and clear [24].

Within the ProBO methodology, the guide "Prestatiegestuurde Risicoanalyses (PRA)" is written. This guide translate the methodology into a workable process and more applicable information. In this guide, the RAMSSHEEP-aspects[2] are influencing the performance of the three network systems of Rijkswaterstaat. The goal is to determine an appropriate conservation plan for the assets, and thus eventually the entire networks of Rijkswaterstaat. [19, 27]
The basis of the PRA are two types of risk analyses, a qualitative analysis and a quantitative analysis. The qualitative risk analysis is based on a FMECA, a *Failure mode, effect and criticality analysis*. This risk analysis gives more insight in how the system fails, the risks of the failures and the probability and effects related to the RAMSSHEEP-aspects. When the risks are calculated, a maintenance plan can be derived. For most of the assets, this analysis is enough. Due to the fact that based on this analysis an appropriate set of measures is introduced to keep the chance of failure as low as possible. [19]
While the qualitative analysis focus on all the RAMSSHEEP-aspects, the qualitative analysis is only focusing on the Reliability and Availability of the assets. When assets are more critical or the change to failure is high, a quantitative risk analysis is performed. The goal of the quantitative risk analysis is to increase the reliability and availability of the assets to increase the level of performance. The quantitative risk analysis is an extended form of the qualitative risk analysis. Within the quantitative risk analysis, the failures due to four categories are analysed: hardware, software, human actions and external events. By analysing and modelling the possible failures that could occur, a more accurate probability

---

[2] RAMSSHEEP-aspects: Reliability, Availability, Maintainability, Safety, Security, Health, Environment, Economics and Politics.

can be derived for possible situations in the future. The most important tool that is used is the *Fault Tree Analysis*, which is used to derive a failure that could occur to the four categories, determine the redundancy of the system, the effect of selecting a certain maintenance strategy etc. As a result of this, the maintenance plan can be changed in order to increase the (expected/predicted) level of performance. [19]

3.3.2 RCM-method

Rijkswaterstaat is also using the RCM-method. The RCM-method is already implemented in the ProBO methodology. The quantitative analysis of the ProBO methodology covert most of the aspects of the RCM-method. The critical assets are the starting point of this analysis. By applying the FMECA is derived, the quantitative analysis is used. This involves the FTA and then modelling the assets in order to have a quantitative basis on which the maintenance plan can be based on.

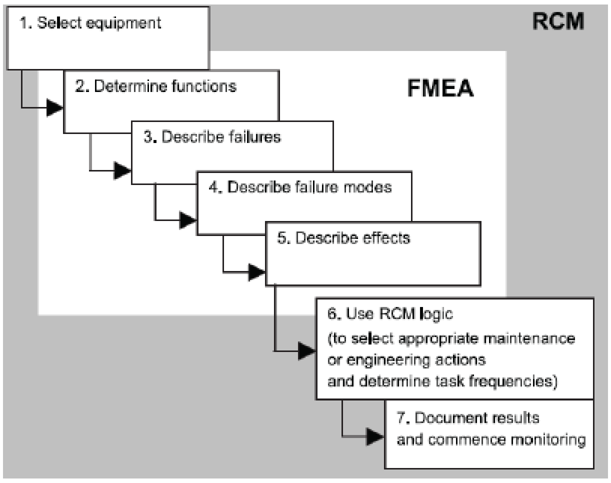


Figure 7: RCM steps [28]

This modelling is done in the RCM Cost model, developed by Isograph and Rijkswaterstaat. Hereby, the different maintenance policies are compared (only corrective maintenance versus preventive maintenance) and an optimal selection is used in order to derive the appropriate maintenance strategy for the assets. This is an small extension of the normal RCM method, which can be seen in Figure 7. The goal of the RCM Model is to more additional information and support for the future conservation plans of the assets. This to have a better insight of the performance, risks and costs of the asset over the long term. [28, 29]

Within the RCM Cost model of Rijkswaterstaat the following steps are taken:

- As input for the RCM Cost model [30]:
  - Document the physical decomposition of the asset (according to the NEN 2767);
  - Document the fail mode analyses of the asset (which are dominant failure modes of the physical decomposition);
  - Document the related maintenance analyses (how to repair and prevent the failure modes);
  - Document the safety analyses (which are relevant safety risks when a failure occurs, and during maintenance).
- As output of the RCM Cost model:
  - Execute a performance analysis (what if only corrective maintenance is done versus only preventive maintenance);
  - Balancing the costs, performance and risks of the maintenance strategies.

Is must be stated that the RCM Cost model only works with the current state of the assets, so no big renovations/overhauls are taken into account in the model. Furthermore, the FTA is not used in the model, only OF-ports (this takes not the redundancy of the assets into account. For example at complex Eefde multiply pumps are available so if one pump is not functioning, this will in reality not result in a failure of the entire system). Finally, the costs of the maintenance tasks can be

ProBO and RCM in practice

In 2012, Rijkswaterstaat in cooperation with Delta Pi performed a case study in relation to the ProBO guidance and RCM method. The subject of study was the IJsselmeergebied, wherein 7 locks are located. By analyzing the assets in relation to their functionality, maintenance and costs two scenarios are performed: Only corrective maintenance and only preventive maintenance. Two main conclusions could be drawn:

- The costs were for both cases at the same level
- The performance of the assets is improved a lot when only preventive maintenance is done. Three main functions improved a lot for their "not availability": draining (1.8% to 0.3%), locking (10% to 2%) and crossing (6.9% to 0.3%) [77]

reduced when the preventive maintenance tasks are clustered (this is not optional for the corrective maintenance tasks because they more or less randomly occur). [30]

3.4 Stakeholder analysis

Rijkswaterstaat is a large company, wherein multiple teams have different visions and responsibilities. As stated before, the relation between other involvers, such as the ministry, users, industry etc., are also important for Rijkswaterstaat. In order to have a better insight in the relevant involvers that could have a relation with performance and condition monitoring, an extended stakeholder analysis is performed [31].

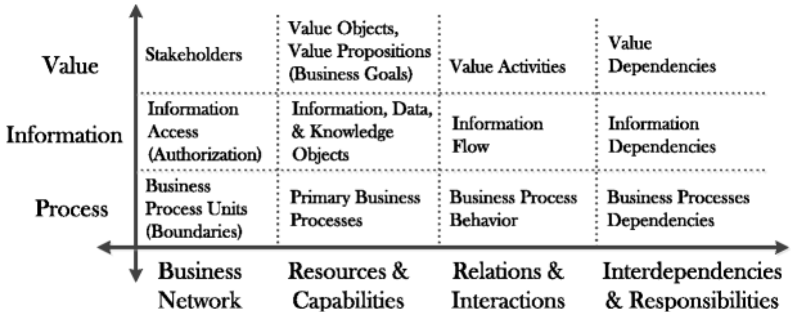


Figure 8: VIP-framework [31]

The extended stakeholder analysis performed by Solaimani et al. is focusing more on the interactions between the different stakeholders, instead of a traditional, more strategic analysis. The proposed framework analyses the interdependencies and dynamic operational arrangements between the different stakeholders, focused on the value (value objects (resources and capabilities) and value activities), the information (information streams and information needs) and the process (business activities of the stakeholders). By determining the influence of the different stakeholders to the Value, Information and Process a more accurate overview of the stakeholders can be obtained. Within the study of Solaimani, Guldemond and Bouwman, a framework is created to show the relevant information that must be kept in mind during the stakeholder analysis, related to the Value, Information and Process, which can be seen in Figure 8. This could make the relationships at strategic level, as well on an operational level more insightful. This could also reveal conflicted interests/processes.
A stakeholder analysis according to this VIP-framework is done and stated in Appendix 7.3 [31].

3.5 Data and information flows

As said before, the baseline of the minimum required performance are stated in the SLA-PINs. In order to report the level of performance of the assets/networks, data is collected into a report and presented in the form of RWS-dashboards and SLA-reports (T-reports) [32, 33], as is displayed in Figure 3. The data is collected through different sources. The most relevant are displayed in Figure 9. The normal information flow for the report is mainly through NIS. NIS is a central information collecting system and functions as a tool to create internal reports over the performance of the system. In the created reports, a lot of in-depth data is lost, but is still available in NIS, NIS and NIS-TIPS are

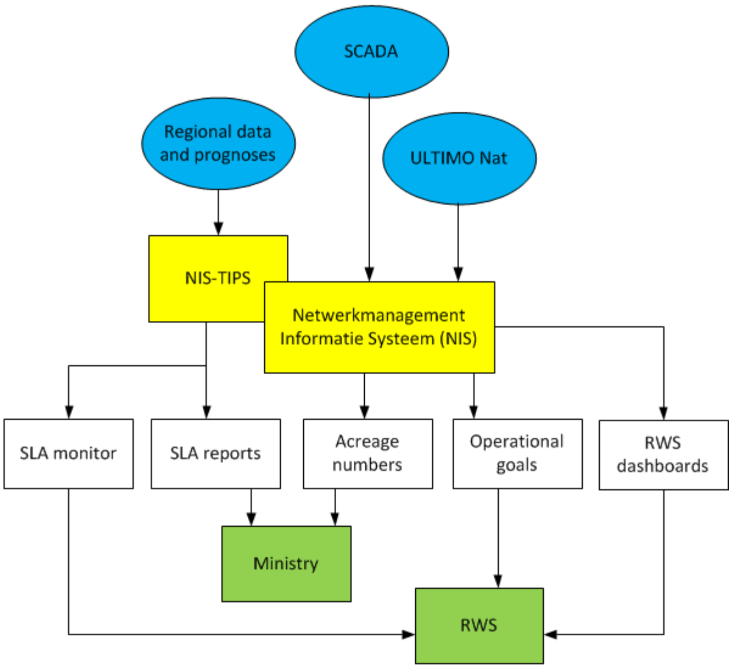


Figure 9: Information flow

explained in more detail below. Besides NIS, a lot of other data is documented, such as acreage information, different kind of inspections, analyses (FTA, FMECA etc.) etc. This information is mainly about one specific asset or asset complex. This information is internal (at district level) collected, saved and distributed. These document are related to different topics, such as safety management, failure behavior or explains more insight in the current state of the art of an asset. The opinion under the employees that at this moment the information is not used correctly, or the information given in the RWS-dashboards and T-reports is not useful.

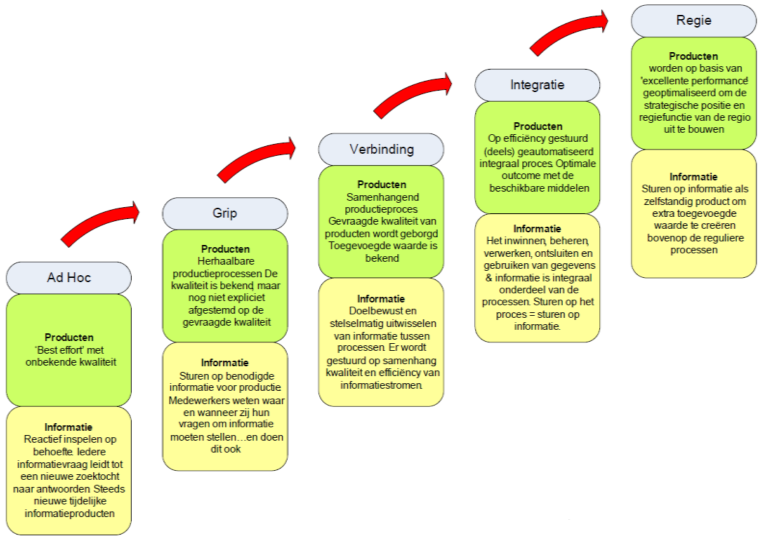


Figure 10: Level of information [Dutch] [34]

At this moment in time, the information winning and usage of the collected information is not at a desired level. Figure 10 [in Dutch], shows the possible levels of information collection and usage, in Table 2 the figure is translated to English. When the document was made (in 2016) the level of information collection and usage was somewhere between "Ad Hoc" and "Grip", which is currently still the state of Rijkswaterstaat related to the performance and condition information of the assets/components. The ambition of Rijkswaterstaat is to be at the level of "Integration" in 2020. It is stated that the available tools related to information collection must be in an effective way organized and partly automated. There must be an optimal outcome of the available data. The information must be an integral part of the work processes and must be used to steer the different working processes within Rijkswaterstaat. When the level of information is at the level of integration, the different teams and managers could potential work way better and can also support the requested financial resources and steer the service provider by the available data. [34] The level of information is mentioned, since data can give more insight in the usage and behaviour of an asset/component. The processed data can give in-depth information about the performance and condition of the installed system.

Table 2: Level of information

Level	English	Products	Information
Ah hoc	Ad hoc	"Best effort" with unknown quality	Reactively respond to need. Every information request leads to a new research of answers. Always new temporary information products
Grip	Grip	Repeatable production processes. The level of quality is known, but not explicit aligned with the requested quality	Steering at needed information for production. Employees know when and where to ask for information, and do this too
Verbinding	Link	Coherent production process. The requested quality of products is guaranteed. The added value is known	Deliberate and systematic exchange of information between processes. The focus in on the coherence, quality and efficiency of information flows
Integratie	Integration	At efficiency controlled (partly) automated	The collection, management, processing, unlocking and usage of

		integral process. Optimal outcome with the available resources	data and information is an integral part of the processes. Steering on process = steering on information
Regie	Direction	Are optimized on the basis of excellent performance to develop the strategic position and direction of the region	Steering on information as an independent product to create extra added value on top of the regular processes

The next section will give an overview of the different information systems that could be relevant in order to see the performance and condition of the assets of Rijkswaterstaat. This is on all kind of levels within the organisation.

NIS/NIS-TIPS

Within Rijkswaterstaat, NIS is used to get a better insight in the financial and personal numbers, as well as the performance indicators of Rijkswaterstaat and its services for all the three networks. This system collects a lot of source information that will be used to create different kind of report, as can be seen in Figure 9. Normally, the data obtained for the NIS-system is automated. The information is obtained for systems such as SCADA and Ultimo. Some data is implemented manual, this is mainly the case for NIS-TIPS. In the NIS-TIPS, information, both manual and automated, is used to create different reports (SLA monitor and SLA report), the manual information can be prognoses and additional information that explains some remarkable numbers/trends in the reports. [35] An overview of the information flow of NIS/NIS-TIPS is given in Appendix 7.2 (appendix is in Dutch) [36].

Ultimo Nat

Ultimo is a maintenance management system, which is both accessible for the service provider, as well as Rijkswaterstaat. In Ultimo all kind of information can be founded. First of all, the planned maintenance tasks are uploaded with the task and the intervals. This contains the standard preventive maintenance tasks, as well as planned inspections. Furthermore, the errors that occur in the assets is reported and the provided solution and handlings. Besides the maintenance tasks and policies, the information of the assets and the decomposition is documented as well in Ultimo.
Rijkswaterstaat is using Ultimo in order to obtain:

- Get insight in the actual status of the acreage in relation to legal requirements;
- Make maintenance policies;
- Inform future service providers;
- Based on information in Ultimo a judgment of a suggested improvement of the service provider can be made [37].

Within Rijkswaterstaat different versions of Ultimo are used. In the team Asset Management of lock complexes, Ultimo Nat is used.

SCADA

SCADA, or Supervisory Control And Data Acquisition system, is a system for data collection, monitoring and steering of processes. SCADA data could be used for real-time monitoring of different sensor/system data. These data-parameters are monitored with a fixed frequency. Furthermore, SCADA can be used for data-logging. This is event data that is logged when certain errors occur or when the system is (de-)activated. [38]

ODS data
ODS is the abbreviation of Object Data Services. It is a real-time data software to monitor sensor-information of assets of Rijkswaterstaat, such as locks and bridges. This is a safe, uniform and standardised way of passing along the sensor data to authorised receivers (this could be Rijkswaterstaat Data lab, but also boatmen to determine their routes).
Furthermore, the sensor data could be used to say something about the current state of the art of the assets. By monitoring the behaviour, usage and performance it could be possible to predict the maintenance of the assets/components, which could eventually result in a better, simpler and cheaper maintenance policy. The possibilities of using sensor data in relation to predictive maintenance is part of the program "Vitale Assets" of Rijkswaterstaat. [39, 40]

Asset data
In data collection, the data be distinguished: event data and real time data. Event data is data that is logged when a certain activity occurs, which can be a failure or starting/shutting down the system.
Real time data is the continues data collection of sensor data. This could be load data, usage data etc. [57]

IVS90
IVS90 is the "*Informatie Volgsysteem voor de Scheepvaart*", or Information Following system of the Shipping. All kind of organizations at different levels (Rijkswaterstaat, provinces and harbour companies) are using this system in order to have a better insight in the management of the waterways. It is used by the traffic posts to guide the ships, provide support systems for operating locks and bridges and could inform the emergency organization when a calamity happens. The system is mainly focused on the inland shipping on the Dutch waterways. [41]
The information is used in order to determine the value of the PIN 1,2,3 and MC PIN 8 for the level of performance of the network system.

Object expert
Finally, every asset has an object expert. This person is the first contact person of Rijkswaterstaat. He is normally also the person that know the most about the asset. He or she has in-depth knowledge of the asset, how the system is working, what kind of machinery is in place, when big errors/calamities occurred, as well as the history of the components etc.

Service provider
The service provider performs the maintenance itself. As well as the object expert, during their contract period they gain a lot of knowledge and knowhow of the assets. During the contract period, they obtain a better insight in the more critical failures, the failure frequency and the state of the art of the assets. With this insight, the maintenance policy could be done in a better way in order to increase the aspects of the RAMSSHEEP methodology.

Pilot: Vitale assets
During different sessions part of the program of Vitale Assets, it came forward that the implementation of sensor data and data analyses has impact on different working processes of Rijkswaterstaat, as well as of the service provider.
By a successful implementation, it is possible to decrease the failure costs of the components and it could provide a better cooperation between the service provider and Rijkswaterstaat, since the service provider could demonstrate that they perform the maintenance at the desired level set by Rijkswaterstaat. [42]

3.5.1 Overview of the relevant stakeholders and the information flows
Figure 11 and Figure 12 give an overview wherein the different stakeholders and the information flows are displayed. Only a global information flow is given. In reality, the information flow is very complex and a lot of interaction between the different stakeholders is required to have well-functional assets and teams.

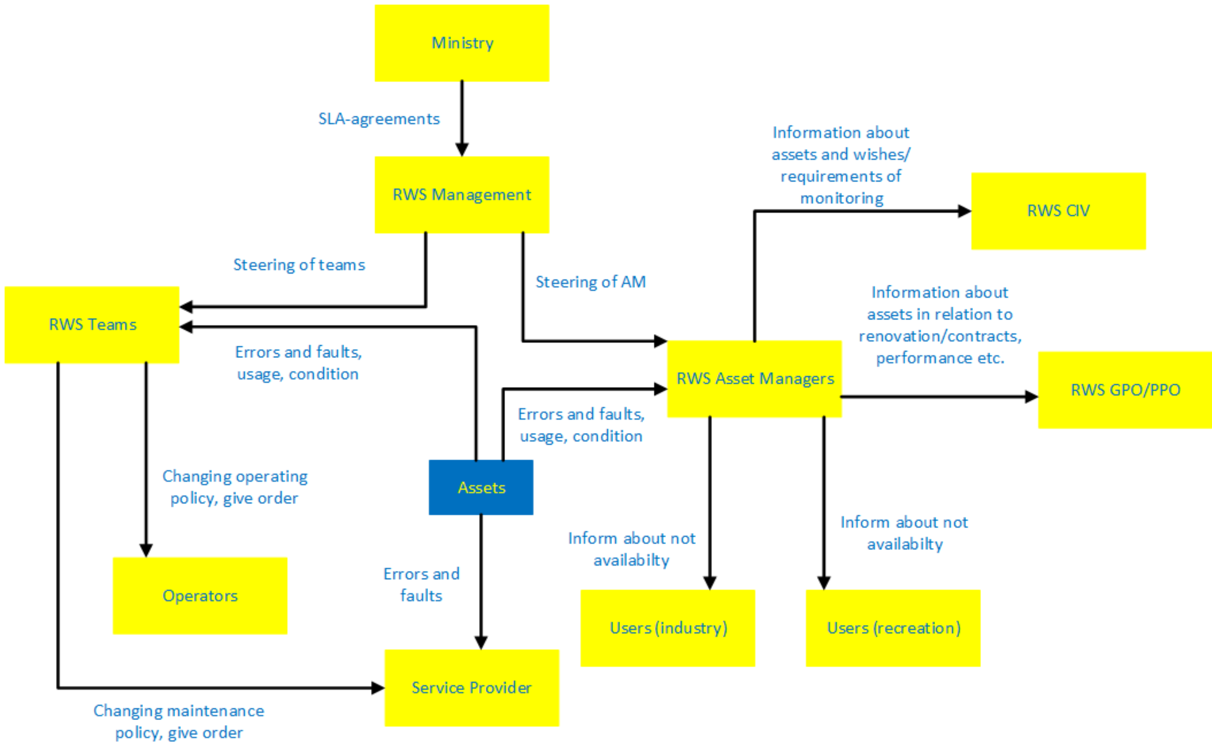


Figure 11: Overview of stakeholders and information flow

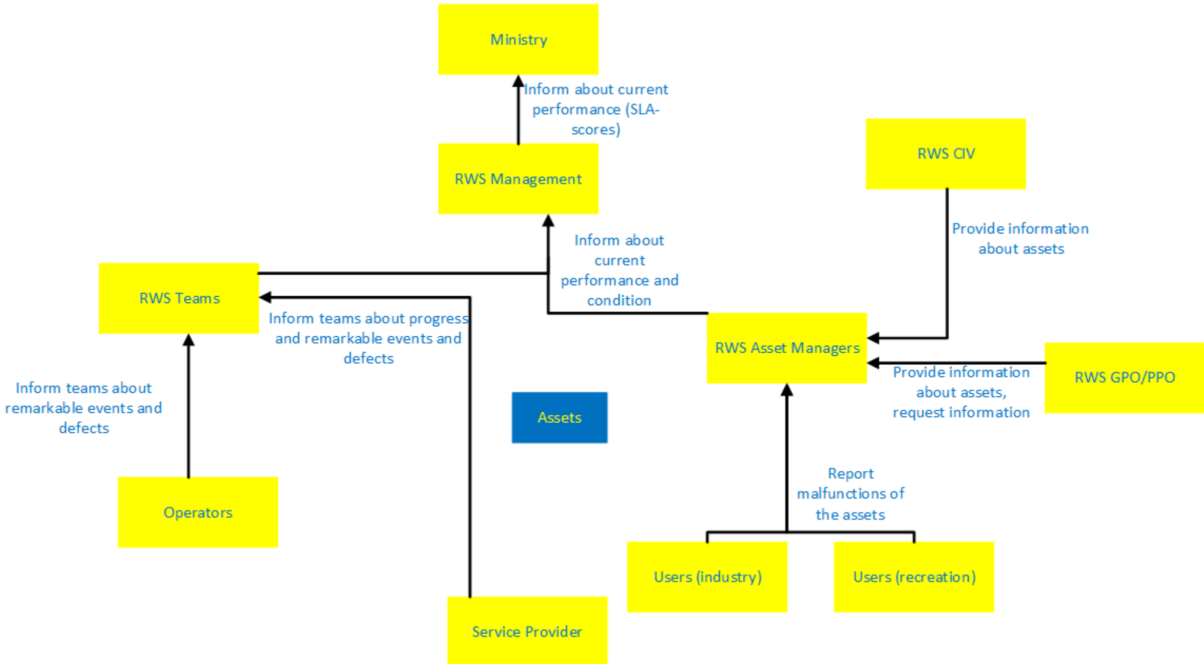


Figure 12: Overview of stakeholders and information flow

4 Possibilities of performance and condition monitoring in Rijkswaterstaat

This section of the report will describe the possibilities of using performance and/or condition monitoring in Rijkswaterstaat. First of all, the vision and objectives ideas of Rijkswaterstaat about a monitoring systems are stated. Followed by an overview about data monitoring systems related to performance and condition, which is based on literature. Subsequently, the vision of Rijkswaterstaat will be compared with the different possibilities in the industry, the assets of Rijkswaterstaat and the working methods and principles of the Asset Managers. The added value of a monitoring system will be defined. Finally, the implementation of a monitoring system in the working processes and policy of the Asset Managers will be discussed.

4.1 Vision about data monitoring in Rijkswaterstaat

In Rijkswaterstaat, there is already a global idea about monitoring of assets. The ideas and thought are specified in this subsection. An internal program of Rijkswaterstaat, Vitale Assets [42], is currently doing some pilots in order to set-up different kinds of monitoring systems. Different assets are now, or will be in a short period, equipped with sensors for further analysis related to performance and condition monitoring, such as the Bernard locks, canal lock Eefde and the locks of Ijmuiden [11, 42, 43].

As mentioned before, Rijkswaterstaat works almost on an ad hoc base. In other words, Rijkswaterstaat works mainly as an error controlled organisation, or else standard preventive maintenance is done according to a specified time interval (which could be far from optimal based on the usage and/or condition of the component). By applying monitoring, it is possible to have a better insight in the functional behaviour and current state of the assets/components. When the data is analysed properly, follow ups may occur (for example the time interval of preventive maintenance tasks could be changed, in order to use more of the remaining useful life). Furthermore, it might be the case that the data shows remarkable numbers/trends that needs to be analysed. For example, this could result in a change in the RCM Cost model if number of failures are deviating a lot compared to the initial guess.

It must be stated that the information obtained from the different analysis fully reliable. Some data contains noise, the sensors are given wrong numbers and errors can still randomly occur. As quoted form Joris ter Heijne from Delta Pi[3]: "The biggest error that people can make related to data analyses, is the fact that results from the past are no assurance for the future."

> "As Asset Manager at Rijkswaterstaat, I want to have a proper support to base my decisions on. As Asset Manager, I want to act and steer with a proper information support, instead of working and reacting ad hoc and without proper information support."
> **Dinant Schippers**
> Senior Advisor Asset Management

For Rijkswaterstaat it is very important to have a clear view of what is possible with the data, as well as the integration with the different decision making processes. There are already some thoughts and ideas related to a monitoring system for Rijkswaterstaat. These are stated below:

- Prevent functional losses: By checking data, it is possible to prevent functional losses due to pro-active signalling of certain parameters;
- Gain more insight in the usage of the assets/components;
- Pro-active maintenance: When returning errors occurs, this could be an indication for a problem in the system. By checking where the source of the error is, a solution could be provided and thus a better system will be obtained;
- Steering on maintenance process: Based on information, Rijkswaterstaat has a better insight in the performance of the service provider and could speak with the service provider if necessary;
- Better decision making support: Based on correct and relevant information, better decisions could be make, wherein all the aspects of the RAMSSHEEP must be evaluated [44].

[3] Joris ter Heijne, consultant Delta Pi, conversation on Tuesday 24 April 2018.

During the determination of the possibilities and implementation in the working processes of Rijkswaterstaat, these needs must be kept in mind.

4.2 General monitoring set-up

As S. Altman says about monitoring: "All performance monitoring systems are composed of three major components: a data component; an analytical component; and an action component" [45]. The data components consist of a framework wherein a system is measured and the data is collected, which is relevant for the performance of the system. The analytical components provide a framework for processing the data. The data must be extracted from the data component and distributed to who need to know and put it in an appropriate analysis. Finally, with the result of the analytical component, acting on the information is necessary in the action component. Actions can be taken to different aspects of the organisation where problems could have occurred, such as unacceptable worker performance, inadequate job engineering etc. [45] The framework of Altman is visualised in Figure 13. This framework is initially designed for performance monitoring of a public organisation, but the basic framework is also applicable for condition monitoring, this since the same steps will be used during the whole process of data collecting, analysing and acting. The study of Altman is in line with other studies, such as the research of Jardine, Lin and Banjevic about a review of implementing condition-based maintenance [46].
The research of Veldman, Klingenberg and Wortmann state an additional fourth step, which is called the "implementation". The output of the decision making step must be implemented and evaluated. This fourth step has a large overlap with the plan step of the PDCA-cycle, which is used within Rijkswaterstaat in order to implement and evaluate new tasks/decisions. [47]

Figure 13: Framework of data by theory of Altman

Condition-based Maintenance program
In line with the research of Altman [45], the research of Jardine, Lin and Banjevic shows a similar outline for a data driven CBM program. They also stated that the program consist of three key steps:
- Data acquisition: obtain data relevant to system health;
- Data processing: handle and analyse the data or signals for better understanding and interpretation of the data;
- Maintenance decision-making step: to recommend efficient maintenance policies [46].

The next subsections will explain the possibilities of monitoring and how it would fit in the working processes of the asset managers of Rijkswaterstaat.

4.3 Performance monitoring

If we compared the how performance is determined within Rijkswaterstaat (according to the SLA-PINS), it can be concluded that this is closely related to KPIs, or Key Performance Indicators. When a certain performance has to be monitored, a required level of performance is normally stated as this KPI [48, 49]. The system has to fulfil to this required level, or the system is not functioning well enough according to the specified targets. KPI are used in order to control the achievements of the goals of the enterprise. The use of KPI enables the operationalisation of these targets set by the company. And "KPI also correspond to the requirement of that targets and their degree of attainment need to be measurable" [48]. By analysing the parameters that have an influence on these KPI, it is possible to say something about the level of required performance of the company. [48, 49] Nowadays, the performance of an asset/component is evaluated digitally and real-time visualised on screens in the form of graphs and meters.
As stated in section 3.5, a lot of data is collected but not analysed. Rijkswaterstaat collects a lot of information through different data systems, such as SCADA, NIS and Ultimo. The data that is nowadays used in the analysis and documents of Rijkswaterstaat is almost only on global level (general information obtained from NIS), which is just a very minor part of the collected data. This information is used as input for different reports (T-report/SLA-report, RWS dashboards etc.). In other words, a lot of data is collected and saved, but not properly analysed or even evaluated. As stated before, Rijkswaterstaat does

want to work better with the collected information. As Figure 10 shows, Rijkswaterstaat does not want to work at the level somewhere between "Ad hoc" and "Grip", but at the level of "Integration" by 2020. This have a major impact on the information and data aspect of Rijkswaterstaat. The level of integration says that the information must be collected, managed, processed, extracted and used as part of the processes. The idea is that the information has an influence on the steering of the processes within Rijkswaterstaat. This is also the case for the level of information, since the information about the usage and performance is a task of the Asset Managers as well. The information about the performance, besides the network as well as the other installed components, must be up-to-date and accurate. [34]

The term "performance" is a wide concept in Rijkswaterstaat. This is due to the used terminology within Rijkswaterstaat related to the word "performance". In Rijkswaterstaat, two main categories can be created that both have its own interpretation of performance. The first one is related to the main networks, while the second one is related to the assets:

- Network performance: The performance of the main networks is related to the contracted SLA-PIN. The SLA-PIN, which can be seen in Appendix 7.1, are a global indication of the performance of the main network of Rijkswaterstaat itself. This network performance is mainly used to inform the higher managers of Rijkswaterstaat of the current state of the performance of the main networks.
- Asset performance: The performance of the asset or components itself, instead of the entire network. The performance is in this case more related to the operational aspect of the asset. In asset performance, the assets are evaluated individual instead of the relation to the entire network. Now the assets are placed in the centre of the attention, different parameters will become relevant, which are not used/useful in the network performance. This due to the different audience of the information. While network performance is more global and orientated to inform the higher managers of Rijkswaterstaat, the asset performance is considered by the asset managers and teams as more important in order to gain more insight in the operational aspects of the assets.

Complex Eefde
As is stated, there are different ideas about performance. First of all, the network performance of the complex. This will be mainly concentrated about the amount of (un)planned maintenance time slots. Furthermore, the passing times of the ships through the canal lock must be within range.
But, there are also other functions in the complex. The water level of the canals must be within range. Due to the pumps and the drainage works, the water level must be within range. The amount of pumped water has a close interface of Rijkswaterstaat with the water agencies. These are using water of the canal for underlying lands. This might not be the main function, but is still a performance of the entire complex.

Since there is a main division between the two kinds of performance, this will also have an impact on the goal of the information gathering, processing and acting. The network performance can give a global indication of the main performance of the assets, while the asset performance will be more relevant for the asset managers to be used to steer their processes and decision making.
From a conservation with Martijn van der Boor, it came clear that direct real time monitoring of the SLA-PIN is not doable at this moment. The level of performance of the network could already be subtracted from NIS. The information behind those numbers can be found in the relevant input data. The data in NIS is mainly obtained from IVS90 for Rijkswaterstaat waterway systems. [43, 50]

As stated in section 3.5, different kind of information systems can be used as relevant input information for monitoring. An overview of the information systems is given in Table 3 and their advantages and disadvantages. The table is only including the information systems and not persons (object expert and service provider). These systems can namely play an important role in the monitoring system for Rijkswaterstaat. [50, 43, 51, 52]

Table 3: Information source for performance monitoring

Information source	Kind of performance	Advantages	Disadvantages
NIS/NIS-TIPS	Network and asset	Gives a proper overview of the state of the performance of the asset within the entire network. SLA-PIN score can be extracted with right information.	Only gives a global overview, based on other information sources. Specific information is not given.
Ultimo Nat	Asset	Amount of errors can be obtained per asset, and even per system. Specific information is given about errors (not always).	Data is not always correct. Difference between the time logging in SCADA. Depending on the input quality of service provider.
SCADA	Asset	Correct time logging of errors. Potential high quality and quantity of error information.	A lot of errors are not relevant. Information interpretation is difficult
IVS90	Network and asset	Fixed form of input information. All information is relevant. Actual and reliable.	Limited information about origin of errors. Not always fully covering.
ODS data	Asset	Real-time parameter visualisation.	Interpretation can be difficult, depending on the level of knowledge of user and asset knowhow. Not all parameters are relevant to monitor.

The steering of the process is both related to the performance aspect of the assets, as well to the condition aspects of the assets. While the framework of collecting and analysing data is the same, the results and actions/follow-ups will be different for both cases. This is due to the fact that condition monitoring will be more orientated to the condition of the assets (and thus related to the maintenance plan/tasks), while the performance is more related to the operational aspect of the installed systems. This aspect will be evaluated in section 4.6.

4.4 Condition monitoring

Besides performance monitoring, condition monitoring for Rijkswaterstaat is also optional. Condition monitoring is the process of determining the condition of assets, while they are still in operation. Condition monitoring is normally using historical data in order to predict the moment of failure in the future. Condition monitoring is thus closely related to the maintenance tasks and processes within a company. [53, 54]
By applying condition monitoring, the real time condition of the asset can be determined according to sensor data. By applying sensors, the parameters can be monitored that are relevant for the systems behaviour and are an indication for the remaining useful lifetime of an asset/component. When the analysis of the data is done correctly and the results are matched with the given system information and failure behaviour, it is possible to predict the failure behaviour in the near future. By using condition-based monitoring and the theory of predictive prognostics, it is possible to make better choices related to

maintenance policies and maintenance tasks. This fits well in the concept of e-maintenance, see text block.

E-maintenance covers well functional usage of a monitoring system what is suitable for Rijkswaterstaat. But, the research of J. Lee et al. describes a transformation map, wherein different maintenances strategies are related to a system complexity and uncertainty. Also, the map displays future trends in the maintenance strategies. The map out of the research of J. Lee et al. is shown in Figure 14. [54] The current situation of Rijkswaterstaat is between CBM (condition based maintenance) and RCM (reliability centred maintenance). The maintenance baseline for Rijkswaterstaat is currently based on the Fault Tree Analyses and FMECAs of assets. Furthermore, the RCM Cost model can be used for a prediction of the maintenance strategy and activities, in relation to the RCM methodology.

E-maintenance

E-maintenance, or excellent maintenance, is a part of excellence manufacturing. The idea is to have efficient maintenance (fewer people, less money), effective maintenance (improve RAMS) and enterprise maintenance (contribute to company performance). With e-maintenance, the idea is to use sensors and controllers on systems. By analysing this data in condition-based monitoring and use the theory of predictive prognostics, it can help the employees to make better decisions and plan better, according to the data obtained from the analyses. This is a key element in order to satisfy the operational requirements and improve overall system performance. [56]

If the assets of Rijkswaterstaat are mapped in the transformation map of J. Lee et al. the maintenance methodologies that can be used, can be improved. This is based on the fact that the complexity of the asset and the uncertainty match more with e-maintenance and prognostics and health management (PHM). [54] A robust design is almost not doable for Rijkswaterstaat. This since the lifetime of assets is very long and during this period of time the internal degrading of components and external influences (environment and accidents) that makes it almost not doable to implement a robust design. [54, 55] The research of J. Lee et al. stated that preventive maintenance is only doable for assets/systems that have a very specified operating range and operating environment. The assets of Rijkswaterstaat almost all have a wide range of operating environment and the usage of these systems is not constantly used or with a very strict operating range. Due to this, preventive maintenance is not applicable for Rijkswaterstaat. [54]

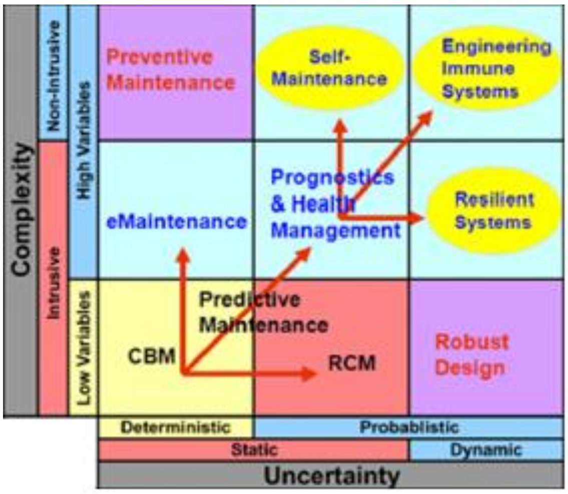


Figure 14: Maintenance transformation map [54]

The topics of self-maintenance, resilient systems and engineering immune systems are trends that may be used in the future. But, according to the complexity and uncertainty of most of the assets, these topics are not relevant to be used as a maintenance strategy. According to the level of complexity of the assets and the uncertainty, it might be useful to check the possibilities of e-maintenance and/or prognostics and health monitoring. [54]

The e-maintenance concept described in [56], can be the first step in the integration of data monitoring within Rijkswaterstaat and Asset Management. When the initial set-up of data monitoring is successful, Rijkswaterstaat can shift from a e-maintenance strategy towards a PHM strategy. This is in line with the research of Tiddens et al. [57], that states that monitoring systems are evolving over time. Besides the chosen monitoring strategy, the required maintenance analysis/analytics must be in line with the goal of the monitoring system [56, 57, 58]. Appendix 7.5 gives examples of filters that are useful for condition monitoring of technical components

By analysing this data, it is possible to change the maintenance policy, which is at this moment preventive maintenance in a fixed interval, to a maintenance policy that is closer

to the end of lifetime of the components. This could result in a better usage of the components, which is besides the economical aspect also more environmental friendly. Furthermore, the maintenance policy could be optimised, wherein the remaining lifetime is maximum used. But, there might be some differences between components. Where some components are rely depending on the system usage, some components are only related to the time they had been used. It might be so that some components have a very small risk and minimum cost, that a policy of run to failure could be applied.
The information sources for condition monitoring within Rijkswaterstaat are less than the possible information source of performance monitoring. Table 4 gives an overview of the potential information source that are relevant for the condition monitoring.

Table 4: Information sources for condition monitoring

Information source	Advantages	Disadvantages
ODS data	Real-time data monitoring.	Interpretation can be difficult, depending on the level of knowledge of user and asset knowhow. Not all parameters are relevant to monitor.
SCADA	All lot of data monitored. Potentially high quality and quantity of data	Not all parameters are relevant.
Ultimo Nat	Gives information about the decomposition and lifetime of the system.	Only very global information. Not very much additional information for interpretation.

Complex Eefde and condition monitoring
The three important parameters that the Asset Managers are able to change a little, are performance, risks and costs. The condition of a component are closely related to risks. With the usage of condition monitoring, the moment of failure could be predicted. This might result in a high usage of the working capacity of a component. However, the prediction of a moment of failure could be close to the moment of detection. This will result in an unplanned maintenance slot, which will result in a lower score of the network performance and a negative impact of the surrounding and image. Even so, the risks of a failure might have some great effects on other components or on the main function. The risks that are related to the failure might be too great in order to let the component operate till failures. Even if the costs are pretty high for certain components.

4.5 Resume of possibilities of monitoring

Based on the experiences about the current usage and level of information and insight of the assets in Rijkswaterstaat related to performance, there is room of improvement for performance monitoring. As Figure 10 and the target stated, the level of used information must be upgraded from “ah hoc/grip” towards “integration”. To come on the level of “link”, the right parameters must be monitored, which are relevant for the performance and functional behaviour of the asset/component. In order to make the step towards “integration”, the process must be optimised to efficiency and must be in a closed process. When the performance monitoring process is a fixed part of the working processes, it can be stated that the level of performance information is on the level of “integration”. This is in line with two goals and thoughts about monitoring stated in section 4.1, namely gaining more insight in the usage of the assets/components and in order to have a better support in the decision making process.
For condition monitoring, two topics stated in section 4.1 can be tackled, preventing functional losses and do pro-active maintenance according to literature. However, as can been seen in the text block of “Complex Eefde and condition monitoring”, the possibilities of maximum usage of the remaining useful lifetime must be evaluated against the

Maintenance analytics
As can been seen in Figure 15, there are three different types of maintenance analytics, namely:
- Descriptive and diagnostics: This described what is happening and how;
- Predictive: When an error could happen;
- Prescriptive: What should be done in the near future, to prevent a failure to happen [58].

potentially possible effects and risks. The triangle of performance, costs and risks is thus important. Also, the level of information is on "ad hoc". By having a well-functioning and integrated condition monitoring system, the level of information can go towards "integration". As well, the information obtained from this monitoring system can be used for better decision making support.
The main difference is between performance and condition monitoring is that historical data is said to say something about the past performance of an asset/component, while in condition monitoring historical data is used to predict the failure behaviour of the asset/system in the future.
It must be stated that a monitoring system will be an extra information input/tool within Rijkswaterstaat. The information obtained will be function as a supporting tool, the decisions can not only be made based on the monitoring system. It must always be compared with historical data, other information sources (as inspection) and knowledge and knowhow of object experts. This is concluded based on different conversations held with different employees of Rijkswaterstaat.

4.6 Implementation of monitoring within Rijkswaterstaat

From the result of section 4.5 can be concluded that the possibilities of monitoring within Rijkswaterstaat are there. Monitoring can give more insight in the performance and behaviour of the assets for the Asset Managers and object experts. Furthermore, it will result in a positive development in the level of information that is the target for 2020.
Since there is room of improvement for monitoring, the integration in the working processes of the Asset Managers is the next step. At Rijkswaterstaat, and especially in the team Asset Management, the decision making process is an important aspect. When having a proper baseline of information, decisions can be made on with better support. These decision can have a relation to different aspects of the working tasks of the Asset Managers, such as steering of the service provider, planning of renovations, aspects of the new maintenance contracts etc. The goal of monitoring within Rijkswaterstaat is to have more insight in the acreage and the condition of the assets. When having this information in a good overview, this information can be used in the integral working processes and decision making of the Asset Managers of Rijkswaterstaat.
The objectives of monitoring are already defined in section 4.1, which are: prevent functional losses, gaining more insight in the usage of the assets/components, do pro-active maintenance, steering on the maintenance process and be used as a supporting tool in decision making [44]. For performance monitoring, the overview of the asset/components is important, so certain critical parameters must be monitored that are an indication for the performance of the asset/component. For condition monitoring, this is a little bit more complicated. The goal of condition monitoring is closely related to preventing functional losses and do pro-active maintenance. In the literature of condition monitoring, three goals of the analyses are available: detection, diagnosis and prognosis. Since data monitoring is nog slowly implemented in Rijkswaterstaat, the main focus of Rijkswaterstaat should be on detection and diagnosis, which is also supported by the research of Tiddens, Braaksma and Tinga [59]. Later on, when historical data is available and can be related to the system behaviour, the data could be used for prognosis. This due to the fact that prognosis requires a lot of work, technical and asset/component knowledge, training of the processing models and the usage of data in Rijkswaterstaat is now only in the first starting phase. This is based on research [40, 44, 59] and different conversations with employees of Rijkswaterstaat of different divisions, such as Asset Management, Central Information Provision and Budgeting, Projects and Maintenance.

4.6.1 Data monitoring overview

As stated before, monitoring will consist of different tasks and analyses. An overview is created of how the general workflow will be of the data monitoring within Rijkswaterstaat.

The workflow is based on the research of "Maintenance analytics for railway infrastructure decision support" [58]. Figure 13 gives an overview of the workflow of data monitoring. The same basic lay-out that is described by Altman can also be seen in Figure 15, the maintenance analytics and close feedback loop is added in comparison to the framework of Altman. [45] It must be stated that the figure only have a relation to the condition monitoring part of an asset. The performance monitoring part will be more used as a visualisation aspect of the performance of an asset/component of an asset. The overview of a global monitoring system for performance monitoring is constructed, based on Figure 13 and can be seen in Figure 16. In subsection 4.6.3, an explanation is given that relates Figures 15 and 16 to the assets and how the monitoring system should be used for Rijkswaterstaat.

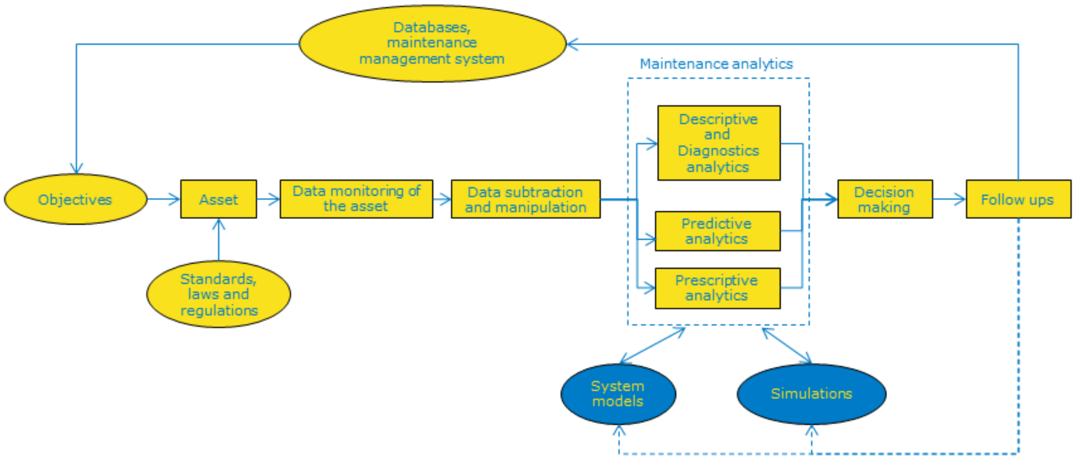


Figure 15: Overview condition data monitoring

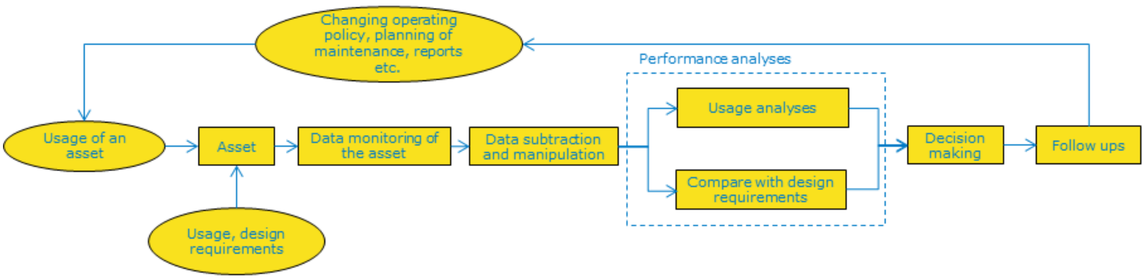


Figure 16: Performance monitoring overview

4.6.2 Decision making process

A direct usage of data of monitoring is related to decision making. As stated before, the triangle of performances, risks and costs is important. By having a proper overview of the condition and performance of the asset at a certain moment in time, this information can be used in order to support the decision making process. At the end of all working processes, the right decision must be made, from design of a new asset, order to condition inspections till the decisions about the end of life of an asset. By many conservations with employees of Rijkswaterstaat, it came clear that the main purpose of data monitoring is to have a better decision support tool. At this moment, the support for certain decisions are mainly based on expert judgement. The idea is by having a data monitoring system, the data can be used as a proper decision support tool.

Tiddens, Braaksma and Tinga have investigated the usage of prognostic maintenance technology in order to aid the asset owner in optimal decision making related to the life cycle making of physical assets. They provided a framework wherein the usage of data is related to decision making support. The first step in this framework is monitoring and data gathering, followed by advanced maintenance analysis and concluded with technical results and life cycle management decision making. This framework can be used by the implementation of monitoring within the working processes of Rijkswaterstaat. [57]
During the implementation of the data monitoring, the goals of monitoring for Rijkswaterstaat must always kept in mind. Over the years, the monitoring system will be evolved and can shift from a global/detecting system towards a specific/prognostic system. [57]

Lessons learned: monitoring and maintenance decision making
From the study of Tiddens, Braaksma and Tinga two lessons can be learned and used in the implementation of monitoring in Rijkswaterstaat.
First of all, the selection of monitoring parameters is not well motivated. By checking if the right parameters are included in the monitoring process, no essential parameters are missing and non-relevant parameters are monitored.
And secondly, the type of maintenance analyses must met the expectations and goals of the usage of data monitoring. When a suitable analysis is used related to the vision and expectations of the employees, the results can be evaluated and used better in decision making. [57]

4.6.3 Lifecycle phases and working processes

During the lifecycle phases of an asset, different aspects of the monitoring are important. An Asset Manager in Rijkswaterstaat is responsible for the decisions related to the asset with their impact over a long period of time. Figure 17 shows a global overview of a fictive asset of Rijkswaterstaat over its life time related to the costs. Over the different life cycle phases, different decisions are expected of the Asset Managers. The basis of the decision making is always the consideration between the influence of performance, risks and costs and how it is related to the life cycle of the asset. [21, 22, 60]

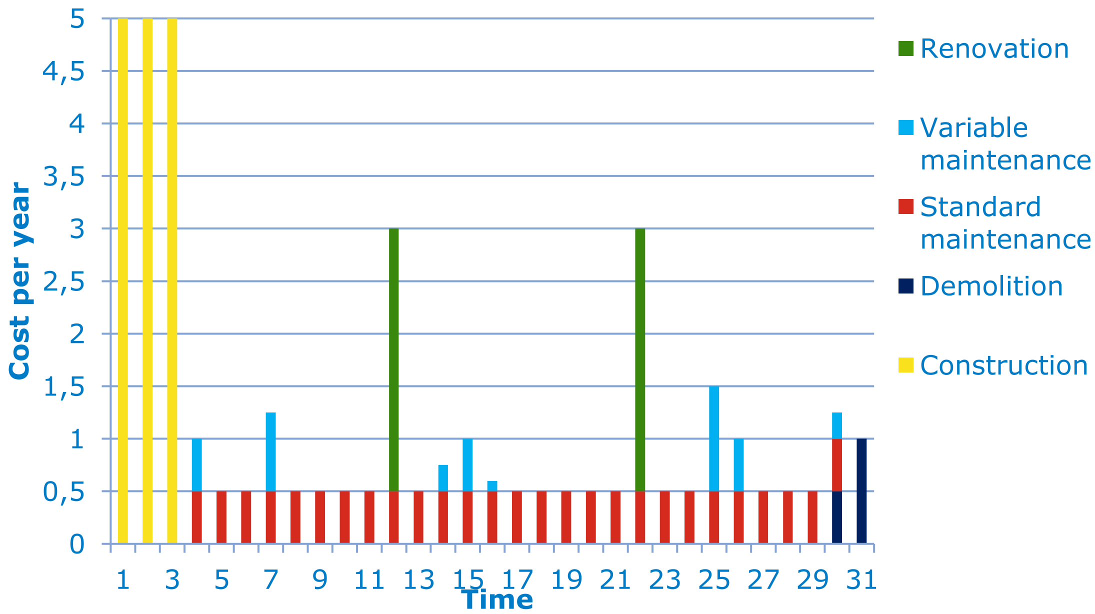


Figure 17: Life Cycle Costs global example, based on research of L. van Dongen [60]

This part of the report will explain how monitoring fits in the work tasks and working processes of an Asset Manager at Rijkswaterstaat. The tasks are related to the different life cycle phases of an asset, since Asset Management focused on the performance, costs and risks over the entire life cycle of an asset, the fifth pillar of asset management in Rijkswaterstaat.

Due to the fact that Rijkswaterstaat already have a lot of assets under its supervision, the implementation of data monitoring will not always start during the design of an asset. But, the steps that are required for data monitoring will be needed when data monitoring is implemented in the operational phase of an asset, see text block "Designing versus existing assets". This will be described in more detail in section 4.6.3.3. The implementation is mainly focused around the condition monitoring of the assets, this due to the fact that the condition monitoring is more described in literature. The performance monitoring is not described well in literature and is mainly based on conservations with different people of Rijkswaterstaat and based on logical thinking. The initial set-up of the performance monitoring although, contains the same process step as condition monitoring.
An overview of tools that can be used in relation to monitoring and required knowledge fields related to monitoring is given in Appendix 7.4, based on information described in [61].

Designing versus existing assets
Rijkswaterstaat already owns a lot of assets. Some of these assets dates back to 1930, or even older. But Rijkswaterstaat is still investing in new assets. The implementation approach of monitoring for these two kind of assets, new versus old, is logically different. For new assets, monitoring could directly be implemented in an asset, as well in the design of a maintenance policy. While for an existing asset, there is already a lot of knowledge and knowhow of failure modes/frequencies. This knowledge can be used for the implementation of an addition monitoring system.

4.6.3.1 Design
The design of a new asset is fixed in a process, named "Aanleg en Onderhoud", or in English "Construction and Maintenance". In this process, multiple teams and division of Rijkswaterstaat have a responsibility in the entire scope of the design. [62] First of all, the relevant stakeholders and shareholders must be analysed. This is an important aspect of the design process, because these stake- and shareholders have all lot of influence on the decision making process of an asset. This because the overall costs of an asset are normally very expensive. Besides the costs, the assets will be placed in a public area and these stakeholders expect a certain level of performance, but also want to have a less as possible negative influences, such as noise and obstructions in view. Furthermore, a lot of agreements must be made with local governments, people and industry in the direct area of the new asset. From all these stake- and shareholders a list of requirements and wishes must be derived. This will result in an agreement of the required level of functionality, services and performance of the new asset. This will form the input for the project assignment, which will be placed in the market. [62, 63]
The role of the Asset Managers is related to the analysis and evaluation of the stakeholders, customer wishes and requirements derivation, derivation of the project assignment, given an overview of the requirement functionality and the expected performance of the asset in the network. In the overview of the required performance and functionality the requirements and wishes related to monitoring could be implemented.
The monitoring system can contain both performance as well as condition monitoring. In this phase of the design, only a global indication can be given related to the monitoring system. A start for the monitoring system can already be made. First of all, a functional overview can be created. This functional overview must make all the different (sub)functions of an asset clear. This due to the fact that most of the assets have multiple functions within the network, or even within one complex. These functions are important for the performance analysis of an asset. From the functions of the overview, a selection of critical performance parameters can be derived for the function of the asset. These parameters must be taken into account for the monitoring system and must thus be stated as a requirement to be measured. The parameters that are relevant to monitor are the parameters that result in the numbers that are used in the SLA-PIN, such as passage time of ships for canal locks, how long a canal lock is unplanned not available etc. Besides the parameters of the SLA-PIN, parameters such as energy consumption, amount of pumped water, water level are relevant to monitor as well since these parameters can say also something about the performance of an asset.

A kick-off of the condition monitoring can be done as well. For the creation of the initial condition monitoring plan, a few tools can be used in order to determine the parameters that needs to be checked during operating of an asset. These tool are design FME(C)A, fault tree analysis, risks management and four quadrant method [61]. These tools can indicate where the potential risks for an asset are and what the reason for the risk to occur. If the initial failure behaviour is known, the failure depending parameters could be determined and checked if these could be monitored and how. [19, 64] Nowadays, with the upcoming of Industry 4.0, systems/components become smarter. This leads to the fact that sensors are already be built in in systems. These are mostly related to the failure behaviour of the critical components. [6] Otherwise, sensors could be added to the system in order to measure the critical parameters. The initial FME(C)A and the initial FTA forms thus a major information input for the monitoring system. These analysis are also important for the derivation of the initial maintenance policy and the initial inspection planning. [19, 24]
To make sure that the wishes and requirements related to monitoring are implemented well in the design, a good interaction between the Asset Managers and the teams of PPO/GPO are necessary. This will result into the fact that the requirements and wishes are implemented in the project assignment. The implementation of data monitoring will be different depending on the kind of contract, see text block "Design and Construct versus DBFM". The Asset Managers must make sure in a D&C contract that the implementation of data monitoring is guaranteed, since it otherwise will not be done. The implementation of data monitoring in a DBFM contract is logically better, since it is beneficial for the service provider to monitor an asset. However, a good interaction between the service provider and the Asset Managers must make sure that the wishes of the Asset Managers are implemented as well. This will probably be on the performance part of the asset, since the service provider is more interested in the condition of the asset in order to determine the moment of maintenance tasks. Furthermore, the initial monitoring setup must be designed according to the framework of Altman [45]. If monitoring will be implemented in the asset, the design of the data gathering and processing system must be started. This requires documentation and distribution of the right information and agreements between the relevant parties (Asset Managers, service provider, design team, Central Information Provision etc.). In this stage, an initial monitoring plan can be derived, which later can changed based on the PDCA-cycle [25, 26]. The initial monitoring plan consist of configuration of the entire global monitoring system, so how the data is subtracted, transported, how/where the data is stored and processed and who will have access to the data in a safe way. Furthermore, an initial visualisation can be made based on previous data monitoring projects. The Asset Managers must derive the scope for the monitoring process, which will be initial be detection and diagnosis and later shift to prognosis, this is based on the research of Tiddens, Braaksma and Tinga [59] and the research of J. Lee et al [54]. The scope and goal of data monitoring must result in coherent frameworks of maintenance analyses.

Design and Construct versus DBFM
There will be a different outcome of the design of an asset depending on the kind of contract. When a DBFM contract is used for a new asset, the service provider could implement monitoring if it is necessary in his opinion, since he could use that data for its own maintenance policy.
In a D&C contract, the possibilities for monitoring must be stated in the contract, or it is possible that it will not be implemented. This since it cost time and money, and the constructor could be another service provider than the maintainers. So, it will not be beneficial for the constructor to implement possibilities of monitoring.

4.6.3.2 Construction
During the construction, the design will be realised. The configuration that is installed can be different from the initial design, so changes must be documented and initial FME(C)As and FTAs must maybe updated as well.
In the construction phase, a test plan can be used in order to check the calibration of the monitoring equipment and the first data output must be evaluated. The initial setup of data monitoring can be evaluated and changes can be implemented according to the PDCA-

cycle [25, 26]. This could be related to the selected parameters that are monitored, the way the data is saved and/or subtracted, or the way the data is visualised.

4.6.3.3 Operation phase
As in the text block of "Designing versus existing assets" can be read, it is logical that there will be a difference between the two scenarios. If the asset is new designed and monitoring already is integrated in the design, this phase will look different then when monitoring will be implemented in an existing asset. The two different cases will be explained in this section.

Existing asset
The general maintenance plan and tasks are already defined. Furthermore, normally the failure modes, failure frequencies and the condition of the asset are already known. But, the implementation of monitoring will bringing some extra tasks. These tasks are already defined in section 4.6.3.1 and 4.6.3.2. The goal is now to have a data workflow that is given in Figure 13. This will thus contain a selection of the relevant parameters to monitor, the requirement tools/sensors and setting-up of the data management system. This requires and intensive interaction between the Asset Managers, the Central Information Provision and the service provider. This in order to make sure that the requirements and wishes of the Asset Managers are covert within the monitoring system.
At the end of this stage, the data monitoring must be at the same level as described in section 4.6.3.2. The follow ups will be the same for the new asset and are described in the section below titled "New asset".

New asset
The implementation of performance and condition monitoring must be an integral part of the working processes of Rijkswaterstaat in order to make it beneficial to create a monitoring system. The data/information evaluation is the final step of the monitoring system itself. The possibilities for condition monitoring and performance monitoring will be discussed below.
For the condition aspect of the monitoring system, the data evaluation is depending on the kind of maintenance analytics, related to the goal of monitoring (detecting, diagnosis or prognosis). Furthermore, the monitoring system is a tool that is an added information source besides the existing information source. As stated before, the initial goal of monitoring will be towards detecting and diagnosis. The threshold values of the critical parameters are useful to monitor, as well as their trends over time. Thereafter, errors that occur often are useful to investigate in more detail. Information about the root of the cause and the solution are provided in Ultimo Nat. These two information sources could be combined, in order to determine if remarkable trends occur in the condition data. If so, the threshold values must be changed, in order to prevent function failure. This will result in a more robust monitoring model [65, 66]. In the most ideal situation, the system of the data processing can give a warning if thresholds are reached that gives an indication that an error will occur in the near future and thus maintenance is required. [65, 66] By analysing the trends, it might come forward that the performance over time is degrading, but still is within an acceptable range. When the reduction in performance is remarked before the threshold is reached, the system/component could be analysed in more detail and replaced/repaired when necessary or planned if it is not that urgent. Even so, SCADA data can be used to determine the amount of occurring errors, the working area and duration of the errors can be plotted. These give a proper indication of a degrading system [43, 50]. A coupling between Ultimo and SCADA data is not possible yet, due to misalignment between the two systems. However, the database of Ultimo can give more insight in the origin of the error. By doing some error analysis, the problems might be prevented in the near future. The goal of monitoring is doing proactive maintenance, but this might be hard to do for Rijkswaterstaat. This requires a robust model for data processing. The drawback of Rijkswaterstaat is that most of the critical failures are prevented by doing preventive maintenance. Due to this, a lot of useful data about the behaviour of the system before a failure is not recorded and thus can not be used in order to train the model for data

processing. The effects are mostly too risky in order to let the system run to failure. However, if more and more assets are monitored, different components can be clustered and analysed together in order to train the model in this way. In the end, it might happen that the monitoring system will shift from detection and diagnosis, towards prognosis. Finally, the analyses of the data could have influence on the maintenance plan and the modelling of the asset in the RCM Cost model. The influence on the maintenance plan have a great interface with the ProBO methodology and the guidance "Prestatiegestuurde risicoanalyses" and of course the PDCA-cycle [19, 24, 25, 26]. This will be discussed later on. The main input for a condition monitoring system will be obtained from SCADA and ODS, in order to monitoring the data in real time. Ultimo Nat can be used as information source in order to determine the root causes and solutions for errors.
The performance monitoring can be periodically checked, in order to check the performance of an asset over time. These values can be used for internal reports, summaries to water agencies, or to start improvement projects such as reduction in energy consumption according to the PDCA-cycle [25, 26]. The data can give an accurate insight in the usage and performance of the installed components. Nowadays, the level of information is not accurate enough. The data can be used as a proper information baseline. The usage of the system can also be compared with the design requirements, in order to determine if these are correct or not much over dimensioned. When the performance monitoring is a fixed part of the integral process of information collection, the level of information can go from "ad hoc/grip" towards "integration", which is a goal of the information vision of Rijkswaterstaat. A global roadmap of how to come from "Ad hoc" towards "Integration" is visualised in Figure 20, according to the level of information described in the presentation of IV-koers Regio 2020 [34]. The roadmap is inspired on the document of T. Zwanenbeek, G. Ras and A. de Waard [67]. Based on the document [67] the information need of performance and condition monitoring is created, as can be seen in Figure 18 and **Figure 19**. These steps can help in order to identify the need for a monitoring system. In relation to the performance of an asset, information for other sources can be used as well. According to M. van der Boor [50], it is very difficult to have the SLA-PINs monitored in a real time system. However, information about this subject can be obtained from other sources. The NIS-portal and IVS90 can be used as a side-input in the monitoring system [68]. The values from these information sources give indication of the network/asset as accurate as possible. The real time monitoring of the usage of an asset can be obtained from SCADA and ODS data. Ultimo Nat can be used the main performance killers of the installed components/working fields (mechanical engineering, electrical engineering, ICT etc.). The performance monitoring system must thus mainly focused on the operational aspects of the performance.

Performance monitoring
The design of an asset are normally very over dimensioned for special events. For example, the capacity of the pumps can be evaluated according to the maximum capacity of the entire complex. When the capacity of the entire pump installation is always well below the design requirement, the decision can be made to reduce the actual capacity of the pump installation, from 4 pumps to 3 pumps as an example. The decision must be evaluated according to the performance, risks and costs of the remaining installation.
The data can also be summarised and used for reports and supporting information. A clear example is the amount of water that is pumped. The regional water management agencies have to pay Rijkswaterstaat for this function, since they are using water from the network to irrigate the land besides the main water network. The data gives a clear and measurable value for Rijkswaterstaat to determine the bill for these agencies. These summaries about running time and capacities etc. result in a better insight in the performance of the asset/components.

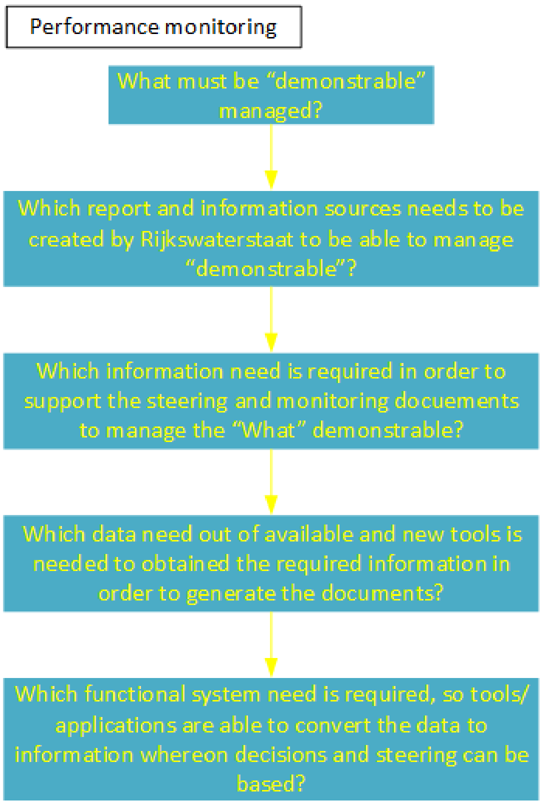


Figure 18: Steps for performance monitoring

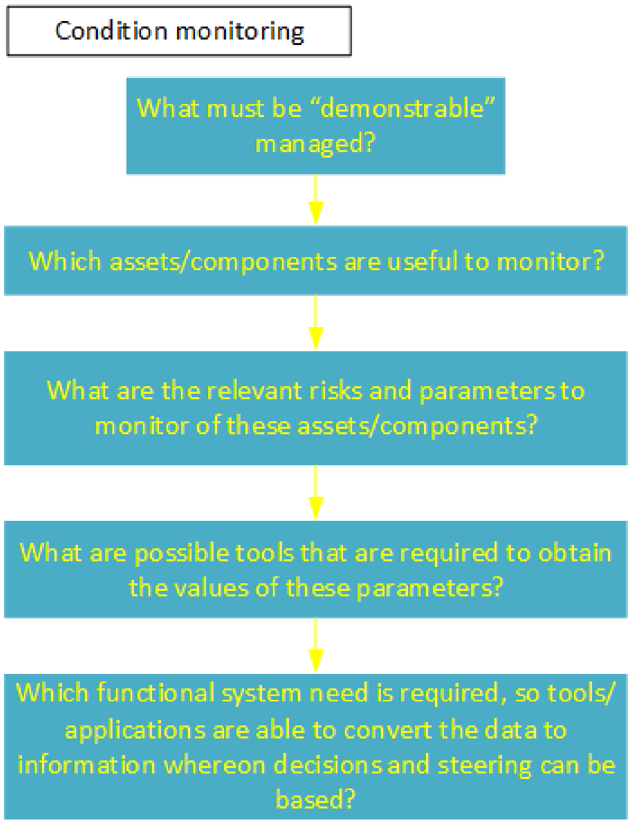


Figure 19: Steps for condition monitoring

Figure 20:Roadmap of improvement level of information

ProBO methodology

With the usage of monitoring it is possible to have a better insight in the condition and performance of the assets. The data can be an extra input for decision making support. Be the fact that data is autonomous and real time monitored, the data can have more insight in the state of the asset besides inspections and tests.
In the ProBO methodology, the guidance of "Prestatiegestuurde risicoanalyses" is used. Several theory related to failure behaviour is used, such as FME(C)A and risk matrices. An

addition to this guidance, is the guidance "Kwalitatieve objectrisicoanalyse" [64]. This additional guidance contains several methods that are work out and documented in more detail. This guidance could be used with some addition for monitoring as well. The baseline of the object risk analyses are the derived FME(C)A for an asset. These could be used as an input as well. There will be a few additions to these set frameworks. The additions as a result of the monitoring analyses have an influence on the PDCA-cycle of the ORA. This cycle is also stated in the guidance "Prestatiegestuurde risicoanalyses" [19]. The cycle is based on the fact that the performance of an asset is contained in a conservation plan. The conclusions out of the data analyses could be implemented in the set framework. The new qualitative ORA with the input of monitoring is given in Figure 21.

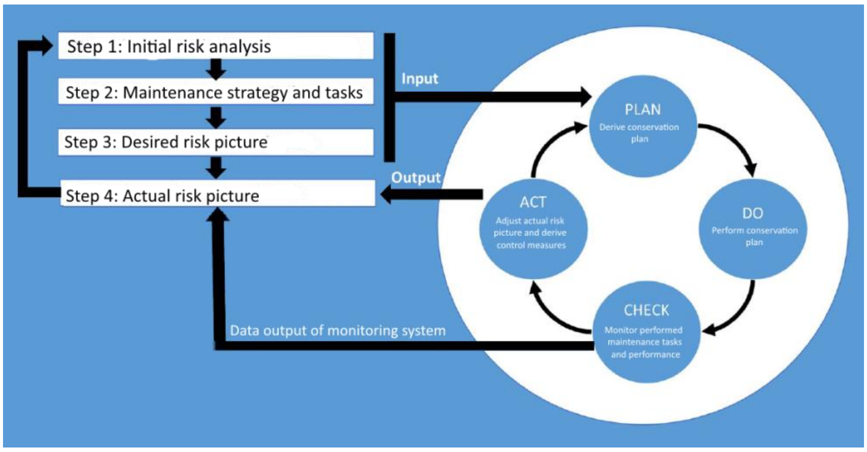


Figure 21: new qualitative ORA

The output that can be obtained from the data will have some influences on the step of the object risk analysis. The four steps of the object risks analysis and the addition of data monitoring will be explained in Table 5. As in the table comes forward, the change of the time between failures can be the main aspect to steer the maintenance policy. This due to the fact that the effect of a failure is not changed, but the change of failure of a system/component could be determined with more accuracy. This is related to the score obtained of the risk matrix that is used by Rijkswaterstaat, which can be seen Table 6. The change of failure can have a different score, which can result in a different outcome for the risk matrix. The effect on the maintenance policy will be remarkable when a score turns from green to red/yellow, or vice versa. A green risk will result in a maintenance policy of SAO, but a red/yellow risk will result in a maintenance policy wherein TAO or GAO will be used [64]. The outcome of the model risk matrix will also be used in the used FMEA model of Rijkswaterstaat. [4] It must be stated that this is only doable when a lot of historical data is available for components installed in the asset, or in assets with the same configuration/identical installed components. Otherwise, the initial maintenance strategy and tasks must still be used. However, as research shows it is possible to predict the occurring failure of a component very close [65, 66]. Either, the remarkable measurements are very closely related to the occurring failure of an component. For Rijkswaterstaat it is not doable to have a prediction for an occurring failure within an hour. The trends for parameters must thus be checked and evaluated over a long period. When the measurements are showing a remarkable increase or decrease trend, it

SAO, TAO and GAO
Rijkswaterstaat defines three maintenance strategies:
SAO (StoringsAfhankelijk Onderhoud): Error based maintenance, when a failure occurs, it will be fixed.
TAO (ToestandAfhankelijk Onderhoud): Maintenance based on inspection/measurement of certain parameters.
GAO (GebruiksAfhankelijk Onderhoud): Maintenance according to a fixed interval (time, operation, start-stops). [64]

[4] Rijkswaterstaat is using a FMEA template for their analyses, named "RWS Template FMEA KWAL v2.2".

is beneficial to do some further inspections. The data before a failure can still be used in order to train the monitoring model, which will result in the fact that trends will become more insightful and thresholds can be set, which will lead to a more accurate data monitoring system. To do this, many historical data must be used and analysed in order to train the models. This might take a long time at Rijkswaterstaat since a lot of component are replaced before a failure could occur or because a lot of preventive maintenance is done.

Table 5: Influence of monitoring on the object risk analysis

Product/ Activity	Original process steps	Influence of monitoring
Step 1: initial risk analysis		
Product	Initial object and function analysis	The performance analysis gives more insight in the usage of the asset/component
Product	Initial FMECA	If it came forward that components failure much more/less than expected, the values in the FMECA must be changed. That might result in a changed model-risk matrix, and thus a different outcome of the FMEA
Activity	Collect all available data of the object/asset	The data obtained for monitoring can be used as extra relevant data input
Step 2: maintenance strategy and tasks		
Product	Maintenance analysis	
Activity	Determine current maintenance strategy and all corresponding maintenance measures	
Step 3: desired risk picture		
Product	Desired risk picture FMECA	
Activity	Determine risk picture with the effect of all maintenance measures	
Step 4: actual risk picture		
Product	Actual object and function analysis	
Product	Actual FMECA	
Activity	- Process of conditions, damages and inaccuracies that are detected - Process the effect of the effected maintenance measures - Determine actual risk picture	Herein, the monitoring of the asset can be implemented as an extra activity. This because the data could provide more insight in the failure behaviour and performance of the asset and thus are necessary for determining the actual risk picture

Table 6: Risk matrix used by Rijkswaterstaat

Risk matrix		Effect			
		1	**2**	**3**	**4**
Change of failure	**1**	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12
	4	4	8	12	16
	5	5	10	15	20

RCM Cost model

For modelling the asset in a RCM Cost model, which are used to support the maintenance policy and support the input of the Asset Managers for the maintenance contracts. The usage of the RCM Cost model is explained in the guide for Rijkswaterstaat by Delta Pi [30]. The additional influence of monitoring on the model is explained below.

First of all, when failures occur more/less than expected, the initial MTTF is not right defined. As explained in the ProBO methodology section, monitoring could have an influence on the FMEA and maintenance policy according to the likelihood of occurring. In the same way, monitoring has an influence on modelling in the RCM Cost model. The MTTF forms namely a great influence on the outcome of the simulation, because this is the main input parameter for the simulation of the model.[5] The amount of failures that occurs might result in an adjustment in the RCM Cost model. This can be based on the number of failures and their mean time between failures of components. This can also be based on identical components in different assets.

Besides the MTTF, the demand frequency is used as an input parameter for the simulation. This is mainly the case for start/stops of a specific component. By checking the usage of these components in the data, the number of the demand frequency could be changed, if the initial guess was not right.[6] This will result in a better representation of the model in the program. It might thus be beneficial to check which components are related to the demand frequency and monitor these components in the real situation.

Based on a different outcome of the simulations due to changes in the model, it might occur that the risk matrix is changed and thus a different maintenance policy might be chosen. The shifting of maintenance policy will mainly be from SAO to TAO/GAO, or vice versa. The maintenance modelling of an asset will change from a corrective maintenance task to a preventive maintenance task, or vice versa.[7]

Eventually, the model will be updated and improved every time and thus result in a better and a more accurate representation of the asset. After each iteration of the model, the results must be evaluated and their might be some follow-ups as a result of these simulations. These must be handled according to the PDCA-cycle, in order to determine if the problem is really solved.

Others

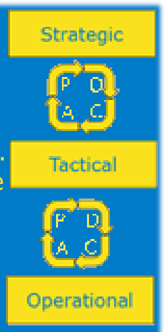
During different meetings, it came forwards that different teams, and even within teams employees, there is a different vision about what should be monitored. They all stated that the level of information is at this moment not sufficient enough. Since the main focus of what to monitor is different, this will result in a non-uniform way of monitoring and represent data. Either, this has a positive effect that the requested information is better fitted in the needs of the employees/teams. The level of information can thus be increased and the information can be used for better decision making.

Finally, different projects can be improved according to the PDCA-cycle [25, 26]. These improvement can be more focused at the other aspect of the RAMSSHEEP, besides Reliability and Availability, which are already covered in the ProBO and RCM. For example, the energy consumption can be monitored. Rijkswaterstaat wants to be a sustainable organisation. By checking the energy consumption, the Asset Managers can identify components with a remarkably high energy consumption. When a remarkably high consumption is identified, different follow-ups could be done. So, when a component or system must be replaced because it ranges its end of life, a more environmental component/system can be installed. This is in line with the vision of Rijkswaterstaat to be more sustainable. Even so, the time of an energy consumption can be evaluated. In the Netherlands, the energy price is different for day and night. It might be beneficial to change the operation policy of pumps. This to let the pump operates more at night, since the price of the energy is lower. This has some influences on the water level management. The water

[5] Page 36 of the Quick guide RCM Cost voor Rijkswaterstaat [30]
[6] Page 37 of the Quick guide RCM Cost voor Rijkswaterstaat [30]
[7] Chapter 7 of the Quick guide RCM Cost voor Rijkswaterstaat [30]

level management must be within a certain range. The operators must be able to determine the influence of the operating of the canal lock and the pumps related to the water level of the canal. The water level has a desired value, but the level is allowed to fluctuate within a certain range. The operators must have a different mind-set, since the wants to keep the level as close as possible to the desired value, to a mind-set wherein the level is allowed to fluctuate within the entire range. All these changes must in the end be evaluated and checked if the modification in the operational policy really resulted into an improvement or a reduction of the asset/component performance.
As is stated in the text block "Levels of management", a continues improvement can be obtained between all the levels of management related to an asset. As stated before, the data can help in supporting the decisions for the construction of the maintenance plan. These plan are derived on tactical level and executed at operational level. Also, by changing the operating policy for the pumps are a direct influence on the operational level of the asset. Furthermore, by modelling the asset in RCM Cost, the outcome can be used for the construction of the conservation plans, so what inspections are planned and when. This is the continues improvement between tactical level and strategic level of Rijkswaterstaat.

Levels of management
The improvement/follow-ups that are proposed after the analyses of the data can have influence on different level of management. Normally, the Asset Managers are working on the tactical level. But some actions will have an influence on the operational or strategic level of management in Rijkswaterstaat. [78]



4.6.3.4 Renovations
The influence of monitoring on renovation is not that great. The usage and performance of the components could be monitored and compared with the guide line of the manufacturer. This will give a proper support tool for the planning of the renovations of components. The influence of trend analysis is not that great, this due to the fact that historical data is of specific component is not that great and the trend analysis might not be known near the end of a product life time. So, for planned renovations must be based on usage and performance, while monitoring could have a support role in the trend analysis of the components. Due to the fact that the renovations are planned far in advance, the influence of data monitoring can be neglected.

4.6.3.5 Calamities
Data can be used in order to check how the failure did occur. The trends of relevant parameters and usage of the components can function as a support for the reporting of the occurred calamity. The data can be used as an extra information input in order to find the root of the cause.
The outcome of the investigation might have some impact on the monitoring system. If certain trends did occur before a component fails, additional thresholds could be implemented in the monitoring system. The outcome of the investigation might also have an impact on other assets that have the same configuration. This will eventually result in a more reliable network of Rijkswaterstaat.

4.6.3.6 Demolition
Just a in section 4.6.3.4, monitoring could have supporting role in relation to the planning of the demolition. When the remaining lifetime of components of assets is more or less clear, the planning of the demolition can be started. In advance, a global planning of renovations can be made till the expected end of life of an asset. Decisions about renovation that will not be done, depending on their performance, risks and costs are relevant for the Asset Managers of Rijkswaterstaat. So, the planning of renovations/ overhauling based on experience and simulations of the RCM Cost model must be evaluated based on the three important parameters.
But, normally the planning of the demolition of asset is determined a long period before the actual demolition itself. The contracts must be made and placed in the market. In this phase of the life cycle, the data obtained for monitoring will be mainly focused on the

operational aspects and not on the strategic/tactical level. So, over the different life cycle phases of an asset, the focus and goals of monitoring will be different.

4.7 Implementation in the working methods of the Asset Managers

It can be stated that in the different life-cycle phases, the goal of monitoring will be different. The effect of monitoring can also be seen in the main working processes of the Asset Managers. The main processes of the Asset Managers can be found in ARIS [69]. The main overview of the working process of the Asset Managers is stated in the process "Assetmanagement". The overviews of the processes and on which block monitoring have some influences is given in Appendix 7.6. [67, 69]
Monitoring can have different effects on the working processes. In the process "Visie en Aanpak AM", monitoring can have an additional input, namely in the input-block "Monitoring info gebruik netwerken". The information obtained of the monitoring data about the performance and condition of the assets can be used to derive the network chain plans and might have some influence on the management and conservation strategy of the assets.
In the process of "Integrale Netwerkvraagformulering assets", monitoring can have some input for the derivation of the performance oriented conservation plans. The input block of "Actuele gebruiks- en prestatie-informatie netwerk" can be extended with the usage of data monitoring. Even so, condition monitoring can have some relevant input information in the block "Toestandsinspecties".
In the process of "Managen opdrachten OG-ON", when implementing a monitoring system, an assignment must be made in order to set up the entire monitoring system. So, from using smart systems (sensors, or other data tools), data transmitting and data processing systems. The interface between the project teams, the Asset Managers and the Central Information Provision is very thick in order to create a useful monitoring system. Just as in the process of "Integrale Netwerkvraagformulering assets", the information about the acreage can be used in the derivation of the assignments.

Knowledge assurance
Besides the extra information input, the data is also a nice medium of information and knowledge assurance. This becomes an additional benefit, since the level of flexibility in an organization be higher and changing of jobs is very common nowadays. [80]

In the process of "Beheren assets", the acreage information is also stated. Furthermore, the new information and processing system have an influence on the qualitative and quantitative information unlocking and collecting of performance and condition data.
In the process of "Monitoren assetmangement (resultaat en effect)" the control blocks of inventory and analyzing the data, the data obtained of a monitoring system will be added. If the data shows remarkable trends and/or numbers, the next block of the process will be started, which is to formulate an improvement proposal, which could have an influence on the installed network or on the operational aspects of the assets.
Appendix 7.6 shows the processes of the Asset Managers and where the extra input of a monitoring system is. [67, 69]

4.8 Lessons learned from literature

The usage of data is nowadays an important tool for maintenance engineering. The usage of data is potentially and theoretically very high. But in reality, there must be some remarks stated. These remarks are very relevant for the employees of Rijkswaterstaat when the final implementation of monitoring will be enrolled. This subsection will give an overview of problems that have been occurred during the implementation of monitoring and the analysis and evaluation of monitoring as well, and how Rijkswaterstaat has to act on these problems.

First of all, the goal of data monitoring must be determined for Rijkswaterstaat. As said before, there are three types of goals for data monitoring: detection, diagnostics and prognostics. These types of goals requires another approach and processes in order to make a proper decision based on the available data. For detection, the system output is normally a set of value that can be compared with a certain threshold for a specific

component. These specifications can be from a manufacturer of the component or from the design requirements related to the performance/operation of the asset. Prognostics deals with the fact that a failure will be prediction based on the data and a model/simulation. The output will predict when a failure will occur with a certain likelihood. [46, 59] Of course, it is desirable to have a fully predictive maintenance model, in order to predict the failures and plan the maintenance tasks just in time. But, this requires a lot of the initial analysis model. As stated in research [57], the performance of the models evolve and improve over time. It is stated that the employees has to understand the model and the interpretation of the data output, in order to make proper decisions based on the output [57]. Furthermore, the goal of Rijkswaterstaat must be determined in relation to data monitoring and analysis. In the ideal world, the data can predict the right moment in time when a failure could occur. But, in reality some failures occur randomly [46, 59], so the monitoring system will not be fully waterproof. As stated in literature [59], the goal of Rijkswaterstaat will be on detection and diagnostics. This is also in line with the research of J. Lee et al [54] wherein an asset is related by its uncertainty and complexity to a maintenance methodology. The assets of Rijkswaterstaat are not related to preventive maintenance or prognostics and health management yet. In alignment with the research, the initial set-up of Rijkswaterstaat must be focused on detection and diagnostics.[8] Over the years, the data system can be improved on a trial and error base, which is in alignment with the research of Tiddens et al. [57]. As came forward by the meeting of June 8, the monitoring will first be on a global level and later improved and extended. Then, it might be possible to implement a model that will extrapolate data in order to function more like a preventive/prognostic model. But, this will take a while, since first the focus will be on the first data monitoring set-up, the evaluation of that and the upcoming improvements of the initial setup. Later on, when the initial setup and first data is monitored and evaluated, the system will be improved stepwise. When having sufficient historical data, the real time data could be extrapolated whereon decisions can be based. [11]
Furthermore, it is stated that the quality and amount of data collection is important. The data will form the baseline for the entire data monitoring process. It is common know that for any analysis, if it is a maintenance analysis or a stakeholder analysis, the quality of the input determines the quality of the output. In other words: "Garbage in, garbage out". As stated in the researches of Tiddens, Braaksma and Tinga [57, 59], the selection of parameters to be stored is very important. It is stated that 30% of the industrial equipment is not suitable for monitoring. Also, it is stated that the selection of parameters is not well motivated. When the asset are evaluated and scored to their suitability, the selection of parameters must fit the expectations and wishes of the relevant stakeholders. By using the right tools to identify suitable assets, critical parameters and the equipment to do so, the amount of input data is very well motivated and will come close to the expectations and wishes of the analysers. This is also in line with the research of Jardine et al. [46] They stated that the first step of data processing is data cleaning. When the amount of data is already reduced by the fact that the right parameters are selected in order to obtain only the relevant data set, data cleaning is already be secured. As is stated in research of Jardine et al [46], the event data and condition data could be combined. It is possible to use both data sets in the maintenance analytics. By comparing the data sets, it is possible to have a better insight in the behaviour of the system. This is a very important step since Rijkswaterstaat have a lot of asset under control. The amount of data that could be extracted is huge and will result in consuming a lot of computational power. The selection of parameters that needs to be stored and evaluated must thus be limited as much as possible, if more and more asset are implemented to a uniform monitoring system. Figure 22 shows a workflow of how the useful parameters can be selected for condition monitoring. This global workflow can be used in order to identify the right components to monitor, without monitoring and processing all the data of the entire Rijkswaterstaat networks.

[8] Based on the meeting on June 8, 2018 with Dinant Schippers, Maria Angenent (CIV), Martijn Koole (CIV) and Anton Kösters (CIV).

Even so, the type of selected maintenance analytics must be well suited for both the available data set as the goal of the maintenance analytics part itself. The input of the maintenance analytics also defines the selection of the maintenance analytics. The goal of the usage of the monitoring system can help to determine the required maintenance analytics. As is stated in the research about the adoption of prognostic technologies [57], the selection of the used type of maintenance technique is not well motivated. A clear way to design and implement a monitoring system is not available, because the applications/assets are very specific. [54] But, in the case of Rijkswaterstaat, this is not fully true. The assets itself are very specific, but in the beginning the configuration for certain sets of assets will be the same. When a configuration are more or less the same, the main framework for data monitoring can be used for multiple cases.

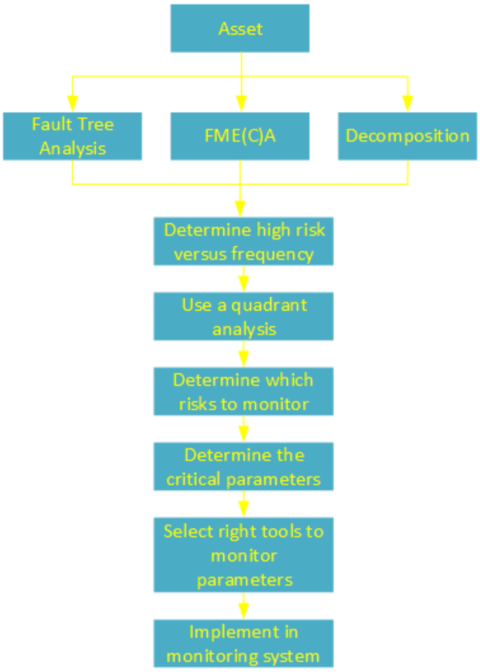


Figure 22: Workflow of parameter selection

Furthermore, the level of knowledge and knowhow related to maintenance analyses and data monitoring must be up-to-date. Besides the theoretical knowledge, the practical insight of the asset/systems is very important. For Rijkswaterstaat, a lot of assets are already built and can thus later be implemented with data monitoring. The selection of which assets, and one layer deeper which component, must be chosen wisely, as stated before. The available methodologies and tools must be used in the right way to make a proper indication of which asset/component is suitable for monitoring, how the analysis is done and as a result of that how the decision making process is executed and what the influence of the decisions is for future performances.

Finally, the acceptance and implementation itself must be done right. There must be support of the employees to see the added value of the monitoring system. When the added value is seen, the monitoring system can be used more intense. It is not doable to set up a costly monitoring system, when the usage of the system itself is not done. [59, 56] A more detail explanation about the support and acceptance is given in section 4.10.

4.9 Representation and working tasks of monitoring data at Rijkswaterstaat

The representation of the data is possible through different ways. The data can be visualised in different tools and mediums. For the visualisation of the data, different possibilities for visualisation tools are possible. It is also possible to generate different kind of overviews of the analyses depending per frequency/task. This subsection will describe the possible solutions for different ways of visualising the data and how to act on the additional work and tasks of different monitoring.

It can directly be thought of that the visualisation is a great tool to show the trends and different kind of monitoring possibilities. The way the data will be represented is influencing a lot of how good the data will be used by the employees of Rijkswaterstaat. The obtained information of the assets must be ready for further utilization to support the decision making process. In the research of J. Lee et al. [54] is stated that one valuable objective of prognostics and health monitoring is to enable a support system to convey the right information to the right person, so right decisions can be made at the right time. Therefore, visualisation tools are an essential part of a PHM, and for other data monitoring systems as well. The most common tools for data visualisation for monitoring systems are listed below [54, 70], which are displayed in Figure 23 [70].

- Degradation chart: The confidence level of a parameter is displayed between 1 (as good as new) and 0 (unacceptable). The value curve gives an overview of the historical

and current state of the parameter, and could be extrapolated in a prediction step. A threshold give can display the level of when an alarm will be triggered;
- Performance Radar Chart: Will give a global overview of the level of performance status of a component. Each axis correspond with a confidence for a specific component;
- Classification and Fault Map: Is used to determine the root causes of failures. It classified different failure modes of the components by presenting failure modes in clusters;
- Risk Chart: A tool in order to display the risk values that indicate the component maintenance priorities. The higher the value, the more urgent maintenance tasks are required [54, 70].

Besides these visualisation tools, other kinds of visualisation can be used such as column graphs and circle diagrams. Even so, data could be represented in words/tables. The kind of data representation tools is depending on the kind of parameter and the preference of the user.

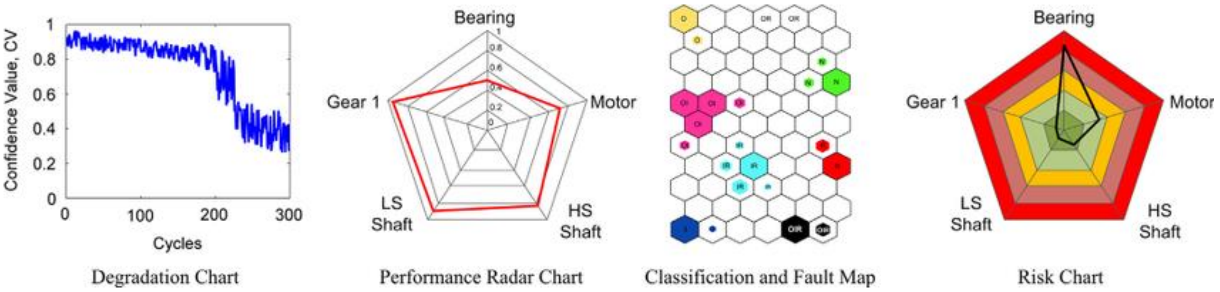


Figure 23: Four common visualisation tools [70]

From the book of T. Rahlf [70], there are some remarks stated that are related to the representation and visualisation of the data. The three remarks that are stated are:
- It does make sense if graphs are embedded or free standing. If embedded in the general text block, the graphs header and font sizes have to be adjust in order to make a clear difference. Furthermore, an explanation block and/or arrows are normally removed, but still desirable;
- There is not just one best way of visualising the data in an adequate way. Sometimes different data can be combined in order to make a combined graph;
- The source and title can be omitted, if it is possible to find wherein the figure is embedded [70].

The research of J. Eldridge stated that the actual requirements of the data analysers to keep in mind. Some people wants to see a the raw data, while others just want a small summary of the historical data. The data must give an overview of data that is normally not easily available. Clustering and categorisation of data must be done as much as possible, but is sometimes challenging to achieve. If the resulting overview will lead to a better decision making process, the entire framework of visualisation is a real selling point. [71]
At this moment, there are many possibilities that are useful for representing the data. These must fit the wishes of the users as much as possible. The appropriate representations must be used in order to make it easier to interact with data easier, give more insight in the asset and provide as a clear way of communicating the obtained insights. [72]
At this moment, the generated reports and dashboards of Rijkswaterstaat are not often communicated with the team itself. The reports are written to normally inform the higher managers of Rijkswaterstaat. The dashboards are just one page of A4 and contains only very global information about the network. The reports and dashboards are not experienced as useful. The stated data is to global and contains not sufficient data to be able to be "in control" over the performance of the asset. By having another kind of report/dashboard, the available data can be used better in order to improve the current insight in the performance of the assets. The network reports [33] and the RWS dashboards [32] form a good starting point for an upgraded report format. The suggested dashboard

format presented by J. Wagenvoort [73] can be used as well. This must result in a more functional report/dashboard format for Rijkswaterstaat.
Besides the conventional report format, nowadays online tools become more and more common. With the usage of ODS data and real time processing, the data out of the components can directly be visualised and viewed online. A pilot for a dashboard is currently in development by RWS Datalab[9] to visualise real time data for lock complex Eefde. In mine opinion, this will be the right direction for data monitoring and visualisation. In this way, the data is very accessible and the performance of an asset can be seen very well over a certain period. The condition monitoring, so detail information and trend analysis, can run in the background and only be shown directly if certain thresholds are reached. The frequency can be depended by the users of the data itself. The new dashboard can be divided in different parts. So parameters for performance and condition can be clustered in the same section. Even so, the current SLA-Pin score can be subtracted from NIS and used as a side input next to the SCADA and ODS data.

4.10 Support and acceptance

For a successful implementation of the usage of monitoring, the support and acceptance of the employees is very important. The most important aspect is the support of the teams within Rijkswaterstaat. This due to the fact that the employees of Rijkswaterstaat are the people that have to work with the collected data and must related the data to the operating and performance behaviour of the system(s). An important aspect in the successful implementation are the resources and level of knowledge. First of all, the level of knowledge about the asset and failure behaviour must be up-to-date for the employees. The knowhow of failure mechanism and failure behaviour must be at a sufficient level. Furthermore, the level of knowledge related to the interpretation of the data must be at an appropriate level. When this is not correct, it is possible that wrong decisions will be made according to a wrong interpretation of the data. [59]

Lessons learned: Organisational feasibility
The study of Tiddens, Braaksma and Tinga say that certain issues can hinder the implementation of monitoring and predictive maintenance. These issues are a lack of system and domain knowledge, a lack of trust in monitoring systems and the organization not being ready for implementation. These issues must be tackled in order to have a successful implementation of monitoring. [59]
The study of Jonsson and Westegren state that the firm should work hard on showing the added value of a new system, in this case of Rijkswaterstaat a new monitoring system for assets. [74]

The monitoring is thus extra information input for the employees of Rijkswaterstaat. It is to the employees of Rijkswaterstaat to work with the collected data in an organised way. A lot of data is now collected, but the additional value of the data is not seen, or fully seen. So the data is not used at this moment in Rijkswaterstaat. By using the data, it is possible to get a better insight in the assets and their behaviour. The level of information can be reached by the set target of 2020. With a right interpretation of the data, it might lead to a better maintenance policy, a better performance of the assets and reduce the costs (both Rijkswaterstaat and the service provider) over a few years.
Furthermore, the acceptance is another important aspect for the employees of Rijkswaterstaat. When the support is there, the data collection and analyses must be a fixed and integral part of the job. Within Rijkswaterstaat, a lot of action plans and working processes are created. In the beginning, these new plans and processes are followed. But after a while, the employees fall back into their fixed routine.[10] When there is support for using the different collected data, different follow-ups must be created. This must not directly be big tasks with a lot of influence on the work processes, but let start with small steps/tasks at the time. This will not result in an big increase of the working tasks of the employees stepwise. When the employees have a clear view of the added value of a new

[9] RWS Datalab is an internal program of Rijkswaterstaat to develop smart applications for different project.
[10] This came forward during different meetings with different employees during mine internship period in Rijkswaterstaat.

implemented process and this is well integrated in the working processes of the entire company, it is possible to have a successful implementation in the organisation. [74, 75, 67]

4.11 Resume possibilities of monitoring

As can be read in this section, there is a lot of possibilities for monitoring within Rijkswaterstaat. The main benefit will be the increase in the level of information for performance management. The possibilities for performance monitoring can increase the level of information form "ad hoc" towards "integration", which is the target of 2020 set by Rijkswaterstaat. The data processing system which is now in development by RWS Datalab can give a lot of insight in how the assets are used and with which capacity the components are using etc. This give a proper baseline of how the performance of the assets is in reality. The performance comparison between the design requirements and the usage might lead to a reduction or increasing of the installed capacity. This to have a required level of performance, with the risks and costs as low as possible. By using other input sources, such as NIS and IVS90, the performance of the asset in the network can be obtained and used as a side-input besides a new sensor monitoring system.
The idea of condition monitoring within Rijkswaterstaat was focused around preventing functional losses, do pro-active maintenance and steering on the maintenance process. The first step for Rijkswaterstaat will be to set up a data processing system which is able to detect threshold values in the data. The follow-ups will then require a proper interaction between the Asset Managers and the service provider. If a threshold is reached, the service provider must be instructed to do the maintenance task. The development of a trend analysis of the data will be based on a trial and error based. When failures occur, the data processing system can be trained in order to do prognoses for the assets. However, the potential risks might lead to the fact that the system will be replaced before a failure will occur. So, it might take a long time to have a proper functional prognosis system.
But, by using the SCADA data in relation to the maintenance system Ultimo, it is possible to determine the root causes of critical or common errors. By solving these root of the problems together with the service provider, errors could be prevented in the near future. The lessons learned from these errors, might be useful for training of the monitoring system.
Finally, the obtained information can also be a good input besides other information sources for better decision making. In the first place, it will be mainly focused on the operational and performance aspect and later on the condition aspect in relation to the maintenance tasks can become more relevant.

5 Conclusions and future work

As stated at the end of chapter 4, there is room of improvement for monitoring. The main improvement will be for performance monitoring the increase in the level of obtained and used information. The performance monitoring can be well implemented for the performances of the assets and individual components. The SLA-PINs are hardly to monitor real time, but can be obtained from other information sources of Rijkswaterstaat. For condition monitoring, the expectations and goals must be adjust downward in mine opinion. The goal of having a totally preventive maintenance policy is very nice to have. However, this requires a lot of insight in the behaviour of the assets and the installed components. The options to do the maintenance just in time to have an optimal operating lifetime of components, requires a very good interaction between the service provider and Rijkswaterstaat. Furthermore, as is literature is stated some errors can only be seen on short notice, so the maintenance tasks must be done very fast in order to reduce unplanned downtime and the increase in the level of risks. The main target of Rijkswaterstaat must be firstly on the detection of errors and on monitoring the thresholds values prescribed by the manufactures. Later on, the model can be trained when historical data is obtained, saved and processed. Then, the model can be trained by machine learning in order to provide extrapolation of the data, doing trend analysis, which will result in the fact that prognosis can be done on monitored parameters and components.

The potential option of data sharing is not investigated. As is stated in the report, Rijkswaterstaat is always the owner of the data, if this is the raw data or processed data is not specified. The ministry wants to have transparent organisations, so data must be open. However, this specific data maybe wanted to keep insight due to external risks. Furthermore, if the data is shared with one specific service provider, they gain benefit from the data and thus have an advantage for the new maintenance contracts. This could potentially result in an unfair market situation. A proper decision about data sharing must be made by the management, based on all advantages and disadvantages.

6 References

[1] M. Jongman, 8 April 2016. [Online]. Available: https://www.ifv.nl/kennisplein/Documents/4-startbijeenkomst-lec-tv-jongman-blok-1.pdf. [Accessed 1 May 2018].

[2] R. F. Cox, R. R. Issa and D. Ahrens, "Management's Perception of Key Performance Indicators for Constrution," *Journal of Construction Engineering and Management,* pp. 142-151, April 2003.

[3] S.-u.-R. Toor en S. O. Ogunlana, „Beyond the 'iron triangle': Stakeholders perception of key performance indicators (KPIs) for large-scale public sector development projects," *International Journal of Project Management,* pp. 228-236, April 2010.

[4] J. F. G. Fernández and A. C. Márquiz, Maintenance Management in Network Utilities, London: Springer, 2012.

[5] E. Fitch, Proactive Maintenance for Mechanical Systems, Abingdon: Elsevier Science, 1992.

[6] S. Vaidya, P. Ambad and S. Bhosle, "Industry 4.0," *Procedia Manufacturing,* no. 20, pp. 233-238, 2018.

[7] J. Lee, H. Kao and S. Yang, "Service innovation and smart analytics for Industry 4.0 and big data environment," in *Proceedings of the 6th CIRP Conference on Industrial Product-Service Systems*, 2014.

[8] M. Bahrin, M. Othman, N. Nor and M. Azlo, "Industry 4.0: A Review on Industrial Automation and Robotic," *Jurnal Teknologi,* pp. 137-143, 2016.

[9] F. Almado-Lobo, "The Industry 4.0 revolution and teh future of Manufacturing Execution Systems," *Journal of Innovation Management JIM 3,* vol. 4, pp. 16-21, 2015.

[10] D. Schippers, "Het ontwikkelen van mogelijkheden voor condition-based maintenance voor sluizencomplex Eefde van Rijkswaterstaat [concept]," Rijkswaterstaat, Hengelo, 2018.

[11] D. v. d. Maas, "Vitale Asset," 22 March 2018. [Online]. Available: https://waterwegenwiki.cf-prod.intranet.rws.nl/index.php?title=Vitale_Assets. [Accessed 1 May 2018].

[12] "About us," 2018. [Online]. Available: https://www.rijkswaterstaat.nl/english/about-us/index.aspx. [Accessed 2 May 2018].

[13] "Our organistation," 2018. [Online]. Available: https://www.rijkswaterstaat.nl/english/about-us/our-organization/index.aspx. [Accessed 2 May 2018].

[14] „Highways," 2018. [Online]. Available: https://www.rijkswaterstaat.nl/english/highways/index.aspx. [Geopend 2 May 2018].

[15] "Water systems," 2018. [Online]. Available: https://www.rijkswaterstaat.nl/english/water-systems/index.aspx. [Accessed 2 May 2018].

[16] "Waterways," 2018. [Online]. Available: https://www.rijkswaterstaat.nl/english/waterways/index.aspx. [Accessed 2 May 2018].

[17] Rijkswaterstaat, "LCC en ramingen van beheer- en onderhoudskosten," October 2017. [Online]. Available: http://corporate.intranet.rws.nl/Content/Media/297d2841-2742-4a39-9cc9-ce45ced96b7f/Factsheet%20LCC%20en%20BenO-ramingen.pdf. [Accessed 25 May 2018].

[18] Rijkswaterstaat, Handreiking prestatiegestuurde risicoanalyses (PRA), Rijkswaterstaat, 2018.

[19] A. v. Maaren, Handreiking prestatiegestuurde risicoanalyses (PRA), Rijkswaterstaat, 2018.

[20] R. v. d. Plaat, *Rijkwaterstaat Aanleg & Onderhoud - Assetmanagement Projectmanagement [presentation],* Rijkswaterstaat, 2017.

[21] "Assetmanagement," 2018. [Online]. Available: http://corporate.intranet.rws.nl/kennis_en_expertise/kennisvelden/assetmanagement/. [Accessed 4 May 2018].

[22] "Kennisveld Life Cycle Management," 2017. [Online]. Available: http://corporate.intranet.rws.nl/Kennis_en_Expertise/Kennisvelden/Assetmanagement/Kennisveld_Life_Cycle_Management/. [Accessed 1 May 2018].

[23] J. v. d. Velde and H. Hooimeijer, Asset Management binnen Rijkswaterstaat, Rijkswaterstaat, 2010.

[24] A. v. Maaren, "ProBO methodiek," 20 February 2017. [Online]. Available: http://corporate.intranet.rws.nl/Kennis_en_Expertise/Kennis_bij_RWS/Steunpunten/Steunpunt_ProBO/ProBO_methodiek/. [Accessed 20 April 2018].

[25] M. Pietrzak en J. Paliszkiewicz, „Framework of Strategic Learning: The PDCA Cycle," *Management,* vol. 10, nr. 2, pp. 149-161, 2015.

[26] M. Park, "RAMS Management of Railway Systems," University of Birmingham, Birmingham, 2013.

[27] A. Martinetti, A. Braaksma and L. v. Dongen, "Beyond RAMS Design: Towards an Integral Asset and Process Approach," in *Advances in Through-life Engineering Services*, Springer, 2017, pp. 417-428.

[28] J. Braaksma, Asset information for FMEA-based maintenance, Groningen: University of Groningen, 2012.

[29] J. Braaksma, "Maintenance Engineering & Management [presentation]," University of Twente, Enschede, 2018.

[30] F. d. Jong, Quick guide opstellen RCMCost model, 1.1 ed., Duiven: Delta pi, 2013.

[31] S. Solaimani, N. Guldemond and H. Bouwman, "Dynamic stakeholders interaction analysis: Innovative smart living design cases," *Electron Markets,* no. 23, pp. 317-328, 29 September 2013.

[32] D. Vons, „Infographic Periodieke Netwerkrapportage - RWS Oost Nederland T1 2018," Rijkswaterstaat, Utrecht, 2018.

[33] D. Vons, "Netwerkrapportage ON T1 2018," Rijkswaterstaat, Utrecht, 2018.

[34] Rijkswaterstaat, "IV-koers Regio 2020 [presentation]," 2016.

[35] Rijkswaterstaat, "Rijkswaterstaat Managementinformatie," [Online]. Available: https://nis.rijkswaterstaat.nl/SASLogon/login. [Accessed 15 May 2018].

[36] NIS Rijkswaterstaat, "Verantwoorden en (bij)sturen met het NIS," 2015.

[37] Rijkswaterstaat, "Ultimo," [Online]. Available: https://www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat/werkwijzen/werkwijze-in-gww/data-eisen-rijkswaterstaatcontracten/ultimo.aspx. [Accessed 15 May 2018].

[38] Rijkswaterstaat, "De Rijkswaterstaat Standaard - voor de inwinning, verwerking en uitgifte van hydrologische en meteorologische gegevens," January 2010. [Online]. Available: https://staticresources.rijkswaterstaat.nl/binaries/RWS%20Standaard_tcm174-346480_tcm21-20510.pdf. [Accessed 15 May 2018].

[39] K. Triep, "Amerikaanse leger "impressed" door CIV," 2018 March 2018. [Online]. Available: http://corporate.intranet.rws.nl/Actueel/Nieuws/Nieuws_Centrale_Informatievoorziening/2018.03.20/Amerikaanse_leger_impressed_door_CIV.htm. [Accessed 16 May 2018].

[40] Rijkswaterstaat, "Vitale Assets [presentation]," July 2016. [Online]. Available: https://www.platformwow.nl/media/2356/vitale-asserts-conditiegestuurd-onderhoud-rijkswaterstaat-juli-2016.pdf. [Accessed 15 May 2018].

[41] Rijkswaterstaat, "IVS90," [Online]. Available: https://www.rijkswaterstaat.nl/zakelijk/verkeersmanagement/scheepvaart/scheepvaartverkeersbegeleiding/ivs90/index.aspx. [Accessed 15 May 2018].

[42] Rijkswaterstaat, "Corporate innovatieprogramma [presentation]," January 2017. [Online]. Available: https://staticresources.rijkswaterstaat.nl/binaries/Projectenoverzicht-totaal_tcm21-100458.pdf. [Accessed 16 May 2018].

[43] M. v. d. Boor, *Storingsinformatie uit SCADA [presentation],* Rijkswaterstaat, 2017.

[44] A. Vashoeey, "Ontwerp SCADA raportage [presentation]," 2018.

[45] S. Altman, "Performance Monitoring Systems for Public Managers," *Public Administration Review,* no. 39, pp. 31-35, January 1979.

[46] A. K. Jardine, D. Lin en D. Banjevic, „A review on machinery diagnostics and prognostics implementing condition-based maintenance," *Mechanical Systems and Signal Processing,* nr. 20, pp. 1483-1510, 2006.

[47] J. Veldman, W. Klingenberg en H. Wortmann, „Managing condition-based maintenance technology," *Journal of Quality in Maintenance Engineering,* nr. 17, pp. 40-62, 2011.

[48] U. Dombrowski, K. Schmidtchen and D. Ebentreich, "Balanced Key Performance Indicators in Product Development," *International Journal of Materials, Mechanics and Manudacturing,* pp. 27-31, February 2013.

[49] B. S. Blanchard, Systems engineering and analysis, 5th ed., London: Pearson, 2014, p. 837.

[50] M. v. d. Boor, Interviewee, *Ervaring uitwisseling informatie verwerking.* [Interview]. 8 May 2018.

[51] RWS Data Science, "Storingen - Informatie uit verschillende bronnen [presentation]," [Online]. Available: https://docs.google.com/presentation/d/1HJcYA4OHUgqTFqjHFBf2_Rn1_dCUtQrPWsTJy75v2l0/edit#slide=id.g1e49b40ef3_0_42. [Accessed 8 May 2018].

[52] Datalab Rijkswaterstaat, "Datalab project storingen," May 2018. [Online]. Available: http://storingen-datalab.cf-prod.intranet.rws.nl/. [Accessed 30 May 2018].

[53] SKF, "Condition Monitoring," SKF, [Online]. Available: http://www.skf.com/group/products/condition-monitoring/index.html. [Accessed 28 June 2018].

[54] J. Lee, F. Wu, W. Zhao, M. Ghaffari, L. Liao en D. Siegel, „Prognostics and health management design for rotary machinery systems- Reviews, methodology and applications," *Mechanical Systems and Signal Processing,* nr. 42, pp. 314-334, 2014.

[55] K. Maurer and S. Lau, "Robust Design," *Industrial Engineering,* no. 361, 11 February 2000.

[56] A. Muller, A. C. Marquez en B. Iung, „On the concept of e-maintenance: Review and current research," *Reliability Engineering and System Safety,* nr. 93, pp. 1165-1187, September 2008.

[57] W. Tiddens, A. Braaksma and T. Tinga, "The adaption of prognostic technologies in maintenance decision making: a multiple case study," in *The Fourth International Conference on Through-life Engineering Services*, 2015.

[58] S. Famurewa, L. Zhang and M. Asplund, "Maintenance analytics for railway infrastructure decision support," *Journal of Quality in Maintenance Engineering,* vol. 23, no. 3, pp. 310-325, 2017.

[59] W. Tiddens, A. Braaksma en T. Tinga, „Selecting Suitable Candidates for Predictive Maintenance," *International Journal of Prognostics and Health Management,* vol. 9, nr. 1, 2018.

[60] L. A. v. Dongen, "Asset Life Cycle Management - Rolling Stock of Netherlands Railways [presentation]," 18 October 2017. [Online]. Available: https://blackboard.utwente.nl/bbcswebdav/pid-1091593-dt-content-rid-2753307_2/courses/2017-201200146-1A/MEM.LvD.17.10.18.pdf. [Accessed 24 May 2018].

[61] M. Cross and S. Sivaloganathan, "A methodology for developing company-specific design process models," *Proceedings of the Institution of Mechanical Engineering,* no. 219, pp. 265-282, March 2005.

[62] Ministerie van Infrastructuur en Milieu, "Aanleg en Onderhoud [internal website]," 1 June 2018. [Online]. Available: https://processen.intranet.minienm.nl/businesspublisher/modelView.do?ExportName=RWS&test=false&c=1528183562904#!modelGUID=a74b0f30-05d3-11e4-0876-0050568860de&prevNodeID=2_547_1&scale=100&view=full. [Accessed 4 June 2018].

[63] Ministerie van Infrastructuur en Milieu, "Voorbereiden en Uitvoeren A&O ingrepen [internal website]," 1 June 2018. [Online]. Available: https://processen.intranet.minienm.nl/businesspublisher/modelView.do?ExportName=RWS&test=false&c=1528183849950#!modelGUID=a74b0f30-05d3-11e4-0876-0050568860de&prevNodeID=2_547_1&scale=100&view=full. [Accessed 4 June 2018].

[64] T. v. Gazelle and J.-L. Beguin, Handreiking Kwalitatieve objectrisicoanalyse, 2.1.1. ed., Rijkswaterstaat, 2017.

[65] K. Maynard, "Interstitial Processing: The Application of Noise Processing to Gear Fault Detection," in *Proceedings of the International Conference on Condition Monitoring*, Swansea, 1999.

[66] M. Lebold, K. McClintic, K. Campbell, C. Byington and K. Maynard, "Review of Vibration Analysis Methods for Gearbox Diagnostics and Prognostics," in *Proceedings of teh 54th Meeting of the Society for Machinery Failure Prevention Technology*, Virginia Beach, VA, 2000.

[67] T. Zwanenbeek, G. Ras and A. de Waard, Actieplan om het nieuwe werken in de Assetmanagementketen te realiseren met behulp van Informatiebouwstenen, 4 ed., Utrecht: Rijkswaterstaat, 2016, p. 72.

[68] M. Koole, Interviewee, *Dashboard monitoring.* [Interview]. 21 June 2018.

[69] Ministerie van Infrastructuur en Milieu, "Processen RWS," Rijkswaterstaat, 3 July 2018. [Online]. Available: https://processen.intranet.minienm.nl/businesspublisher/index.do?test=false&ExportName=RWS. [Accessed 3 July 2018].

[70] T. Rahlf, Data Visualisation with R, Cham: Springer International Publishing AG, 2017.

[71] J. Eldridge, „Data visualisation tools - a perspective from the pharmaceutical industry," in *International Patent Information Conference and Exhibition*, Benalmàdena, 2006.

[72] M. Blumenay and J. Rehermann, "DATAPINE – ONE OF THE BEST ONLINE DATA VISUALIZATION TOOLS," datapine, [Online]. Available: https://www.datapine.com/data-visualization-tools. [Accessed 13 June 2018].

[73] J. Wagenvoort, "Ontwerp SCADA rapportage [presentation]," Rijkswaterstaat, Utrecht, 2018.

[74] K. Jonsson and U. Westergren, "Developing remote monitoring services: Important points to consider," 2004.

[75] T. Zaal, "Structureren gaat voor Automatiseren & Informeren," Hogeschool Utrecht, Utrecht, 2015.

[76] "Onze organistatie," 2018. [Online]. Available: https://www.rijkswaterstaat.nl/over-ons/onze-organisatie/index.aspx. [Accessed 2 May 2018].

[77] P. d. Jong, P. Bakker, H. Apau, J. Luyk and P. Webbers, "Prestatiegestuurde Instandhoudingsplannen IJsselmeergebied," Delta Pi, Duiven, 2012.

[78] K. Koning, Interviewee, *Data monitoring en Asset Management.* [Interview]. 29 May 2018.

[79] ANP, "Defecte draadstang oorzaak sluisongeluk Eefde," 27 March 2012. [Online]. Available: https://www.nu.nl/binnenland/2773499/defecte-draadstang-oorzaak-sluisongeluk-eefde.html. [Accessed 14 May 2018].

[80] A. Bomers, Interviewee, *Kennisborging Rijkswaterstaat.* [Interview]. 6 July 2018.

Pictures between chapters:

Maaren, A. v. (2018, March). *Handreiking prestatiegestuurde risicoanalyses (PRA)*. Rijkswaterstaat.

7 Appendices

7.1 Appendix 1: SLA-PIN at Rijkswaterstaat

Main highway network
Table 7: Main highway network SLA-PIN

SLA-PIN 2018-2021	MC 2018	PIN description	Norm	Remarks
SLA-PIN 1	**MC PIN 1**	Technical availability of the road – planned work	97,00%	MC is same as SLA-PIN
SLA-PIN 2		Traffic jams by work in progress, construction and planned maintenance	10,00%	
	MC PIN 2a	Traffic jams by work in progress, construction and planned maintenance	Region dependent	SLA-PIN 2 is same as MC PIN 2a
	MC PIN 2b	Traffic jams by work in progress, unplanned maintenance	1,00%	
SLA PIN 3a		Delivery traffic data – availability	90,00%	
SLA PIN 3b		Delivery traffic data – actuality	95,00%	
	MC PIN 3a	Delivery traffic data – availability	Region dependent	SLA-PIN 3a is same as MC PIN 3a
	MC PIN 3b	Delivery traffic data – actuality	95,00%	SLA-PIN 3b is same as MC PIN 3b
SLA-PIN 4a		Traffic safety – pavements: norms – surface	99,70%	
SLA-PIN 4b		Traffic safety – slipperiness control: forehanded preventive scatter	95,00%	
	MC PIN 4a	Traffic safety – timely delivery of mandatory reports	70,00%	
	MC PIN 4b	Traffic safety – timely handling serious findings	70,00%	
	MC PIN 4c	Traffic safety – pavements: norms – timely	100,00%	Timely implementation of compensatory measures
	MC PIN 4d	Traffic safety – slipperiness control: forehanded preventive scatter	95,00%	SLA-PIN 4b same as MC PIN 4d
SLA-PIN 5	**MC PIN 5**	Sound – compliance report	On time	MC is same as SLA-PIN
	MC PIN 6a	Pavements must meet with advice	Region dependent	
	MC PIN 6b	Pavement must meet with norms	100,00%	
	MC PIN 7	Artworks[11] must meet with advice	Region dependent	

[11] Artworks at Rijkswaterstaat are bridges, viaducts etc.

	MC PIN 8a	Driving times – IM-area's (Incident Manager)	80,00%	
	MC PIN 8b	Driving times – IM-plus-area's (Incident Manager with special authorizations)	80,00%	
	MC PIN 9	DRIP's	90,00%	

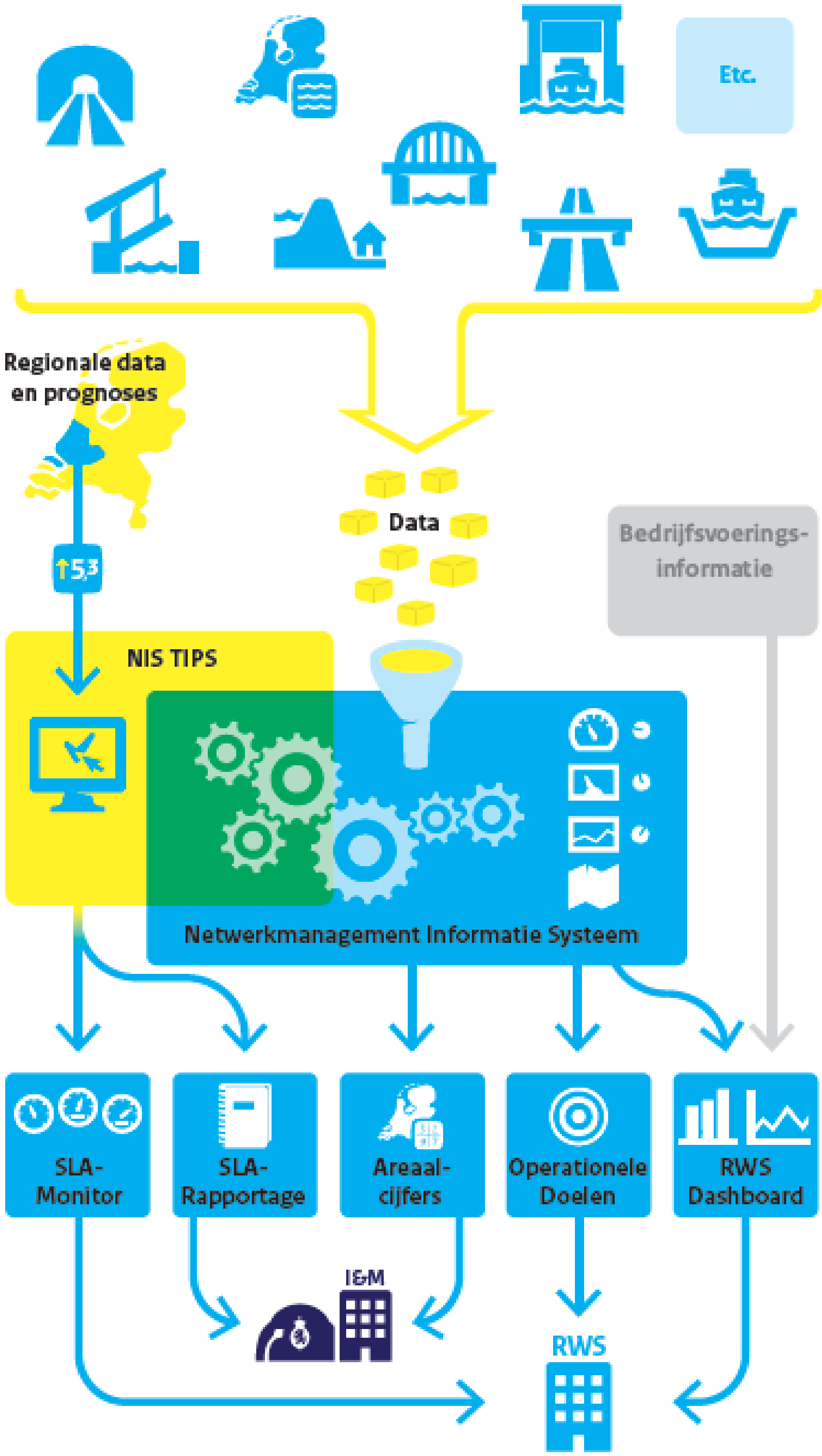
Main waterways
Table 8: Main waterways SLA-PIN

SLA-PIN 2018-2021	MC 2018	PIN description	Norm
SLA-PIN 1		Blocks due to planned maintenance	0,80%
SLA-PIN 2		Blocks due to unplanned maintenance	0,20%
SLA-PIN 3		Timely report of unplanned blocks	97,00%
SLA-PIN 4		Shipping channel in shape	As defined
SLA-PIN 5		Waterway marking in right condition	95,00%
	MC PIN 6	Enforcement related to ships	80,00%
	MC PIN 7	Evaluation of accidents with ship(s)	100,00%
	MC PIN 8	Reliable time of passes canal locks	As defined

Main watersystem
Table 9: Main watersystem SLA-PIN

SLA-PIN 2018-2021	MC 2018	PIN description	Norm
SLA-PIN 1		Enforcement coastline	90,00%
SLA-PIN 2		Availability 6 storm surge barrier	100,00%
SLA-PIN 3		Watermanagement in control	100,00%
	MC PIN 3b	Water level management channels and lakes	98,00%
	MC PIN 3c	High water management channels and lakes	98,00%
	MC PIN 3f	Water supply	98,00%
	MC PIN 3g	Salinization control	98,00%
SLA-PIN 4		Reliability information services	95,00%
	MC PIN 5	Repel high water	95,00%
	MC PIN 6	Drain high water rivers	95,00%
	MC PIN 7	Clean and healthy water	-
	MC PIN 7h	Living area of flora and fauna	95,00%
	MC PIN 7i	Reduction of pollution of (swimming) water quality	95,00%
	MC PIN 7j	Natural fish migration routes	95,00%

7.2 Appendix 2: Overview data in NIS



7.3 Appendix 3: Extended stakeholder analysis

Extended Stakeholder analysis according to the VIP-framework of Solaimani and Bouwman [31].

Stakeholder	Involvement	Focus	Outcome
RWS Teams	- Keeping the assets in right operating state - Steering service provider - Technical knowhow and knowledge - Contact with service provider, industry and other provisions	- Condition and performance of the asset (RAMSSHEEP-aspects) - Provide technical requirements for contract	- Up-to-date operating policy - Up-to-date maintenance plan - Condition and performance of assets up-to-date and safe
RWS AM	- Keeping assets in the right operating state - Setting up inspection forms and renovations - Determine strategic choices related to remaining life time - Knowledge about internal and external processes and technical knowhow	- Condition and performance of the asset (RAMSSHEEP-aspects) - Life cycle management - Keep asset information up-to-date - Long term planning	- Up-to-date operating policy - Up-to-date maintenance plan - Correct models of the assets (e.g. RCM Cost) - Condition and performance of assets up-to-date and safe
RWS PPO/GPO	- Provide contract for project related to the assets - Planning and execution of renovations	- Budgeting - Planning of projects - Set up contracts	- Provide different kind of contracts (services, small projects, big projects etc.)
RWS management	- To be informed about the level of performance and condition of assets	- Global steering of the organisation	- Steering of the teams and districts on global level
RWS CIV	- Set up information portals - Keeping information system operating - Provide information among employees	- Information services - Asset information systems	- Information systems - Data collection and analyses - Provide dashboards/ overviews of collected data
Service provider	- Keeping asset in condition according to contract	- Provide services according to contract	Perform maintenance tasks (standard and variable maintenance tasks, inspections etc.)

User (industry)	- Using the asset during operating time	- Benefits for company	- Usage of system for transportation of material and goods
User (recreation)	- Using the assets during operating time	- Enjoying	- Using systems for recreation (shipping, fishing etc.)
Ministry of I&W	- Having the assets at the SLA-PIN - Determine the budgets among the regions/teams	- Accountability to government - Service provider to users - Budgeting - Laws and regulations	- Having systems at expected level - Having budget within limits - New/chancing laws and regulations
Operator	- Operate the assets during operating time - Monitor the assets during operating time - Make notes of possible errors	- Operating assets	- Operate assets according to policies

7.4 Appendix 4: Tools and knowledge fields

In this appendix, the tables are given of potential tools that could be used by the Asset Managers of Rijkswaterstaat and the knowledge fields that should be up-to-date related to monitoring. Table 10 is based on the research of Cross and Sivaloganathan [61]. Table 11 gives an overview of the required knowledge fields which are related to monitoring during the implementation/evaluation.

Table 10: Tools related to monitoring and life cycle phases

Tools	Benefit	Life Cycle phase			
		Des.	Con.	Op.	Dem.
Model-risk matrix	In order to identify the risks of an error based on the effect and frequency	X	X	X	
FME(C)A	In order to identify the failure modes and effects of a system/component	X	X	X	
Fault Tree Analysis	In order to determine how a system can fail, in order to reduce risk or to determine event rates	X	X	X	
Quadrant Method	Determine the maintenance strategy by plotting downtime versus frequency of a failure	X	X	X	
Gantt Chart	Gives a proper overview of which tasks are done and when a task should be started/finished during a project	X	X	X	X
Check sheets	Have a fixed check list to control if everything is done	X	X	X	X
Risk Management	Determine how the risks of an asset/component are identified, controlled and reviewed	X	X	X	X
Stakeholder Analysis	Determine all the relevant stakeholders, which might have some benefits/drawbacks of a project	X	X	X	X
Cost-benefit analysis	Determine the benefit of an project	X	X	X	X

Table 11: Knowledge fields and relation to monitoring

Knowledge field	Purpose	How related to monitoring
RAMSSHEEP	The asset must perform according to a standard, which is related to the RAMSSHEEP-aspects. All the decisions made related to an asset somehow have a relation to one/multiple aspects of the RAMSSHEEP methodology [19, 27]	Data could be obtained for different parameters that defined aspects of the RAMSSHEEP, these will mainly be focused around RA. Analyses and decision making have impact on all the aspects of the RAMSSHEEP methodology
TECCO	The decisions made by the Asset Managers could also be related to the TECCO-aspects. These are more organisational related aspects compared to the RAMSSHEEP methodology	Analyses and decision making have impact on all the aspects of the TECCO methodology
Life Cycle Management	Decision must be made by the Asset Managers which are the best in line with the remaining lifetime of an asset. For different life cycle phases/stages in a	Analyses and decision making have impact on the future condition and performance of the asset

	phase, different decisions will be made [21, 22]	
Function analysis	Determine the main function of an asset/component [19]	Parameters can check the current function and/or state of the asset/component that are monitored
FME(C)A	Determine the failure mechanisms and their failure frequencies. [19, 28]	Errors can indicate the MTTF/MTBF of components
Failure behaviour	How components of an asset fails and how these are related to the functional behaviour of an asset	Can help to indicate which parameters should be monitored, the monitoring system must be close to the root of the error
Failure mechanisms	The root cause of failures can be determined according to their failure mechanisms. When the causes are known, these could be solved/restricted to occur.	Can help to indicate which parameters should be monitored since they are the determining failure parameter [64]
Parameter selection	Determine with parameters are relevant to monitor [59, 54]	Parameters must be selected, since not too much data is obtained and only for relevant components
Sensor equipment	Knowing which sensor are available and what are the possibilities of implementation and functions	Known which sensors are capable of measuring the required parameters
Maintenance policies	Knowing which maintenance policies are available and what the reasons are to use these policies. A well thought out maintenance plan is mainly based on the selection of the right maintenance policies. [24]	
Maintenance analytics	Relate the data gathering and monitoring to the right maintenance analysis in order to have a proper maintenance and life cycle decision making support. [57]	Knowing what kind of data is required per maintenance analytics in order to have a good analysis
RCM	Have insight in how the aspects of the RAMSSHEEP have an influence on the different maintenance strategies and vice versa. The methodology helps the Asset Managers to determine the optimal combination of different maintenance strategies	The theory is required in order to make the connection between the data and the modelling inside the RCM methodology
Algorithms	Have insight which algorithms are capable of processing sensor output in relation to the common features of components [54]	Algorithms are used for processing large amount of data and must result in a workable output of the data processing step.
LCC	How decisions have an impact on the costs over different periods in time and how different scenarios differ	Related the decision based on data to the cost per life cycle
ProBO	Give guidance in order to derive the maintenance strategy in relation to cost, performance and risks [24]	Relate the data to the work flow/processes of the ProBO methodology

ORA	The qualitative risk analysis gives insight in the failure behaviour and risks (FMECA) and the prioritation of risks [64]	Relate the data to the work flow/processes of the ORA methodology
Data visualisation	What the different possibilities are for data visualisation and what the best visualisation is per parameter/analysis [54]	Make a proper decision what the best way of visualising data is
Data evaluation	The interpretation of the output data of the data analysis and how to act on the different outcomes	Is required to make the connection between the data output and the functions, performance and condition of the asset
Decision making	What the influences is of decisions on the risks, performance and costs and how different scenarios have different impact on the product life cycle and the product life cycle costs	Use the data as a supporting tool for decision making processes. The outcome of the data must be obtained, analysed and evaluated properly before the right decisions can be made

7.5 Appendix 5: Summarisation of PHM tools of critical components

Table 12: Introductory summarisation of PHM tools of critical components displays the summarisation of the PHM tools and algorithms that can be found in the research of J. Lee et al. [54] These table contains components that are relevant since it contains components that are used in many assets of Rijkswaterstaat and contain measures and algorithms that are relevant for many assets of Rijkswaterstaat.
The list of used abbreviation in the table is given below:

Fourier Transform - FT
Short Time Frequency Transform - STFT
Wavelet Transform - WT
Empirical Mode Decomposition - EMD
Hilbert-Huang Transform - HHT
Neural Networks - NN
Hidden Markov Modeling - HMM
Support Vector Machine - SVM
Genetic Algortihm - GM
Autoregressive Moving Average - ARMA
Principal Component Analysis - PCA
Wigner-Ville Transforms - WVT
Support Vector Regression - SVR

Table 12: Introductory summarisation of PHM tools of critical components

Component	Issue and failure	Characteristics	Common measures	Common features	Common use algorithms
Bearing	Outer-race, inner-racem roller and cage failures	Raw data does not contain insightful information; low amplitude; high noise	Vibration, oil debris, acoustic emission	Vibration characteristics frequency, time domain statistical characteristics, metallic debris shape, size, quantity, sharp pulses and rate of development of stress-waves propagation	FT, STFT, WT, EMD, Bispectrum, Autoregression Frequency spectra, HHT, NN, HMM, Fuzzy logic, SVM, GA, Rough set, ARMA, Stochastic model, PCA
Gear	Manufacturing error, tooth missing, tooth pitting/spall, gear crack, gear fatigue/wear	High noise; high dynamic; signal modulated with other factors (bearing, shaft, transmission path effect); gear specs need to be known	Vibration, oil debris, acoustic emission	Time domain statistical features, vibration signature frequencies, oil debris quantity and chemical analysis	FT, STFT, WT, EMD, HHT, NN, Fuzzy logic, Neuro-Fuzzy Hybrid Model, Energy Index Analysis, Kalman filter, SVM, Autoregressive Model , Particle Filter
Shaft	Unbalance, bend, crack, misalignment, rub	Vibration signal is relatively clean and harmonic frequency components of rotating speed can be indicate the defects	Vibration	Vibration characteristics frequency, time domain statistical characteristics, system modal characteristics	FT, WT, WVT, EMD, Analytical or Numerical Models, NN, Fuzzy logic, SVR, GA, ARMA
Pump	Valve impact, score, fracture, piston slap, defective bearing and revolving crank, hydraulic problem	Pump's dynamic responses; generated by a wide range of possible impulsive sources; are very complex; nonlinear, time-	Vibration, pressure, acoustic emission	Vibration characteristics frequency, pressure time domain statistical characteristics, sharp pulses and rate of development of stress-waves propagation	FT, STFT, WT, Envelop Analysis, NN, Fuzzy logic, Neuro-Fuzzy Hybrid Model, Rough set, PCA

		varying behaviour			
Alternator	Stator faults, rotor electrical faults, rotor mechanical faults	Currents and voltages are preferred for non-invasive and economical testing	Stator currents and voltages, magnetic fields and frame vibrations	Specific harmonic components, sideband components	FT, WT, Instantaneous Power Fourier Transform, Bisprectrum, High Resolution Spectral Analysis, Expert systems, NN, HMM, Fuzzy logic, GA, Higher Order Stastics, Park's Current Vector Pattern, Petri Net, Kalman Filter

7.6 Appendix 6: Working processes of the Asset Managers

This appendix will give an overview of how a monitoring system have an influence on the current working processes of the Asset Managers of Rijkswaterstaat. It must be stated the appendix and figures are in Dutch. [67, 69] The red dots indicate that there is an influence of monitoring on the process.

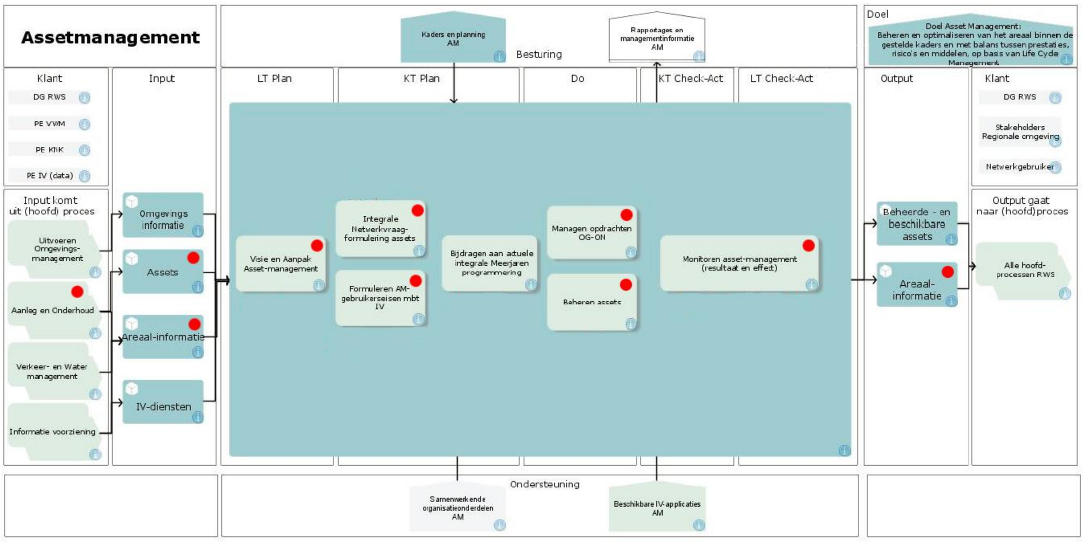


Figure 24: Main process AM

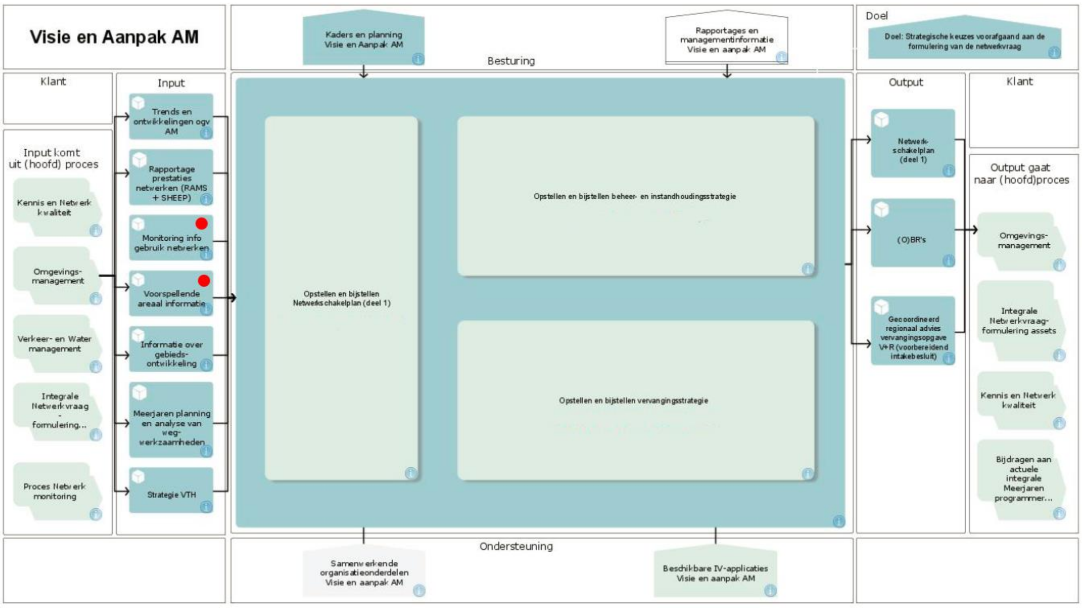


Figure 25: Process "Visie en Aanpak AM"

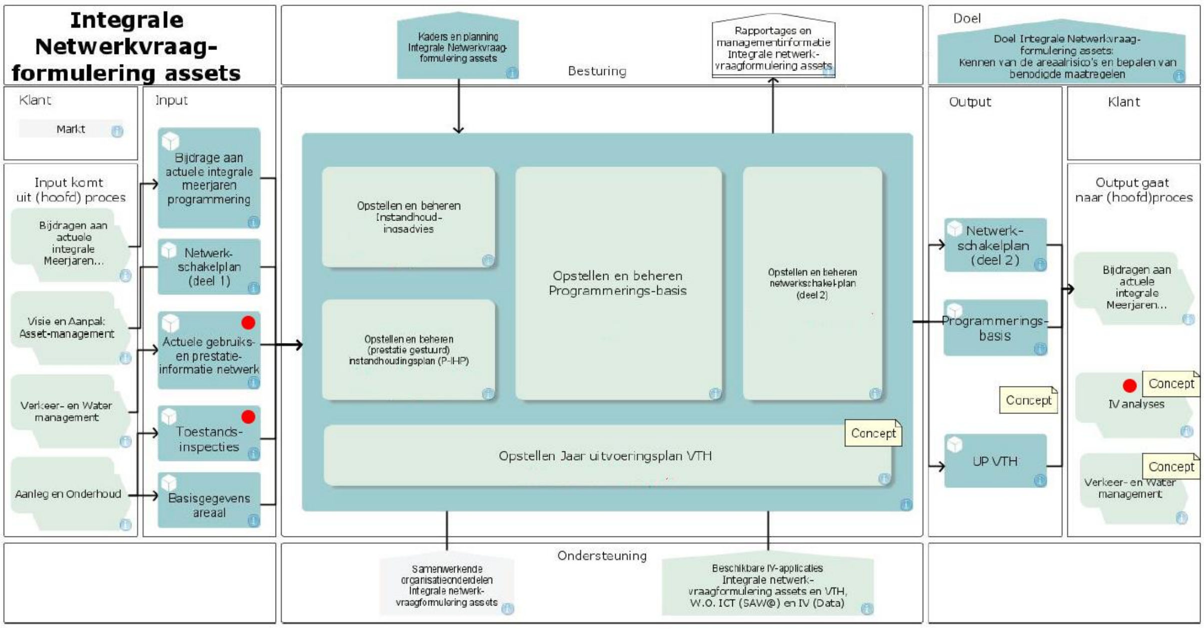


Figure 26: Process "Integrale Netwerkvraagformulering assets"

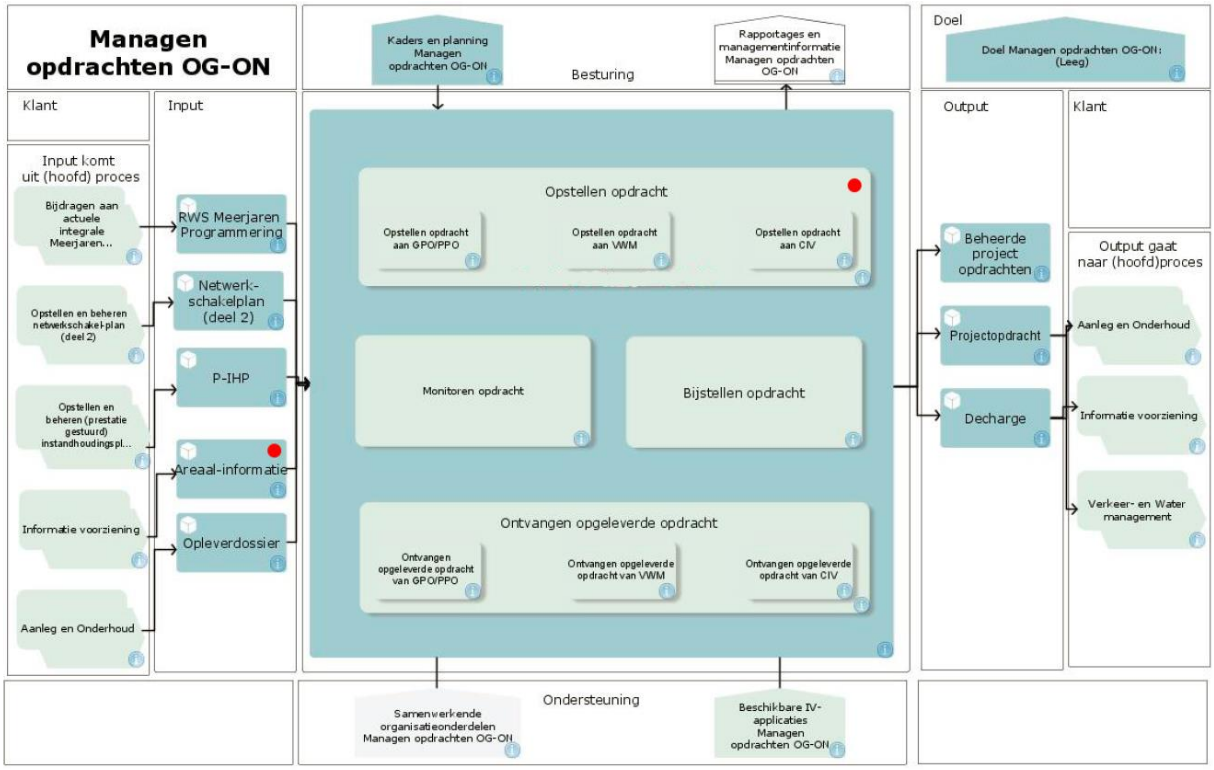


Figure 27: Process "Managen opdrachten OG-ON"

Rijkswaterstaat
Ministry of Infrastructure and Water Management

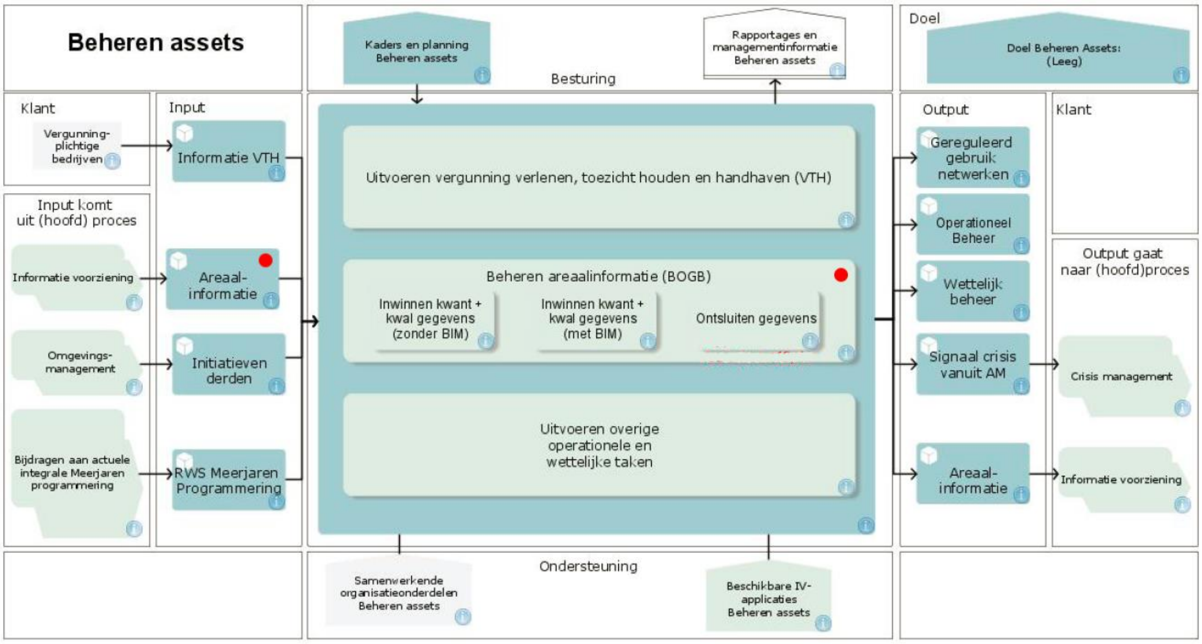


Figure 28: Process "Beheren Assets"

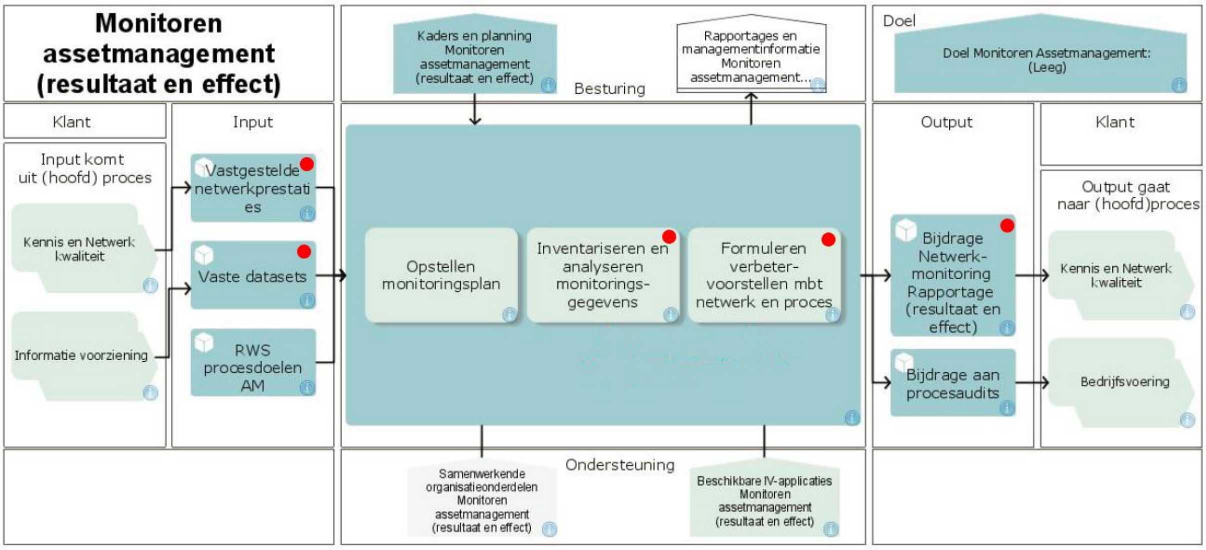


Figure 29: Process "Monitoren assetmanagement"

7.7 Appendix 7: Reflection on internship

During mien internship I gained a lot of information and insight of Rijkswaterstaat. As is stated in the report, Rijkswaterstaat has the responsibility of the three main networks in the Netherlands. In order to do this, many teams and departments are working together (from national level till very local). Besides keeping the assets available for the users, the organisation is also responsible for licenses, traffic control and enforcement on the canals and rivers. During mine internship it was positioned in the team that is responsible for the canals locks on the Twente canal. For more information about the organisation and working processes, see section 3.1 and 3.2.

During mine internship, I worked on the assignment to investigate the possibilities of performance and condition monitoring within Rijkswaterstaat. The results of this research can be read in the conclusion, see chapter 5. While working on the assignment, I had in the beginning a lot of talks with mine external supervisor and other employees. This gave me a lot of inside in the entire organisation (how the company is organised, what the normal working tasks and processes are, the room of improvement on employees personal level). The expectations of the organisation before I started seems not entirely good. I expected a way more hierarchical organised company, since Rijkswaterstaat has a lot of employees and a lot of different departments. Over the time being here, I gained more and more insight in the organisation and all the different working possibilities for myself.

In the beginning, I was a little bit struggling to find the right way to go. This due to the fact that an assignment like this, I did not experienced in mine bachelor or master program before. Furthermore, since a lot of information is only given globally or specific in the organisation, I experienced this as difficult to find the right information. With some help, or by looking a bit wider in the information sources of Rijkswaterstaat, the right information was founded. While working on mine assignment, I think that is worked quite independent and flexible. During the assignment, I was able to use the theory that I gained in mine bachelor and especially master program in a real practical manner.

A shortcoming of mine, is that I am quite reservedly. This due to the fact, that I want to find my niche before I openly express myself. In line with this, I could approach other people more often in order to obtain insight information and experiences that I could use as input in mine assignment.

Finally, I improved mine soft skills as communication and personal development a lot during mine internship period at Rijkswaterstaat. I also received time of mine employer to visit working sessions in the different offices of Rijkswaterstaat, visiting assets of Rijkswaterstaat and was involved in the team organisation of team canal locks. This gave me a lot of insight knowledge about the entire organisation and I am very thankful that I received and seized these opportunities. This gave me a great insight on mine professional career opportunities and preferences.

Rijkswaterstaat
Ministry of Infrastructure and Water Management

Internship report of
Sven de Haan
As part of the master
Mechanical Engineering at
the University of Twente

In corporation with:
Rijkswaterstaat
www.rijkswaterstaat.nl
0800 – 8002

July 2018