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Guiding the implementation of Predictive Maintenance Projects

by developing a Predictive Maintenance Implementation Process

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Summary

In this thesis the aim is to develop a design to support the implementation of Data Gedreven Asset Management (DGAM) (*English: Data Driven Asset Management*) at Rijkswaterstaat. Rijkswaterstaat has the ambition to optimize their maintenance strategy to get a better insight in the condition of their assets as Rijkswaterstaat faces a major challenge to keep their assets available and in a healthy condition in the upcoming years. To achieve this objective, Rijkswaterstaat established the program Data Gedreven Asset Management. However, the implementation of DGAM poses a complex process. During this thesis a Predictive Maintenance Implementation Process (PIP) is developed to support the implementation manager to overcome the difficulties faced during the implementation of DGAM at Rijkswaterstaat.

Rijkswaterstaat is a public organization which is responsible for the management and development of a tremendous amount of assets, all of which have an unique design and components. Furthermore, Rijkswaterstaat consist of two branches: Nationwide and Regional and both branches operate with a significant degree of autonomy. This organizational structure have lots of similarities with a non-ambidextrous organization and contributes with the difficulties faced during the implementation of DGAM at Rijkswaterstaat.

The program Data Gedreven Asset Management can be seen as a tool to transition towards the maintenance strategy Predictive Maintenance. The concept of Predictive Maintenance is to use data to make more and better predictions about occurred and future maintenance actions as well as having a better understanding of why failures happened in the past and prevent them from happening again. This will result in a better insight in the current condition of the asset.
Predictive Maintenance is often new to an organization and can be considered an innovation implementation. The challenges associated with Innovation Implementation are therefore relevant for the implementation of Predictive Maintenance.

During this thesis the Design Science Research Methodology is used as methodology to systematically develop a solution which aims to support the implementation of DGAM. Resulting in the PIP, which should be followed by the implementation manager to ensure a successful implementation.
This process is built upon factors derived from Innovation Implementation literature and complimented with factors relevant for the implementation of Predictive Maintenance. This resulted in a set of factors which should be in place to be able to effectively implement DGAM (i.e. the framework factors). In line with the Design Science Research Methodology the first version of the PIP is demonstrated at two (historical) implementation cases at Rijkswaterstaat and subsequently an evaluation is performed. The demonstrations and evaluations proved valuable insight in improvement areas for the implementation process at Rijkswaterstaat and modifications for the design, such as the alteration to a more voluntary implementation approach. This resulted into an iteration step in which a new version of the PIP is developed. This second version of the PIP is again demonstrated and evaluated, resulting in the finding that the framework factors should be presented in a manner which foster the collaboration between the nationwide DGAM program team and the regional teams. During a second iteration step is a roadmap developed. The roadmap is a visual representation of the framework factors and the step-by-step plan. The roadmap will assist by presenting the framework factors in a clearly divided and structured manner to enhance focus and align the objectives of both teams.

The final proposed design solution is the PIP version developed in the second iteration, this design consists of 2 parts; 'how' and 'what'. The 'what' gives answer on which factors need to be taken care off to ensure an effective innovation implementation. The 'what' consists of a conceptual framework and framework factors. The conceptual framework is the theoretical foundation of this design and provides the different categories. The framework factors provide interpretation to the conceptual framework by giving definitions to the categories (e.g. the factors).
The 'how' gives answer on how to use the conceptual framework and framework factors and consist of a step-by-step plan. The 'how' is supported by the roadmap, which supports the collaboration

between the nationwide and regional teams and is a visual representation of the framework factors and the step-by-step plan.

Samenvatting

In deze scriptie is het doel om een ontwerp te ontwikkelen ter ondersteuning van de implementatie van Data Gedreven Asset Management (DGAM) bij Rijkswaterstaat. Rijkswaterstaat heeft de ambitie om hun onderhoudsstrategie te optimaliseren om een beter inzicht te krijgen in de staat van hun assets, aangezien Rijkswaterstaat voor een grote uitdaging staat om hun assets beschikbaar en in goede staat te houden de komende jaren. Om dit doel te bereiken wordt het programma Data Gedreven Asset Management ingezet.

Rijkswaterstaat is een publieke organisatie die verantwoordelijk is voor het beheer en de ontwikkeling van een groot aantal assets, die allemaal een uniek ontwerp en componenten hebben. Bovendien bestaat Rijkswaterstaat uit twee takken: Landelijk en Regionaal, en beide takken opereren met een aanzienlijke mate van autonomie. Deze organisatiestructuur vertoont veel overeenkomsten met een niet-ambidextere organisatie en draagt bij aan de moeilijkheden waarmee wordt geconfronteerd tijdens de implementatie van DGAM bij Rijkswaterstaat.

Data Gedreven Asset Management is een hulpmiddel om over te stappen naar de onderhoudsstrategie van Predictive Maintenance. Het concept van Predictive Maintenance is om gegevens te gebruiken om meer en betere voorspellingen te doen over opgetreden en toekomstige onderhoudsacties, evenals een beter begrip te hebben waarom fouten in het verleden zijn opgetreden en ze te voorkomen in de toekomst. Dit zal leiden tot een beter inzicht in de huidige staat van het asset.

Predictive Maintenance is vaak nieuw voor een organisatie en kan daarom worden beschouwd als een innovatie implementatie. De moeilijkheden die gepaard gaan met Innovatie Implementatie zijn daarom relevant voor de implementatie van Predictive Maintenance.

Tijdens deze scriptie wordt de Design Science Research Methodology gebruikt als methodologie om systematisch een oplossing te ontwikkelen die tot doel heeft de implementatie van DGAM te ondersteunen. Het resultaat is een Predictive Maintenance Implementation Process (PIP) dat moet worden uitgevoerd om een succesvolle implementatie te waarborgen.

Dit proces is opgebouwd uit factoren afgeleid uit de literatuur over Innovatie Implementatie en gecombineerd met factoren die relevant zijn voor de implementatie van Predictive Maintenance. In lijn met de Design Science Research Methodology wordt de PIP gedemonstreerd bij twee (historische) implementaties van Rijkswaterstaat en vervolgens wordt een evaluatie uitgevoerd. De demonstraties en evaluaties leverden waardevolle inzichten op voor verbeterpunten in het implementatieproces bij Rijkswaterstaat en aanpassingen aan het ontwerp. Dit resulteerde in een iteratiestap waarin een nieuwe versie van de PIP werd ontwikkeld. Deze tweede versie van de PIP wordt opnieuw onderworpen aan een demonstratie en evaluatie, resulterend in de bevinding dat de factoren op een manier moeten worden gepresenteerd die de samenwerking tussen het landelijke DGAM-programmateam en de regionale teams bevordert. Dit wordt geprobeerd te bereiken met een tweede iteratiestap waarin een roadmap wordt ontwikkeld. De roadmap is een visuele representatie van de framework factoren en het stapsgewijze plan. De roadmap helpt door de factoren op een duidelijk ingedeelde en gestructureerde manier te presenteren om de focus te verbeteren en de doelstellingen van beide teams op één lijn te brengen.
De uiteindelijke oplossing bestaat uit de PIP, die wordt ondersteund door een roadmap waarin de factoren zijn opgenomen. Deze roadmap bevordert de samenwerking tussen de verschillende teams en dient als visualisatie van de voortgang van de implementatie.

Het uiteindelijke voorgestelde ontwerp is het Predictive Maintenance Implementation Process, zoals ontworpen in de tweede iteratie. Dit ontwerp bestaat uit twee delen: 'hoe' en 'wat'. Het 'wat' geeft antwoord op welke factoren aanwezig moeten zijn om een effectieve implementatie van innovatie te waarborgen. Het 'wat' bestaat uit een conceptueel framework en framework factoren. Het conceptuele framework vormt de theoretische basis van dit ontwerp en levert de verschillende categorieën.

De framework factoren geven interpretatie aan het conceptuele framework door definities aan de categorieën te geven.
Het 'hoe' geeft antwoord op hoe het conceptuele framework en de framework factoren moeten worden gebruikt en bestaat uit een stapsgewijs plan. Het 'hoe' wordt ondersteund door de roadmap, die de samenwerking tussen de landelijke en regionale teams ondersteunt en een visuele representatie is van de framework factoren en het stapsgewijze plan.

Contents

Abbreviations

CBM	Condition Based Management
CIV	Centrale Informatie Voorziening (*English: Central Information Facility*)
DGAM	Data Gedreven Asset Management (*English: Data Driven Asset Management*)
DSRM	Design Science Research Methodology
IS	Information Science
II	Innovation Implementation
ISO	International Organization for Standardization
IT	Information Technology
ODS	Object Data Services
OEM	Original Equipment Manufacturer
PdM	Predictive Maintenance
PIP	Predictive Maintenance Implementation Process
RAMS	Reliability, Availability, Maintainability and Safety
RUL	Remaining Useful Life
RWS	Rijkswaterstaat
SAAM	Senior Advisor Asset Management
STT	Salland Twente Tunnel

Chapter 1

Introduction

Having an insight in the current condition of an asset (e.g. bridges and locks) is vital, as unfortunately showed during the collapse of the Morandi Bridge in Genoa, Italy. The bridge, named after its designer Riccardo Morandi, collapsed on 14 August 2018. A 210-meter section of the bridge collapsed causing around 35 vehicles to fall off the bridge and 43 people lost their lives as result of the collapse. In the years before the collapse several indications were given that the bridge was in need of maintenance. In 2017, a confidential report noted that the stays of one of the pillars showed severe disparities in behaviour (Stampa, 2023) and one year later the government was informed that the cross-section of the tendons were on average reduced by 10 to 20 percent (L'Espresso, 2023, New York Times, 2023). In 2020 the final investigation report was published, which stated that the cause of the collapse was a combination of factors including poor maintenance (rfi, 2023). This example illustrates the importance of the ability to have an adequate insight of the current condition of an asset, and ensuring that the surrounding processes are implemented correctly to be able to react appropriately to any abnormality.

It can be concluded that issues related to the inability of having an insight in the current condition can have tremendous impact. A similar issue is currently evolving within Rijkswaterstaat. Rijkswaterstaat is confronted with a tremendous challenge due to a substantial number of assets nearing the end of their operational lifespan and needs increasing numbers of inspection to ensure the safety of these assets. However, Rijkswaterstaat is also facing issues with regard to scarce labour and therefore Rijkswaterstaat decided to change their maintenance strategy to get a better understanding of the current condition with limited use of these scarce resources. The transition to a new maintenance strategy is accompanied by a number of challenges, which will be thoroughly examined in this thesis. A suitable solution to support this transition will be developed.

1.1 Maintenance strategies

In the past decade the possibilities of data are grown tremendously. Data collecting and processing can be done in bigger quantities, faster and cheaper than ever before resulting in new opportunities. To achieve the most value out of these new opportunities, it can be seen that they are implemented in areas in which the impact is large. As maintenance is, in a wide variety of industries, a large part of the annual spending it makes sense that this is one of those areas.

One of those opportunities is Predictive Maintenance. The concept of Predictive Maintenance is to use data to make more and better predictions about occurred and future maintenance actions as well as having a better understanding of why failures happened in the past and prevent them from happening again (Jardine et al., 2006).
This can for example be prognostic analyzes by using historical data together with recent data to predict upcoming issues and provide an estimation for the Remaining Useful Life (RUL). But it can also be more focused on diagnostic analyzes for answering the question: Why did something break? With more (historical) data this 'diagnostic trouble shooting' can result in finding the root cause of

the problem in a quicker and cheaper way.

Predictive Maintenance is one of the existing maintenance strategies, as can be seen in Figure 1.1. Other maintenance types are corrective and preventive maintenance. Corrective maintenance is performed when a breakdown already has occurred. Corrective maintenance is therefore always unplanned and frequently involves collateral damage and the total costs are expected to be higher than proactive maintenance (Kerkhof et al., 2016). Preventive maintenance is a strategy at which the maintenance moment is determined based on pre-defined time- or usage based intervals. The main disadvantage of this strategy is that the maintenance is mostly performed 'too early', which results in unused RUL. If the maintenance is performed 'too late' (i.e. the asset had a breakdown before the planned maintenance was performed) the strategy switches to corrective maintenance, which is an unwanted strategy as discussed earlier.

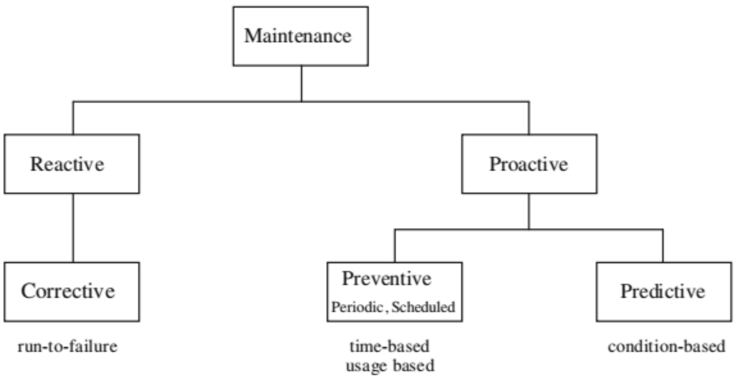

Figure 1.1: Overview of different maintenance strategies (Kerkhof et al., 2016).

In addition to previously discussed advantages, another noteworthy benefit to Predictive Maintenance is the enhanced capacity to get better insight in the state of the maintained item. The information to determine the optimum maintenance moment can also be used to determine the current state of the maintained item. This is for example helpful when other methods to determine the current state are very costly or time consuming. In the case of real time data transfer, this current state information will be available 24/7 and any abnormality can be spotted immediately. This in contrast with physical inspections which depends on the interval between inspections, i.e. a discovered abnormality have been developed moments after the previous inpsection. Critical items should therefore have a small interval between physical inspections, which results in increasing maintenance costs and pressure on available resources.
Besides the positive effects on maintenance costs and pressure on available resources, the enhanced capacity to get better insight in the state of the maintained item can also contribute to an enhancement in safety. For instance a scenario involving an abnormality (such as a crack) with a rapid growth. Should this crack exceed safety thresholds prior to the scheduled physical inspection, it may lead to significant safety concerns. With the real time insight in the current state of the item, this rapid growing crack can be discovered before the safety thresholds are exceeding. This gives the maintenance department an opportunity to conduct an investigation and devise appropriate solutions.
A recent example where this real time insight could prevent major safety issues is the Nelson Mandela bridge over the A12 highway in Zoetermeer. During a scheduled inspection, hazardous cracks were found in the bridge. These cracks were so severe that the bridge was closed immediately. The bridge functioned as foot- and cyclistbridge over the A12 highway, closure resulted in a lengthy diversion. A team of around 40 a 50 people with different backgrounds were gathered to investigate possible solutions. Almost two months later the temporarily construction was ready and the bridge was reopened. During the closure of the bridge the A12 highway was also closed for several days. The total spending were estimated at 8 million euros (Rijkswaterstaat, 2023c,Gemeente Zoetermeer, 2023).

The implementation of Predictive Maintenance is having a large impact on the complete company

or organization. The change to Predictive Maintenance involves the maintenance department obviously, but also the maintenance workers which processes will change. The IT department will play a role in connecting data sources to be receive the data from which predictions could be made. The department accountable for the maintenance planning will also face major changes, especially when the current maintenance strategy is based on preventive maintenance. With preventive maintenance the maintenance planning can be made in advance as time between maintenance is mostly determined by time or usage, which is relatively constant. With predictive maintenance the planning will be far less rigid as the maintenance moment is not based on a, relatively, fixed parameter such as time or usage. The result is that the implementation of Predictive Maintenance is complex and often the intended benefits are not achieved
Predictive Maintenance is a relative expensive maintenance strategy, as it involves equipment (i.e. sensors), software (i.e. dashboards) and employees to assess the information. It is therefore common to use a mix of different maintenance strategies. Complex assets which demands a high availability are maintained according to Predictive Maintenance and others are maintained with a less expensive strategy, such as Preventive Maintenance.

1.2 Case Organization

History

Rijkswaterstaat is the executive agency of the Ministry of Infrastructure and Water Management, dedicated to promote safety, mobility and the quality of life in the Netherlands (Rijkswaterstaat, 2023d). Rijkswaterstaat has a long history, as it is established in 1798 when is was called *Bureau voor den Waterstaat*. Over the years the work altered radically, but it was always centered around ensuring safe infrastructure.
In the 18th century the focus of Rijkswaterstaat was managing flood risk, as The Netherlands is currently for 26% below Amsterdam Ordnance Datum (which is the average water level of the North sea) and 59% is vulnerable for flooding (Planbureau voor de Leefomgeving, 2023) this was (and is) an essential task.
During the 19th century and the begin of the 20th century the organization constructed, managed and maintained rivers, canals, polders and flood defenses and invested in new polders and improved waterways. In addition to the existing responsibilities, Rijkswaterstaat got additional responsibilities such as the rail network and bridges and roads alongside the water. After the end of World War II, Rijkswaterstaat performed a lot of work to repair and rebuild destroyed infrastructure and expanded many other assets. Many assets such as bridges, tunnels, overpasses and fly-overs are built in the years following the end of the war.
Another big change happened in the 1970s. Until that period Rijkswaterstaat was responsible for the complete chain from planning, designing and building the asset. However, this changed from the 1970s as Rijkswaterstaat made the transition ”from builder to steward and from maker to manager”, as they described it themselves (Rijkswaterstaat, 2023d). The result is that Rijkswaterstaat still directs the projects but is no longer the builder, which is done by a contractor. One of the side-effects of this reorganisation is that the ’building expertise’ is slowly decreasing within the organization as it is no longer part of the needed expertise.

Organizational structure

The organization of Rijkswaterstaat consist of multiple subbranches, as can be seen in Figure 1.2. Rijkswaterstaat consist of two main branches: Nationwide and Regional, both branches are directed by the Executive Board/Corporate Affairs. The Nationwide units are mainly responsible for tasks which have an impact on all branches, such as the Corporate Services which is responsible for (among other things) communication or are too big to be handled by the Regional units such as multi-million projects. The Regional units are mainly responsible for the day-to-day operation of the assets which are located in their operating area.

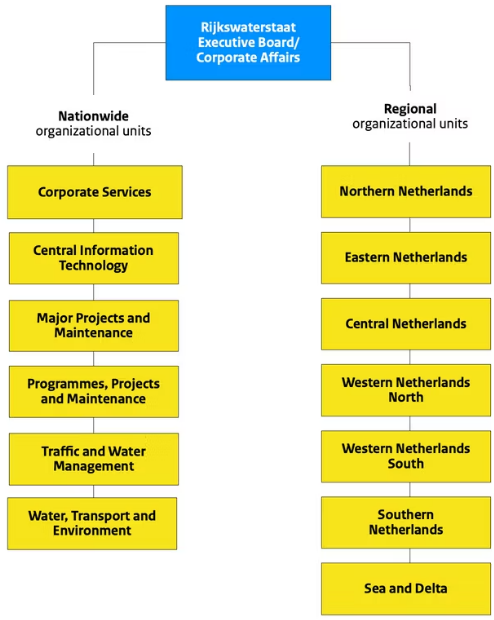

Figure 1.2: Organizational structure Rijkswaterstaat (Rijkswaterstaat, 2023d)

Maintenance Strategy

The assets maintained by Rijkswaterstaat are all vital parts of the infrastructure in The Netherlands and unusable assets will cause significant problems in terms of safety and delays. A corrective maintenance strategy is therefore for almost, if any, asset unable. The result is that at the moment the majority of Rijkswaterstaat's assets are maintained with preventive maintenance as strategy. This strategy has, besides the earlier discussed items, an additional disadvantage as with this strategy the current condition of the asset is unknown. This is an increasing concern as a majority of the assets are reaching their overhaul moment and improving the insight in the current condition is one of the key focus areas for Rijkswaterstaat (Rijkswaterstaat, 2022).
As Rijkswaterstaat is a public organization the expanses should be justified. As a result, the yearly budget for the different branches within Rijkswaterstaat are quite rigid and a change is hard to accomplish. In fact, the yearly budget is determined at Budget Day (Dutch: *Prinsjesdag*), which is at the third Tuesday of September. At this day the National Budget for upcoming year is presented. As Rijkswaterstaat is part of the Ministry of Infrastructure and Water Management their part of the budget, and the allocation between the division, is also determined and changing this budget is complex. therefore, the Regional teams work with tools and concepts which help determining the optimum strategy for their performance criteria. One of the concepts is called RAMS, which stands for reliability, availability, maintainability and safety. This concept is gradually evolved and the first versions can even traced back to the 80's, such as by Lappin, 1988 who investigated the relation between cause and effect. The four factors of RAMS are the most important performance criteria for the construction, managing and maintaining of the assets (Rijkswaterstaat, 2023b). Based on the outcome of these and other concepts and/or tools are the maintenance plans currently conceived for the upcoming period.

Data Gedreven Asset Management

As mentioned, Rijkswaterstaat has the ambition to optimize their maintenance strategy to get a better insight in the condition of their assets. To do this a program called Data Gedreven Asset Management (DGAM) (*English: Data Driven Asset Management*) was put in place. The goal of the DGAM program is: "Helping Rijkswaterstaat by making the Asset Management more data driven and a better utilization of data and digitization." (Rijkswaterstaat, 2022).

There are four main objectives defined for the DGAM program:

1. Implement changes in the current asset management process such that it is possible to work according to data- and information driven standards. This is conducted with newly introduced gathering, handling, analyzing and presentation processes.

2. Implement the needed information equipment (i.e. sensors) and the corresponding connection with the assets. Including the support with respect to service contracts and the embedding of these contracts in relation to the information equipment.

3. Contribute to the development of a data-ecosystem in which Rijkswaterstaat and involved partners could both share their data. This data-ecosystem can be used to support the lifetime, costs and performance of the assets.

4. Securing the competence of the employees related to asset management allowing them to be able to perform data driven asset management with the newly introduced gathering, handling, analyzing and presentation processes.

In Figure 1.3 the roadmap of the DGAM program can be seen. This road map shows the goal (*Dutch: Missie*), ambitions (*Dutch: Ambitie*) and the objectives (*Dutch: Doelen*), the objective are numbered in accordance with the items listed above. It also illustrates that DGAM has a lot of interaction (*Dutch: interactie*) with other programs and divisions within Rijkswaterstaat.

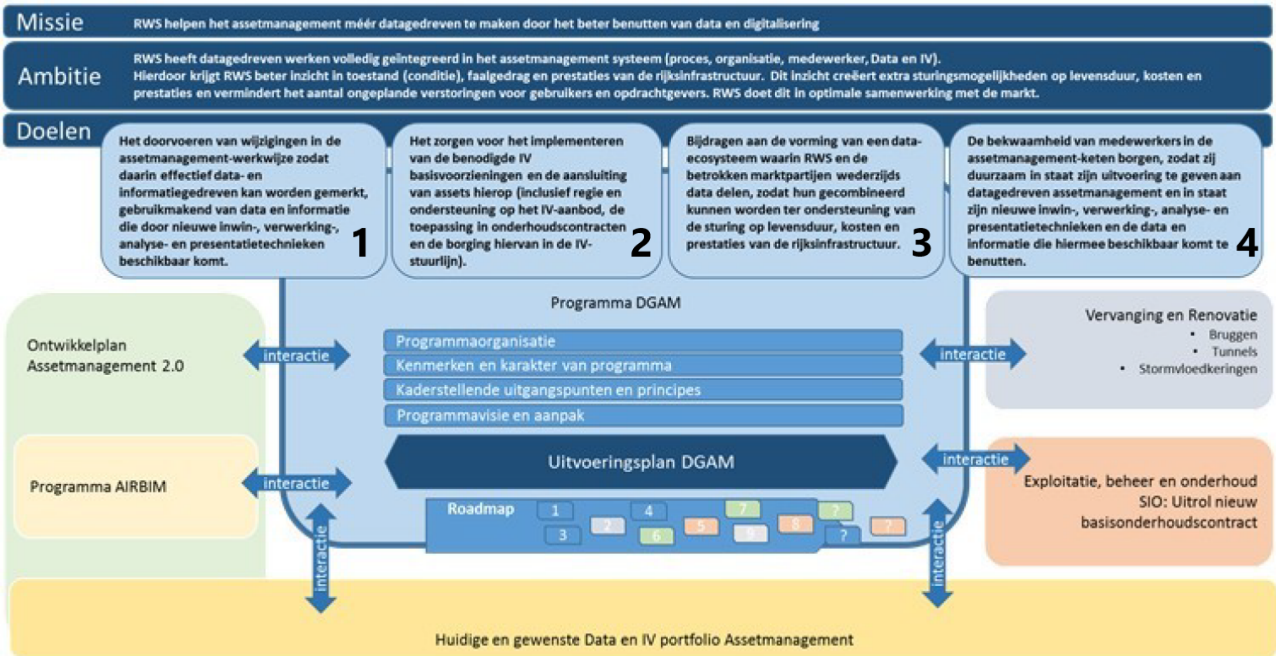

Figure 1.3: Overview roadmap DGAM program (Rijkswaterstaat, 2022)

DGAM is currently being implemented at six different locations, see Figure 1.4. The selection of locations is determined by having a distribution across the various types of assets, the current contractor and geographical location. Being a public organization, Rijkswaterstaat is obligated to conduct contract tendering and this results in a diverse set of contractors among the assets. In the context of DGAM, contractors have a significant role as they serve as the operational entities responsible for the execution of maintenance operations. In order to gain good understanding of the variations among the contractors, the implementation locations are all maintained by different contractors.

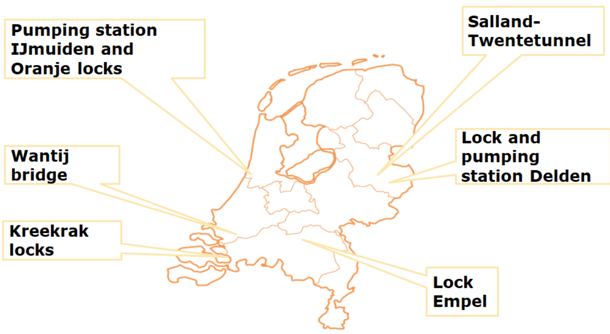

Figure 1.4: Overview of DGAM implementation locations (Rijkswaterstaat, 2023d)

The DGAM program consist of 25 employees and is divided into 7 work packages, all responsible for a part of the program. For example: *implementations* or *collaboration and applications in Asset Management*.
Currently, the DGAM program is mostly concerned with the "Standardization phase". Which involves preparing Rijkswaterstaat to be able to use DGAM on a larger scale at all assets.
The DGAM program presents a perfect opportunity for this thesis to examine issues, formulate solutions, and evaluate them within an operational context.

Chapter 2

Problem Statement

Rijkswaterstaat is striving to transition its maintenance strategy towards predictive maintenance, with the primary objective to get better insight in the current condition of their assets, among other benefits related to the DGAM program. However, as briefly mentioned earlier, the shift towards a predictive maintenance strategy poses a complex process.

DGAM is very related to Predictive Maintenance, a maintenance strategy which gained traction among numerous companies over the past decade as part of the shift towards data-driven practices. Consequently, issues linked to Predictive Maintenance find strong relevance within the DGAM program. As the scope for Predictive Maintenance is based on the principle to use data to decide the optimum maintenance moment, the scope for DGAM is even wider as the key element is to have a more accurate insight in the performance, usage and condition of the assets.
The consequence of the even wider scope is that besides the numerous challenges related to Predictive Maintenance, there are even more challenges to overcome to successfully implement DGAM. Furthermore, it is important to emphasize that the implementation of DGAM is not an ultimate objective in itself, but rather a mean for the transformation of the maintenance policy. In this light, DGAM can be regarded as a strategic approach to transition towards a (more) Predictive Maintenance strategy.

In addition to insights obtained from literature, it is also crucial to incorporate valuable observations and lessons learned from individuals who encounter the challenges associated with the implementation of DGAM in their daily roles. This is achieved by semi-structured orientation interviews. These interviews were conducted with the members of the DGAM program and Regional employees to get a broad overview of the challenges the DGAM program is currently facing or expecting to face during the programs duration. A substantial amount of challenges are related to the Rijkswaterstaat organization. It became clear that the current Rijkswaterstaat structure and processes are not cooperative for the implementation of DGAM. Comments made were for example: "Rijkswaterstaat is not used to make decisions based on data" [1], "There is a lack of being proactive as at the moment most maintenance actions are planned or reactive which is embedded in the culture of Rijkswaterstaat." [2] and "Rijkswaterstaat has trouble with changing. As the implementation of DGAM will result in major changes in many different divisions, it is expected that this will cause problems." [3] An additional layer of complexity arises from the organizational structure of Rijkswaterstaat, as explained in Section 1.2. This makes it even harder to implement innovations according to the DGAM program member [4].
But also with respect to the process itself are difficulties expected, such as the observation that some Asset Managers have trouble with having a clear overview of what the benefits of DGAM are and which information they need to make DGAM useful [5][6].

An overview of the function and date of the interview of the interview employees can be found in Table 2.1. The number between brackets corresponds with the number in the first column.

Table 2.1: Overview of interviews

Number	National or Regional	Function	Date
1	Regional	Senior Asset Manager West-Nederland Noord	11-2022
2	National	Member of DGAM program: Manager of work package '6-implementaties'	11-2022
3	National	Member of DGAM program: Manager of work package 'borging'	10-2022
4	National	Member of DGAM program: Member of work package 'Toepassing in Asset Management'	10-2022
5	National	Member of DGAM program: Member of work package 'Toepassing in Asset Management'	11-2022
6	National	Member of DGAM program: Manager of work package 'Toepassing in Asset Management'	11-2022

Based on the insights retrieved from the interviews, it can be concluded that there exist a multitude of challenges associated with the implementation of DGAM. To get a better idea in which category the challenges predominately fall, Atlas.ti (ATLAS.ti Scientific Software Development GmbH, 2022) is used to code the interviews. All codes are linked to either the group organizational processes, technical processes or social. The group organizational processes comprises of challenges related to processes within Rijkswaterstaat which are non-technical, such as the complex organizational structure within Rijkswaterstaat. Technical challenges are grouped in 'technical processes' and include for example the challenge that some essential data is currently missing. The last group is 'social' which comprises of challenges which are not based on either organizational or technical processes but are centered around the opinion regarding DGAM. An example is the unavailability of clear benefits. This coding resulting in the following results: 11 retrieved challenges are grouped in 'organizational processes', 8 in group 'technical processes' and 3 in group 'social'. A complete overview of the codes and groups used in Atlas.ti can be seen in Figure 2.1 and the definition of the used codes can be found after Figure 2.1.

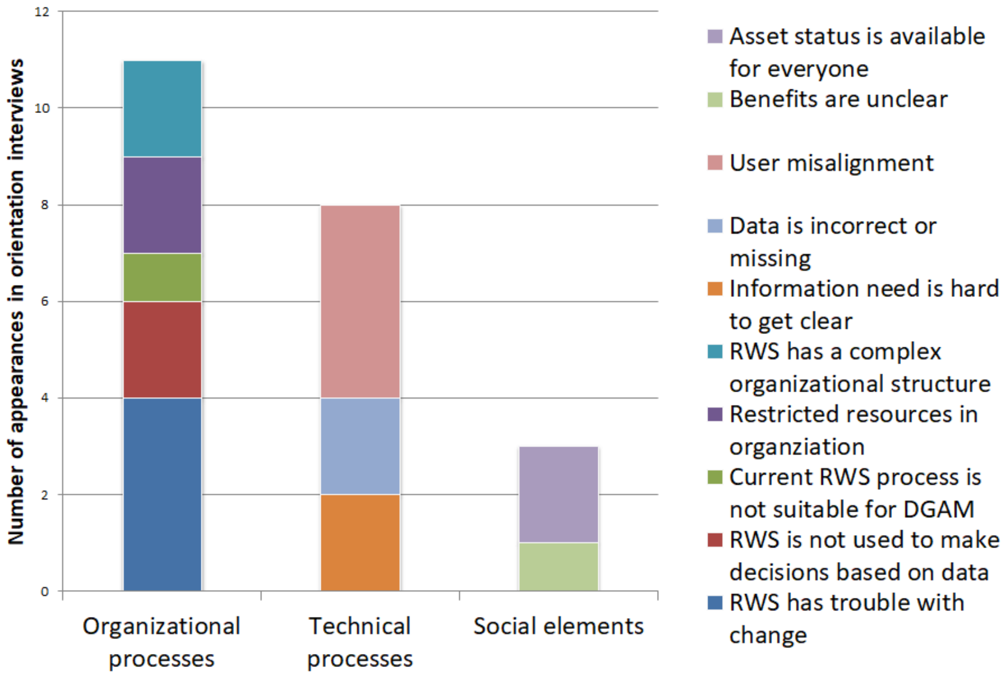

Figure 2.1: Overview of codes and groups of the orientation interviews

- **Asset status is available for everyone**: With DGAM the health status of an asset is available at, for example, easy accessible dashboards. It is therefore not possible to hide certain information.
- **Benefits are unclear**: The benefits from DGAM are hard to measure.
- **User misalignment**: The DGAM program has multiple objectives (see Figure 1.3), it is therefore possible that the focus and resources of differ between stakeholders. Resulting in possibly less effective implementation.
- **Data is incorrect or missing**: Data could contain incorrect or missing values, resulting in (for example) less valuable information.
- **Information need is hard to get clear**: Determining which data is needed to be able to get the desired insights is a complex question, as DGAM (and data driven decision making in general) is new to Rijkswaterstaat.
- **RWS has a complex structure**: Rijkswaterstaat is a complex organization due to split between nationwide and regional division, outsourcing of the maintenance works and the tremendous amount of assets they have to maintain.
- **Restricted resources in organization**: The availability of resources are not limitless at Rijkswaterstaat. Examples are the difficulties to recruit new employees and the problems associated with retrieving data at certain assets.
- **Current RWS process is not suitable for DGAM**: Rijkswaterstaat utilize a large number of processes, for example to determine costs and maintenance actions. Changing these processes to be able to incorporate in DGAM could be hard.
- **RWS is not used to make decisions based on data**: DGAM (and data driven decision making in general) is new to Rijkswaterstaat, using data to make decisions is therefore a huge change and requires a different approach for the decision making process.
- **RWS has trouble with change**: According to Rijkswaterstaat employees, processes at Rijkswaterstaat are hard to change.

The transition towards Predictive Maintenance precipitates a significant set of changes, and given the distinct organizational structure of Rijkswaterstaat, this process becomes even more challenging. As already mentioned in Section 1.2 consists Rijkswaterstaat of two main branches: Nationwide and Regional. The regional units are primarily responsible for the daily operational aspects of the assets, leading to a notable degree of autonomy. This significant level of autonomy further complicates the implementation of DGAM, as the regional units have a certain degree of authority to shape their approach to asset maintenance in alignment with pre-defined standards.
Regarding the enormous set of assets within Rijkswaterstaat; the assets of Rijkswaterstaat consist of a multitude of different types, spanning from locks and highways to bridges and tunnels. Even within an asset type, for example locks, there are countless variations possible for the used pump, data logging and connection methods, usage profile etc. This adds an additional layer of complexity.

Based on the orientation interviews from which can be concluded that the majority of the difficulties are associated with the organizational processes and the distinct organizational structure of Rijkswaterstaat, it can be concluded that the difficulties are broadly orientated. As the implementation of Predictive Maintenance (and therefore DGAM) involves a shear amount of stakeholders, this comes as no surprise. To support the implementation of DGAM, this thesis aims to identify actions necessary to address the observed challenges. In consultation with the DGAM program manager, it is decided to focus the research on the actions necessary to be addressed by the implementation managers to ensure an effective implementation. The focus on supporting the implementation manager should also result in the design being applicable at a majority of the assets at which DGAM will be implemented

in the future. The development of the design can be found in Chapter 7.
The proposed solution will primarily focus on contributing with the achievement of objective one and four of the DGAM program. These objectives are centered around the organizational change to a new process (i.e. DGAM) and securing that the employees have the resources to perform DGAM.

Summarized, the problem statement can be seen as the absence of an adequate guideline for actions needed to be addressed by implementation managers to facilitate the implementation of DGAM at Rijkswaterstaat (i.e. a blueprint for the implementation of DGAM to encounter the challenges gathered during the orientation interviews, see Figure 2.1.). This thesis will provide a proposed solution for this absence of a guideline for implementing DGAM at Rijkswaterstaat.

Chapter 3

Current State of Research

3.1 Towards Predictive Maintenance

Predictive Maintenance is a field in which a lot of research is performed, as there is a large potential. There are even books written about it, for example "An introduction to Predictive Maintenance" by R. Keith Mobley and there a substantial body of literature available, as acknowledged by Tiago et al., 2020 which performed a literature review itself. The urge for research in this field is encourage by the fact that maintenance costs are the second largest operational expense, making it a suitable option for the reduction of the expenses (Garg and Deshmukh, 2006).

There is great confusion regarding the terminologies used for the types of maintenance (Trojan and Marçal, 2017), but a general accepted type division is: Planned Maintenance (also called Preventive Maintenance), Condition-Based Maintenance, Predictive Maintenance and Corrective Maintenance. It can be argued about whether Condition-Based Maintenance is a subdivision of Predictive Maintenance, as done by Tran et al., 2018. An alternative option is to categorize both of them under the term "Data-Driven Maintenance." as done by Bousdekis et al., 2021. Figure 3.1 illustrates when the four types of maintenance are performed on a timeline.

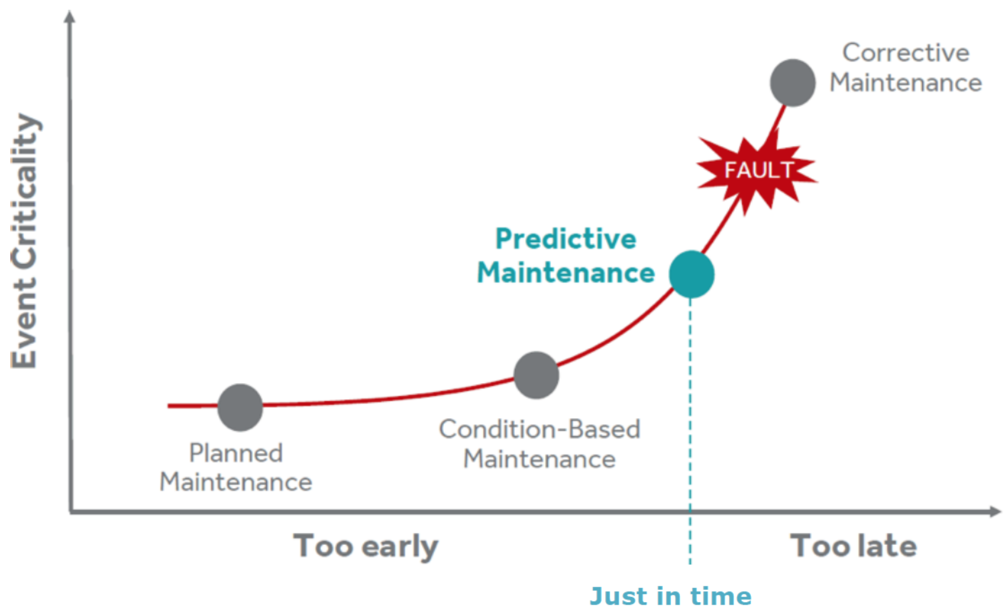

Figure 3.1: Maintenance timeline (PrimaVera, 2023)

Planned Maintenance is a maintenance strategy at which the maintenance is conducted at pre-defined intervals. Resulting in minimized downtime and high plannability but is labor intensive and an amount of the RUL of items is often wasted. Corrective Maintenance is conducted after a fault or breakdown is detected. Resulting in the need of quickly available skilled people to repair the item. The major disadvantage is the unplanned downtime, which is the reason why corrective maintenance is an unfavourable strategy for items that require a high level of uptime. Condition-Based Maintenance and Predictive Maintenance both try to bridge this gap by using monitoring systems, data and algorithms to minimize wasted RUL but preventing downtime (Tran et al., 2018).

Both Planned and Corrective Maintenance are comparatively straightforward strategies, as evidenced by their respective drawbacks. These disadvantages predominately pertain to costs and labor. This in contrast to Condition-Based and Predictive Maintenance which require high investments regarding monitoring and prognostic equipment.

The implementation of Predictive Maintenance is not without challenges. The first set of challenges is with regard to technical aspects: Most applications of Predictive Maintenance are focused on single components, making it hard to be able to extrapolate the existing solutions to asset which consist of multiple components (Kim and Chung, 2017a, Das et al., 2015), or the challenge to incorporate different sources of data. Predictive Maintenance models relay on data, which could have different sources such as sensors or measurements. However, the modelling and fusion of this data is a difficult task and often results in the ignorance of important information (Lei et al., 2018, Si et al., 2011. In addition to this last-mentioned challenge, external influence could have a large impact on the reliability of the data. Changes in operational conditions (e.g. change in temperature) could affect the obtained data, resulting in possible false alarms (Schmidt and Wang, 2015, Si et al., 2011).
Besides technical challenges, the implementation of Predictive Maintenance also comprises of a set of organizational challenges. The first and major challenge being the sheer amount of involved people during the implementation of Predictive Maintenance, including maintenance staff, contractors, managers, IT department etc. (Lindström et al., 2017). Moreover, due to the implementation of Predictive Maintenance the organizational structure will be changed as new roles are needed to be able to fully extract the possibilities of Predictive Maintenance. Examples of new roles are reliability engineers and data analysts. This change could result in a challenge during the implementation process (Van den Boomen et al., 2022)
Furthermore, the implementation of Predictive Maintenance has a large financial impact as models should be designed, sensors should be acquired and connected to the data retrieval system and employees should be trained to be able to work with the new maintenance strategy. This high investment could result in reluctant to implement Predictive Maintenance (Kefalidou et al., 2015).

Predictive Maintenance is not only a field in which a lot of research is performed, it is also a very broad subject with generous amounts of connection to other fields, as described by Ton et al., 2020, who divided predictive maintenance into six steps; data acquisition, data processing and diagnostics, prognostics, optimisation of maintenance and logistic, asset management, and human and organisation factors. But as van de Kerkhof, 2020 and Veldman et al., 2011 noticed there is an abundance of scientific literature about condition monitoring technologies, modelling maintenance policies and developing diagnostic and prognostic models, but the studies on implementation and management of these techniques are scarce. Another well documented research field are the maturity levels, multiple researches are performed to systematically investigate the maturity level with respect to Predictive Maintenance. Example is the Condition Based Maintenance (CBM) Maturity model for asset owners developed by van de Kerkhof, 2020, in which the maturity level of an organization is classified in five levels: No CBM, Reactive CBM, Planned CBM, Proactive CBM and World class CBM. Another example is the 5 stages of Asset Management Excellence by T. Smith (Smith, 2018), which also classified the level of an organization into 5 categories: React, prepare, prevent, predict and systemize.

3.2 Innovation Implementation

An innovation can be seen as something which is new for an organization, according to the official definition (Van Dale, 2023). The result of this is that the implementation of Predictive Maintenance can be considered as an innovation implementation. Despite the difficulties faced during an innovation implementation, it is vital for the future of any organization to keep innovating and it is one of the toughest challenges to balance (O Reilly and Tushman, 2004). Research on the implementation of organizational innovation is rare, as studies are labor intensive. The result is that the existing literature is predominately focused around the implementation of a single innovation across a sample of organizations (Klein and Knight, 2005). In "Innovation Implementation Overcoming the Challenge" by Klein and Knight, a literature review is performed. The result is a description of the organizational characteristics of successful implementation. It also highlighted a fundamental distinction in terminology used to describe the current phase of an innovation; adoption or implementation. Whether the first is the decision to use an innovation and the second is "the transition period during which individuals ideally become increasingly skillful, consistent and committed in their use of an innovation" (Klein and Knight, 2005). The difference is fundamental, as an innovation adoption is often easier that the implementation phase.
According to Klein and Ralls, 1995, one of the innovation difficulties is because of the "hassle factor". Many innovations are unreliable and imperfectly designed, especially newer technology. This low quality was in 61% of the qualitative studies by Klein and Ralls reported as having negative consequences for the employee satisfaction and innovation use. Aiman-Smith and Green, 2002 found that innovations are generally more complicated than the technology it replaced, resulting in lower user satisfaction and increasing time was required to become competent in using the innovation. Predictive Maintenance is often the replacing maintenance strategy for less complex strategies such as Planned Maintenance or Corrective Maintenance, this difficulty is therefore very relevant for the implementation of Predictive Maintenance and DGAM in particular. The decision to adopt, and subsequently implement, an innovation is often made by a manager and not the targeted users. However, targeted users often do not have the desire to chance their processes resulting in great scepticism regarding the innovation according to Nutt, 1986. In addition, the decision to adopt and implement an innovation should be considered thoroughly. The expected benefits related to the innovation may take a long period and managers should therefore expect lower levels of performance during the implementation phase (Repenning, 2002).

As elaborated on in the Introduction, Rijkswaterstaat consist of two branches. Each having their own responsibilities and focus. Allthough the DGAM program is part of the National branch, it has a tremendous influence on the Regional branch as their processes will likely change due to the implementation of DGAM. In the study "The Ambidextrous Organization" by O Reilly and Tushman, 2004, they found that the structure of a project team is a decisive factor whether an innovation implementation resulted in the desired outcome. The study concluded that the examined project which used an ambidextrous project teams had a 90 percent change of succeeding. An ambidextrous organization is defined as follows: "establish project teams that are structurally independent units, each having its own processes, structures, and cultures, but are integrated into the existing management hierarchy". Contrary to other project team type which all share the same characteristics that the implementation team is part of the existing structure. An schematic overview can be found in 3.2.

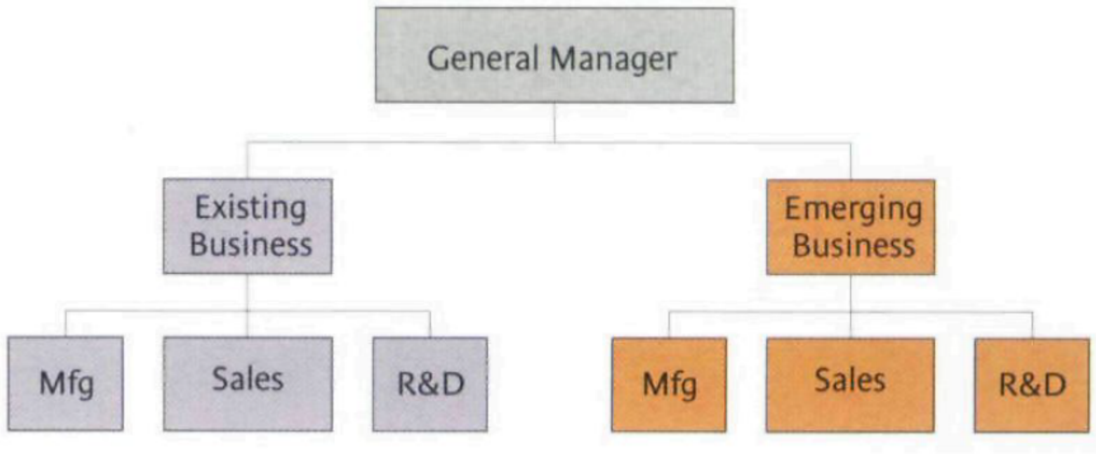

Figure 3.2: Schematic overview of an ambidextrous organization (O Reilly and Tushman, 2004)

Other related literatures are: "Information Technology implementation research: A technology diffusion approach" by Cooper and Zmud, 1990 in which the research questions concerning the implementation of a Material Requirements Planning are identified and examined, and frameworks how to guide these changes such as "A strategic framework for change management" by Price and Chahal, 2006. However, the implementation of change is a complex process that is not always successful due to a variety of reasons as concluded by Price and Chahal, 2006. In addition, it is stated that the failure of most change processes are the result of poor communication and underestimation of the amount of retraining required. The latter statement was also noted by Klein and Sorra, 1996 which concluded that many inability to achieve the intended benefits of an innovation are the result of implementation failure and not innovation failure.

Another observation is made by van de Kerkhof, 2020, who observed that the amount of firms in the process industry which apply CBM are very limited and that the gap between this state of the art and general practice is receiving little attention. Furthermore, the majority of the literature publications are focused on innovation in general and less on the implementation phase as investigated by Kim and Chung, 2017b which analyzed the number of academic papers published in innovation literature with the keyword 'implementation' versus all innovation related subjects (e.g. 'adoption' or 'creativity'). The result can be seen in Figure 3.3.

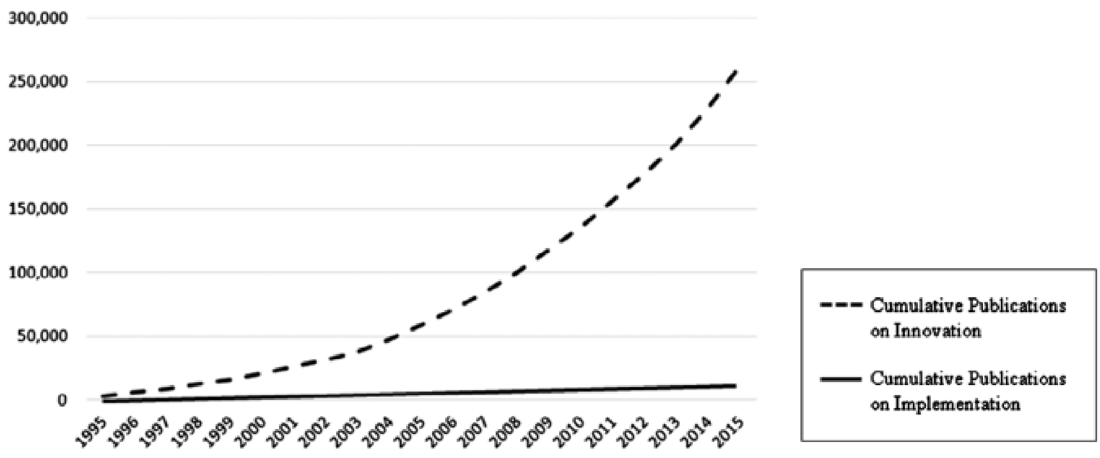

Figure 3.3: Comparison between cumulative publications on innovation and those on implementation by year (Kim and Chung, 2017b)

Kim and Chung, 2017b also performed a literature review of existing studies on Innovation Implementation published in 1995 till 2015. They gathered and categorized the factors which influence the implementation process. This literature review gives an excellent opportunity to investigate if the factors changed over time, i.e. are factors identified by literature from (for example) the 90's still relevant and vice versa. Based on this literature review, it can be concluded that the identified factors are supported by literature from a large time period. For example the factors 'Perceived usefulness' and 'Perceived ease of use', which are both present in literature ranging from 1995 till 2011.

3.3 Research gap and Motivation

It can be concluded that there is a generous amount of ongoing research in fields which are connected to Predictive Maintenance. However, most Innovation Implementation research is focused on the associated (technical) difficulties and less on which factors result in a successful implementation. Moreover, the majority of the research has been applied in various industries but not often in de Asset Management field. An addition research gap is added due to the fact that Rijkswaterstaat is a public organization, as there is still a lack of an adequate framework for understanding and measuring innovation in the public sector (Koch and Hauknes, 2005).

This thesis will combine the research gaps by identifying the decisive factors for a successful Predictive Maintenance implementation at a public organization and subsequently demonstrating the findings to be able to perform an evaluation. This will result in added value to the literature and give an solution for the formulated problem statement in Chapter 2, which was summarized as the absence of an adequate guideline for actions needed to be addressed by implementation managers to facilitate the implementation of DGAM. In addition, this research will add value to the literature by developing a solution to a problem in a field in which little research is performed. Moreover, the conclusions drawn in this thesis could enhance research regarding Predictive Maintenance in other fields. For example by testing if the solution of this thesis is applicable in other fields.

Chapter 4

Research Question

The orientation of this research will be in line with objectives 1 and 4 from the DGAM roadmap (see Figure 1.3), which is centered around the change in current asset management process to be able to use the new standards and securing that employees have the resources needed to perform DGAM. The focus will be on the implementation phase of DGAM, as this is one of the research gaps which were identified in Chapter 3. Other confines of this research are: Firstly, the focus on organizational elements and not technical elements as the organizational issues related to the implementation of predictive maintenance are researched in less detail and secondly: Rijkswaterstaat will be the case organization, which is a perfect candidate for the identified research gap, due to the unique combination of Rijkswaterstaat which is a public organization with outsourced maintenance works. Based on the problem statement and literature review a research question is devised. To reach an answer on this question, the main research question is subdivided into multiple sub-questions.

The main research question is stated as follows:

How can a DGAM implementation manager be supported with a fitting DGAM implementation process to enable maintenance towards Predictive Maintenance?

With the following corresponding sub-questions:

1. What are the decisive factors during an innovation implementation?

2. What are the decisive factors for implementing Predictive Maintenance effectively?

3. How can the identified factors be used to facilitate a successful DGAM implementation at Rijkswaterstaat?

In Table 4.1 an overview can be found in which Section the final answer on the sub-questions will be given.

Research sub-question	Section
1	7.1
2	7.2
3	11.4

Table 4.1: Overview addressed research question

Chapter 5

Design Science Research Methodology

For any research it is vital to have a well-founded plan, certainly for a research with a limited scope and a relative short time frame. To have a guideline for the steps which have to be taken into account during a research, the research will be done by following the Design Science Research Methodology (DSRM) as proposed by Peffers (Peffers et al., 2007), see Figure 5.1. This methodology is intended to solve Design Science problems within the Information Science (IS) field, a field which have a lot of common ground with Predictive Maintenance and therefore a good method to support this research. It is also noted that the DSRM can support in organizational context (Peffers et al., 2007). In addition, the proposed end result is an artifact to address a problem (e.g. difficulties during the implementation phase of an innovation), which is in line with the most important Design Science Research guideline (Hevner et al., 2004). The methodology consist of six steps which will be explained in the following Sections.

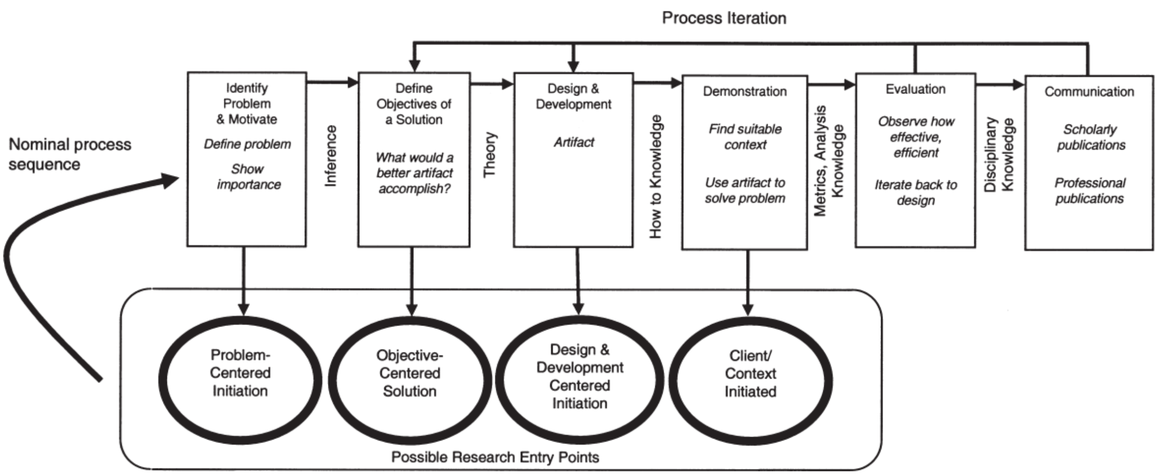

Figure 5.1: Design Science Research Methodology process (Peffers et al., 2007)

The steps from the used methodology be preceded by a "Rijkswaterstaat introduction" to get familiar with Rijkswaterstaat and the organization.
The six steps from the DSRM methodology used in this research will be explained in the following sections. It should be noted that phase 1 (Identify Problem & Motivate) is already performed in Chapter 1 and 2.

1. Identify problem and Motivate

The first step of the DSRM is to identify the challenges faced during the implementation phase. The objective is to comprehensively identify a wide array of challenges to gain a deeper understanding of the current obstacles. As already mentioned is this step already performed in preceding Chapters.

2. Define Objectives of a Solution

In this step the objectives of the solution is defined. These objectives will act as guidelines during the other steps and will be used as final check to ensure that the final design corresponds with the defined objectives.
The objectives will be defined based on findings from the literature research and interviews with the end-users of the design (i.e. the DGAM program members responsible for the implementations) during an Expert Session. during the Expert Session the end-users will provide input for their desired outcome, based on personal preferences. The input will focus on practical aspects, such as design preferences.

3. Design and Development

In this step the design is developed, which is in this research the PIP to effectively implement DGAM at Rijkswaterstaat. The design is based on a model from Innovation Implementation and supplemented with relevant factors for Predictive Maintenance. Subsequently, the design is theoretically validated at Rijkswaterstaat to ensure that the design is suitable for use at Rijkswaterstaat. This validation process consists of two parts. Firstly, the factors are assessed on being relevant for Rijkswaterstaat and the DGAM program. Secondly, the remaining factors are rewritten to align with Rijkswaterstaat specific word usage and translated into Dutch. This validation process is performed with two DGAM program members. The design and development process can be found in Chapter 7.

4. Demonstration

In this step the process designed during the previous step is demonstrated. As the time in which DGAM is planned to be implemented at the 6 DGAM locations exceed the proposed time for this thesis, the framework can not be demonstrated at a location at which DGAM is fully implemented. As alternative is chosen to use a combination of a retrospective implementation case related to DGAM and locations at which the implementation is ongoing. This combination lead to the ability to use the lessons learned from the retrospective implementation case and be able to (partly) demonstrate the PIP at present implementation locations. First, the PIP is demonstrated at lock Eefde. Lock Eefde was in the past a *Proeftuin* location, which is a location at which new processes and techniques are tested. In this period a program similar to DGAM was tested. The second demonstration takes place at the Salland Twente Tunnel, a current DGAM implementation location. During the first iteration step the demonstration will be at lock Delden.

5. Evaluation

Observing and measuring the performance of the design is done by comparing the demonstrations with the proposed PIP, check if the process will indeed foster the implementation of DGAM at Rijkswaterstaat and analyze if the framework factors contain the appropriate factors and there are no missing factors. Based on the outcome of this evaluation an iteration is performed, as suggested by Peffers (Peffers et al., 2007). The first iteration involves adjusting the framework factors and the PIP. After the iteration the modified design is demonstrated at lock Delden, a current DGAM implementation location. Subsequently, a evaluation is performed. Based on this evaluation a second iteration is conducted to refine the PIP further, ensuring alignment with the objectives.

6. Communication

The final step involves communicating the results. This will include presenting the results and providing a comprehensive explanation of the design to the intended users. Additionally, guidance on how to effectively utilize the design to harness its full potential will be provided as part of communicating the results.

5.1 DSRM steps in this thesis

The remainder of this thesis will start with step 2 of the DSRM methodology. Moreover, two iteration cycles are performed. As suggested by Peffers (Peffers et al., 2007), the DSRM methodology can be started at other phases than the first one and is very suitable for modifications by adding iteration steps. The steps included in this thesis can be seen in Figure 5.2. During this thesis de focus will be on phase four and five, i.e. the demonstration and evaluation phase. These phases will be vital to ensure that this thesis will support the implementation of Predictive Maintenance by giving answer on the research question. Furthermore, while there is a generous amount of related literature, being able to demonstrate and evaluate existing research constitutes a valuable contribution to the literature.

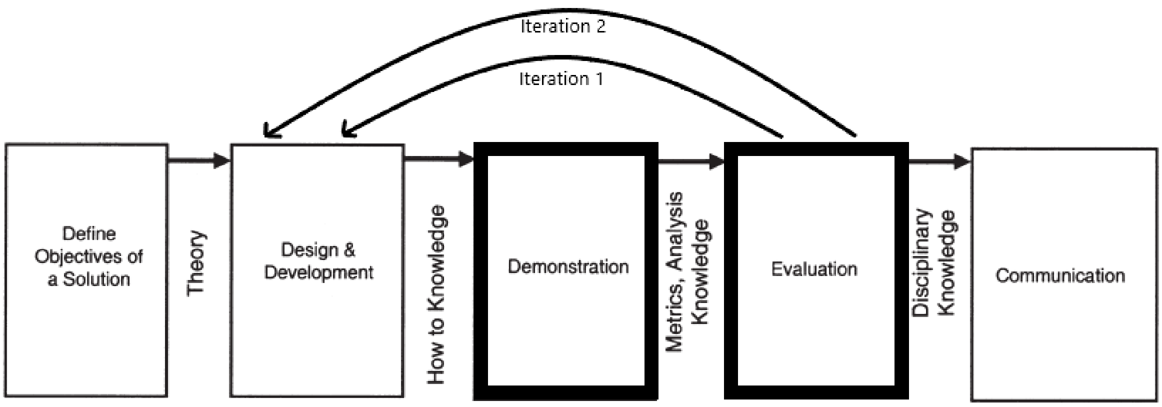

Figure 5.2: Used steps of the DSRM methodology, based on Peffers (Peffers et al., 2007)

Chapter 6

Objectives of the Solution

Defining the objectives is the first step of the DSRM methodology. To guide this design process, it is vital to have guidelines in the form of objectives. These objectives will help during the upcoming activities to act as conditions which the design should met and could function as steering measures when multiple options seems suitable. Furthermore, these objectives will function as validation measures to check if the final design corresponds with the objectives.
The objectives range from technical, organizational and social criteria and are formed during an Expert Session with two DGAM members and from literature review. These two DGAM members are responsible for work package implementations and are the end users of the proposed solution.

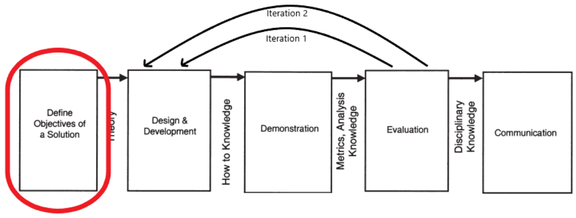

Figure 6.1: Current methodology phase

The primary objective is formulated as follows: The developed design aims to assist the implementation manager by providing guidance on how to effectively implement DGAM at Rijkswaterstaat. The design is tailored for utilization within a public organization, with specific specifications for application at Rijkswaterstaat to be able to demonstrate and evaluate the design.
The primary objective is subdivided into multiple sub-objectives, allowing for an evaluation to ascertain whether the final design aligns with these objectives:

1. The design should be focused on the organizational implementation aspects of DGAM. The technical aspects of the implementation of DGAM are out of scope for this thesis.

2. The users of the design are the members of the DGAM program who are in charge of the implementation of DGAM at the assets of Rijkswaterstaat (i.e. Members of work package: "6-implementations").

3. The design should be supported by a platform which is already used by Rijkswaterstaat. I.e. Excel, PowerPoint, etc.

4. The design should be easy to use and it should be possible to incorporate it within the program team.

5. The design should be Rijkswaterstaat specific, for example: abbreviations should align with those used by Rijkswaterstaat employees.

The objectives are derived from the research gap found in literature (objectives 1 and 2) and are based on an Expert Session with members of the DGAM work package responsible for the implementation (objectives 3, 4 and 5)

During the Expert Session two members of the DGAM work package responsible for the implementation of DGAM indicated what their preferences are regarding the design objectives and criteria of this thesis. The preferences were with regards to the used platform, design format etc.

Based on the problem statement, literature review, objectives and an Expert Session with implementation managers is decided that the proposed form of the design will consist of an enumeration framework of the factors to encounter the challenges, as denoted in the research questions. The set of factors should, if present, foster the effective implementation of DGAM. Designs of this nature are commonly used within Rijkswaterstaat and could therefore with relative ease be implemented in the processes within Rijkswaterstaat. Furthermore, the design aligns seamlessly with the preferences of the design's intended users within the case organization.

Chapter 7

Design and Development

In this section the design will be developed. This is composed of the following sections: In Section 7.1 the key-factors with regarding to Innovation Implementation are introduced and discussed. This is followed by Section 7.2 in which the key-factors with regard to Predictive Maintenance and Information Systems are introduced and discussed. In Section 7.3 both perspectives, being Innovation Implementation and Predictive Maintenance/Information Systems, are merged into one framework. Followed by Section 7.4 in which the Predictive Maintenance Implementation Process is developed. In Section 7.5 an overview of the proposed design is given. This chapter will end with Section 7.6 in which the design is made specific for Rijkswaterstaat and validated for use at Rijkswaterstaat.
Sub-questions 1 and 2 are answered in Section 7.1 and Section 7.2, respectively.

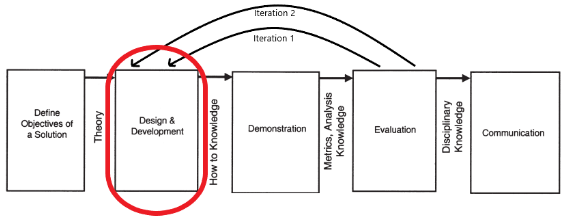

Figure 7.1: Current methodology phase

For the development of the design, a well-established Innovation Implementation model is chosen as a starting point. This approach is adopted because the implementation of DGAM can be viewed as an innovation implementation, as mentioned earlier. Furthermore, the challenges identified are primarily focused on the transition to a new process. To ensure that specific factors for the implementation of a Predictive Maintenance process are not overlooked, the Innovation Implementation model is complemented with factors specific to the implementation of Predictive Maintenance.

7.1 Innovation Implementation

The starting point of the development of this design will be the Determinants and Consequences of Implementation Effectiveness Model by Klein and Sorra, 1996, see Figure 7.2. This model is supplemented with the definitions from Testing Klein and Sorra's innovation implementation model: An empirical examination by Dong et al., 2008.

The Determinants and Consequences of Implementation Effectiveness model serves as a robust foundation, given its prominence within this research field and its pretended usage is closely related to the one at the case organization. The model is based on user-based stage model, in which the innovation (either a technology or practice) is being used for the first time. It should be noted that, in according with the definition of the word 'innovation', this should not implicate that the innovation is not used by other organizations but new to the implementing organization. As DGAM can be seen as the practice and tool to get to the new technology (Predictive Maintenance), the model is a highly suitable option and is a well-established model in the Innovation Implementation literature. According to Klein and

Sorra, 1996: "An organization in which all targeted employees use a given innovation consistently and well is more effective in its implementation effort than is an organization in which only some of the targeted employees use the innovation consistently and well". Consequently, during the design and development phase emphasis should be placed on enhancing user-friendliness and standardization. This approach ensures that the design remains conducive to aiding all implementation processes, resulting in a high rate of implementation success.

According to Klein and Sorra, 1996, the implementation effectiveness (the quality and consistency of targeted organizational members' use of an adopted innovation) is a function of two factors: Firstly: An organizations climate for the implementation of a given innovation and secondly: The targeted organizational members' perceptions of the fit of the innovation to their values. The first can be seen as the need for a supportive environment, examples are the availability of training to get used to the innovation or support by rewarding employees who are using the innovation. When referred to climate for implementation it does not refer to the personal satisfaction of the employee towards the innovation.
The second factor, innovation-values fit, is about how the innovation will foster the organization, i.e: is the innovation beneficial for the organization, or will it result in weakening the strength points of the organization? This was illustrated by Klein and Sorra, 1996 with an example about an organization with one of the strength points being able to facilitate rush orders by using preliminary work of other orders. After the implementation of a new inventory system, the organizational ability to take rush orders was strongly decreased as every production process was coupled to an order in the new system and quickly using semi-finished product from other orders was not possible. Resulting in a poor innovation fit, despite its proven success at other organizations.

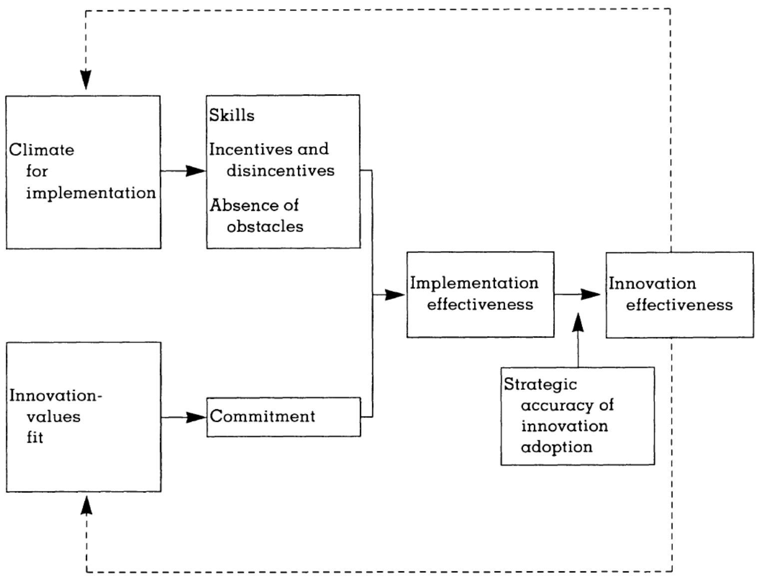

Figure 7.2: Determinants and Consequences of Implementation Effectiveness model (Klein and Sorra, 1996)

The presence of both factors is vital for an effective implementation. To illustrate the consequences of a weak climate for implementation and/or a poor innovation-values fit Klein and Sorra made a table to predict the influence of varying levels of implementation climate and innovation-values fit on innovation use. The table can be seen in Figure 7.3. In this table can be seen that a strong implementation climate and a good innovation-values fit results in a committed, consistent and creative innovation use and enthusiastic employees. This in opposite to the result when there is a weak implementation climate and a poor innovation-values fit, which result in essentially no innovation use and employee relief. There are also combinations possible between these two extremes in which the result generally is that the innovation is not used and/or the employees are not eager to use the innovation.

	Innovation-Values Fit		
	Poor	**Neutral**	**Good**
Strong implementation climate	Employee opposition and resistance Compliant innovation use, at best	Employee indifference Adequate innovation use	Employee enthusiasm Committed, consistent, and creative innovation use
Weak implementation climate	Employee relief Essentially no innovation use	Employee disregard Essentially no innovation use	Employee frustration and disappointment Sporadic and inadequate innovation use

Figure 7.3: Effects on innovation use (Klein and Sorra, 1996)

In the model there is a distinct difference between implementation effectiveness and innovation effectiveness. This distinction is made by Klein and Sorra to help researchers focus on innovation use as implementation effectiveness and innovation effectiveness are often blurred in research. However, the theory serves different purposes as "implementation effectiveness underscores the difficulty of innovation implementation; targeted organizational members' consistent and appropriate innovation use is not guaranteed. Innovation effectiveness underscores the varying effects of innovation implementation; even when the implementation of an innovation is effective, the innovation may fail to yield intended organizational benefits." (Klein and Sorra, 1996). During this thesis the focus of the research will be on implementation effectiveness.
While the Determinants and Consequences of Implementation Effectiveness model is widely applied, its use within the Asset Management field is unexplored. This thesis aims to assess its applicability in Asset Management, providing an additional incentive as it extends the domains where the model is employed.

Altthough the Determinants and Consequences of Implementation Effectiveness model serves as a very suitable initial starting point for the design development, it does not contain specified factors required for an effective implementation. For that reason the model is supplemented by the definitions from the paper: Testing Klein and Sorra's innovation implementation model: An empirical examination. Based on a card-sorting procedure and selected measurements found on definitions and literature the research resulted in a set of factors for each of the categories of the model of Klein and Sorra. For example "Employees were told what they needed to accomplish in using the system" for the category 'Implementation Climate' and "I understand all of the special features of the system." for the category 'Skills'. Consequently, a data analyses was conducted by Dong et al., 2008 using partial least squares to measure if the found factors are indeed a resemblance of the categories in the model of Klein and Sorra. Factors which were found to have a weak connection were dropped, resulting in a full set of factors which resemble the categories of the Determinants and Consequences of Implementation Effectiveness model and foster the innovation implementation. This empirical examination gives therefore a more specific interpretation of the determinants and consequences depicted by the model by Klein and Sorra, 1996. The full set of factors can be found in Appendix A.1.

This full set of factors give an answer on the first research question: "What are the decisive factors during an innovation implementation?". As the set constructed by Dong et al., 2008 consist of the set of factors which are decisive for the implementation of an innovation and the presence of this set of factors should foster the implementation process.

7.2 Predictive Maintenance and Information Systems

To achieve an answer on the second sub-question: "What are the decisive factors for implementing Predictive Maintenance effectively?", a literature research into the key-factors for Predictive Maintenance (PdM)/Condition Based Maintenance (CBM) and Information Systems (IS), as those research fields are closely related to Predictive Maintenance. The aid of this supplementation is to ensure that factors which are specific for the implementation of Predictive Maintenance and/or Information Systems are represented in the framework. It is possible that these factors are not present in the set of factors derived from Innovation Implementation, as these factors are composed for a broad range of Innovation Implementation and not specifically formulated for the application in this thesis, which is Predictive Maintenance.
To select the best literature for both research areas, the following requirements are used as decision-making criteria:

- The literature should focus on, respectively, implementations in IS or the implementation of PdM/CBM.
- The literature should focus on organizational difficulties.

During the literature research it turned out that there is great similarity between the factors observed in literature which comply with the set criteria. In alignment with the research objective, it was therefore decided to select one paper for each research field (PdM/CBM and IS). Literature that encompasses a wide range of factors was the preferred choice, as long as it adhered to the established criteria. As the focus of this thesis is on the demonstration and evaluation step, a well known and often cited literature which complied with the above mentioned criteria is chosen for each research field.

For PdM/CBM this resulted in: Knowledge Lost in Data: Organizational Impediments to Condition-Based Maintenance in the Process Industry by Kerkhof et al., 2016. The paper reports on the common organizational barriers and is therefore a perfect option as supplement for the, in Section 7.1 discussed, factors.
For IS the paper Technology Acceptance Model 3 and a Research Agenda on Interventions (TAM3) by Venkatesh and Bala, 2008 is used as supplement. TAM3 is build upon earlier versions of the Technology Acceptance Model (TAM), in particular the work on the determinants of the adaption of new IS technologies. TAM3 resulted, among other things, a set of pre- and postimplementation interventions.

Examples of the found factors are: "Knowledge lack of the team", "Strategic partnership with innovative maintenance contractors" and "Design can positively influence acceptance". The full set of factors for a successful implementation derived from Knowledge Lost in Data: Organizational Impediments to Condition-Based Maintenance in the Process Industry by Kerkhof et al., 2016 and Technology Acceptance Model 3 and a Research Agenda on Interventions by Venkatesh and Bala, 2008 can be found in Appendix A.2.

7.3 Design development process

The aggregated factors for Innovation Implementation (Section 7.1) and PdM and IS (Section 7.2) are compared and duplicates were removed. The result is the first version of the framework. This framework incorporates the factors for the effective implementation of Predictive Maintenance, or any analogous data-driven maintenance concept. The framework is structured into multiple categories, similar to the Determinants and Consequences of Implementation Effectiveness model on which the framework is build. A representation of this process can be seen in Figure 7.4.

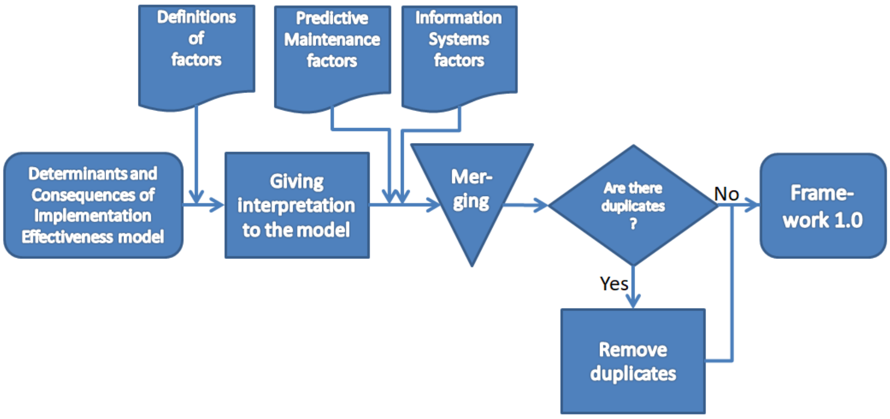

Figure 7.4: Representation of the design development process

The framework consists, similar to the Determinants and Consequences of Implementation Effectiveness model, of two main-categories; the first being Climate for Implementation and the second Innovation-values fit. Both main-categories consist of a set of factors which should be present to foster the respective category.
The set of factors related to Climate for Implementation are focused on giving mean to the implementation (i.e. what are we implementing?) and establishing goals for the newly implemented innovation (i.e. what should we accomplish with the innovation?). But also the availability of task support (i.e. is there support and/or help available if needed?) and reward emphasis to, firstly, emphasize the risk if the innovation is not used, and secondly, reward the employee for correct and effective utilization of the innovation.
All these factors are either based on factors from Innovation Implementation or were initially part of Innovation Implementation and have found support in literature on PdM and/or IS. One set of factors was not present in the Innovation Implementation literature but is added from PdM/IS to this category, which is the factor with respect to design development. This set of factors can be summed up as factors with a high degree of focus on creating an atmosphere which will foster the innovation implementation and primarily come into play during the actual implementation phase.

The set of factors related to Innovation-values fit are centered around the inquiry of whether the innovation aligns with the values and processes of the implementing organization. The category is subdivided into quality, locatibility and flexibility and cooperation. These factors can be summed up as factors which are questioning the implementation manager whether the proposed innovation is indeed a fit for the organization and if the innovation will be beneficial for the organization. The fact that an innovation is proven to be beneficial for a particular organization is not a guarantee that the same innovation will result in positive outcome for another organization, even if those organizations have close resemblance. Small variations between organizations can result in unique abilities, which could vanish with the innovation implementation and resulting in a poor innovation fit. The factors related to this category are therefore factors which should be addressed before the start of the implementation to avoid undesired innovation implementation and give the opportunity to adjust the innovation to ensure a proper fit.

Both main-categories are subdivided into sub-categories, as can be seen in Figure 7.5. The sub-categories for climate for Implementation are Skills, Absence of obstacles, Incentives and Benefits. For Innovation-values fit is one sub-category: Commitment. In line with the main-categories, the first set of sub-categories are centered around fostering the climate for an effective innovation implementation. Examples are factors regarding the skills of the user (i.e. does the user possess sufficient skills and knowledge to effectively utilize the innovation?) and incentive (i.e. the user is motivated to use the innovation).
The factors related to the sub-category Commitment are centered around the question whether the user is able to commit resources (e.g. time) into the innovation. Although this factor is closely comparable with the sub-category incentives, there are some significant differences. Commitment involves a personal decision to take action and is less influence-able with external factors in comparison with incentives. Incentives are external factors or rewards which motivate the person to take action. Consequently, commitment should be present before the start of the implementation and is therefore part of the main-category Innovation-values fit. This in contrast with the factor incentive which could be changed by external factors during the implementation phase.

An overview of all factors can be seen in framework 1.0 which can be found in Appendix A.3. In which also can be found which research field found support for the specific factors (Innovation Implementation (II), Predictive Maintenance (PdM) or Information Systems (IS)). The conceptual framework, based on the model from Klein and Sorra but adapted for the user case of this thesis, can be seen in Figure 7.5.

The framework will aid the implementation manager by providing guidance through the identification of critical factors essential for a successful innovation implementation. Depending on the specific use case, the framework can serve as a baseline assessment tool for defining the current ability to successfully implement an innovation, or as a checklist to pinpoint any absent factors that require attention.

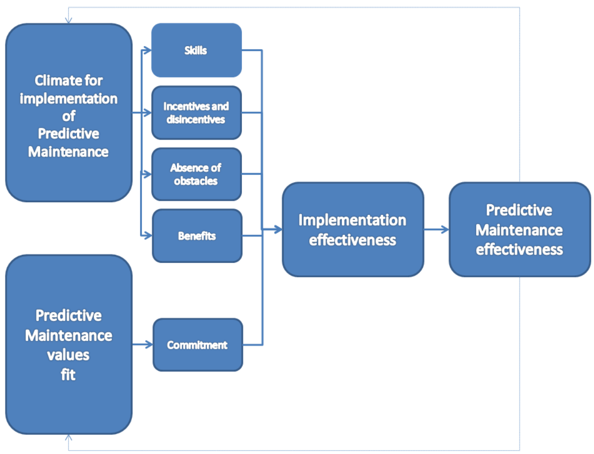

Figure 7.5: Conceptual framework 1.0

7.4 Predictive Maintenance Implementation Process

Based on the design objectives, the framework will be used as a 'box-ticking' framework. When a decision is made to start the implementation of DGAM at a certain asset, the first usage of the framework will be by assessing the current state of the asset. Together with local employees responsible for the maintenance of the asset (e.g. an Asset Manager), the DGAM implementation manager will review the factors listed in the framework and determine, for each factor, whether it is currently in place or not. This first assessment will result in a baseline measurement, which can be utilized to identify areas requiring further attention to facilitate the successful implementation of DGAM. As the framework is divided into multiple categories, the DGAM implementation manager can use the categories to analyze which category should be focused on. If there are multiple categories with factors that are currently not in place, the DGAM implementation manager might decide to postpone the start of the implementation.
It is advised to assure the presence of factors from category *Innovatie fit m.b.t. Predictive Maintenance* before starting the implementation of DGAM, as this category consist of factors which determine if the implementation of DGAM is beneficial for that particular asset. Implementing DGAM at an asset that is not a good fit to the innovation will likely encounter challenges during the implementation. Or even worse, the asset may not function as effectively as before after the implementation (Klein and Sorra, 1996).
Secondly, the framework can be used to analyze if any additional attention to certain factors resulted in the improved ability to effectively implement DGAM. By re-assessing the complete, or certain categories of the framework, the number of factors which are in place should be increased. If this is not the case, the implementation manager should conduct further investigation to determine the necessary actions required to support a successful implementation.

To support the implementation manager, the framework (consisting of the conceptual framework and the set of associated factors) and proposed employment are combined in one single process: **The Predictive Maintenance Implementation Process (PIP)**. This process comprises of the following steps:

1. Identify the location at which DGAM will be implemented and responsible DGAM implementation manager.
2. The DGAM implementation manager identifies and select the relevant stakeholders. Examples of stakeholders are: Local Asset Manager and the maintenance contractor.
3. Perform the 'box-ticking' assessment by reviewing the factors listed in the framework (see Appendix A.3) and determine, for each factor, whether it is currently in place or not.
4. The DGAM implementation manager analyzes the results of the assessment; which factors are in place?
5. Decide if there is a need for improvement to increase the amount of present factors. It is advised to assure that the factors from category A.2 (*Innovation fit*) are all present. If there is a need for improvement, a plan should be made to accomplish this improvement. Afterwards, step 3 should be performed to re-check if the improvement is indeed accomplished.
6. Perform the implementation of DGAM (note: out of scope for the PIP)
7. Perform an evaluation to improve the PIP in the future.

A process diagram of the PIP can be seen in Figure 7.6.

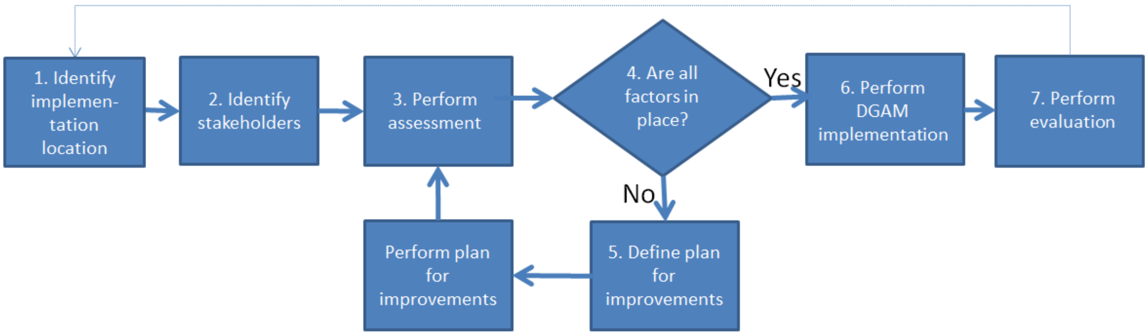

Figure 7.6: Process diagram PIP version 1

7.5 Proposed design solution

To aid further reading of this thesis, the elements of the proposed design, the definitions and relations to each other are clarified.
The proposed design solution is the Predictive Maintenance Implementation Process, this design consists of 2 parts; 'how' and 'what'. The 'what' gives answer on what factors need to be taken care off to ensure an effective innovation implementation. The 'what' consist of a conceptual framework (see Figure 7.5) and framework factors (See Appendix A.3 for version 1). The conceptual framework is the theoretical foundation of this design and provides the different categories. The framework factors provide interpretation to the conceptual framework by giving definitions (i.e. the factors) to the categories.
The 'how' gives answer on how to use the conceptual framework and framework factors and consist of the step-by-step plan as can be seen in Figure 7.6.
An overview can be seen in Figure 7.7.

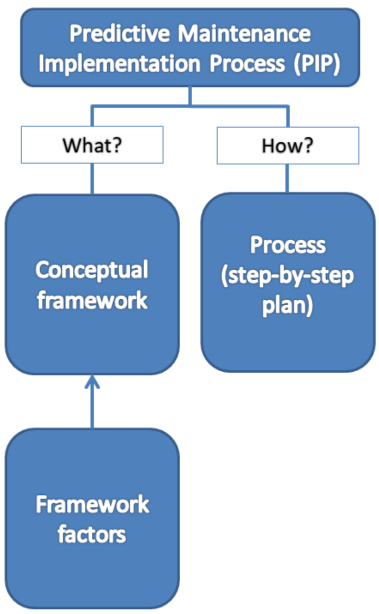

Figure 7.7: Proposed initial design solution

7.6 Rijkswaterstaat validation

The developed design is a generic solution which can be used in a wide variety of environments. To be able to demonstrate the design in the upcoming step, the design is made specific for the case organization Rijkswaterstaat. The design will be modified in two respects:

1. The factors are assessed by two DGAM program members on relevance for Rijkswaterstaat. As the current framework is based on a general innovation implementation for data driven processes, some factors may not be relevant for Rijkswaterstaat.

2. The factors are rewritten to align with Rijkswaterstaat specific word usage and translated into Dutch, as this is the spoken language at Rijkswaterstaat. The factors are also made specific for the implementation of DGAM, this is for example done by replacing pronouns with job roles such as Asset Manager. This is performed to eliminate any ambiguity and avoid misunderstanding by other word usage than typically used at Rijkswaterstaat.

The validation is performed during an Expert Session with two DGAM members responsible for the implementation of DGAM.

The result of this validation is that 4 categories need to be modified, these categories are: Reward emphasis, Quality, Locatibility and Skills. The modifications made for each category are listed below. The remaining categories are only rewritten according to step 2, i.e. rewriting to align with Rijkswaterstaat specific word usage and translation to Dutch.

Reward emphasis (subcategory of the category Implementation climate)
Both DGAM program members mentioned that there is no reward and punishment system at Rijkswaterstaat. Reason is due to the culture at Rijkswaterstaat, which involves a high degree of authority for the employees to decide how they execute their jobs. Moreover, the DGAM program is still developing their goals which makes it even harder to set hard requirements for the users. When there is a noticeable achievement, they sometimes share this within the company via their internal website or employee magazine. However, which achievement is shared can sometimes be a bit arbitrary. It is therefore decided to remove the factors about reward emphasis, with exception of the last factor about recognition: "Employees perceived that they were going to be recognized for time and effort they spent in learning the system.". This factor is rewritten into: *"Asset Manager krijgt waardering voor gebruik van DGAM. Bijv: door het benoemen van behaalde prestaties via een nieuwsbrief."*

Quality (subcategory of the category Innovation-values fit)
During the translation step some factors led to almost similar results. To avoid factors which are almost identical, the last three factors are removed. This is also done to comply with the objectives, as discussed in Chapter 6.
The removed factors are: "The system maintains data I need to carry out my task.", "Sufficiently detailed data are maintained by the system." and "The system keeps data at an appropriate level of details so that I can complete my tasks.".

Locatibility (subcategory of the category Innovation-values fit)
The factor "It is easy to find out what data the system maintains on a given subject" is found to be very closely resembled by the factor "The system helps me locate corporate or department data very easily" and are therefore translated into one factor: *"De informatie is goed geordend en is makkelijk doorzoekbaaar voor de Asset Manager."*

Skills
The factor "I understand all of the special features of the system." is found to be irrelevant for the implementation phase and is therefore removed.

These changes resulted into framework version 2.0. The conceptual framework is only translated into Dutch as the number of categories and names are not changed. The conceptual framework can be seen in Figure 7.8. The changed set of associated factors can be found in Appendix A.4.

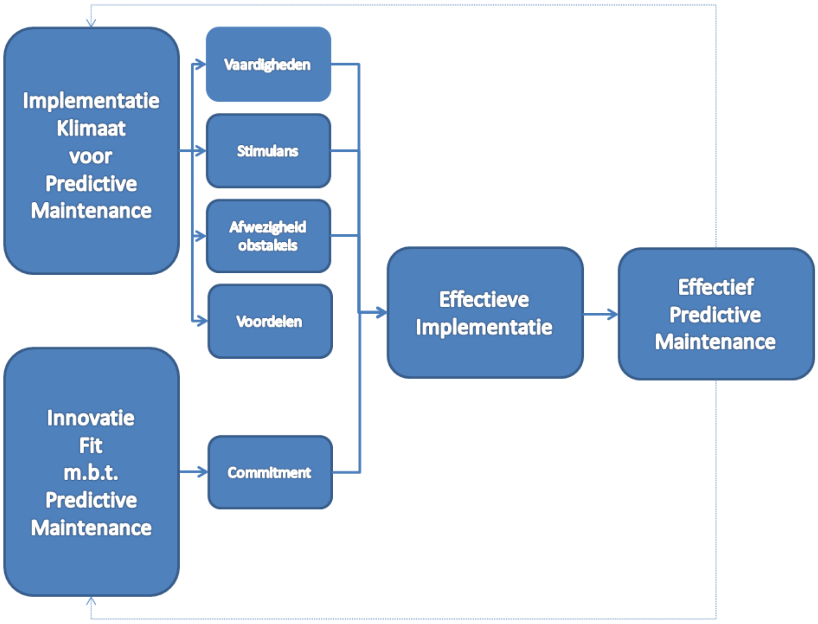

Figure 7.8: Conceptual framework 2.0

Chapter 8

Demonstration of PIP

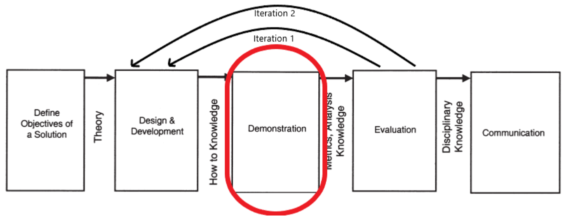

Figure 8.1: Current methodology phase

The demonstration phase is the third phase in the Design Science Research Methodology. The goal of this demonstration is to demonstrate the Predictive Maintenance Implementation Process (PIP) and the associated frameworks. This consist of two parts: Firstly, validating the work done in Section 7.6, which was adapting the framework to a framework which would fit the Rijkswaterstaat environment. Secondly, demonstrating PIP on it's designed purpose; supporting the implementation of DGAM. Due to limited resources with regard to time and available case study locations, the demonstration is performed at locations which were in the past part of an implementation similar to DGAM, or are currently involved in the implementation of DGAM. The use of a retrospective case could result in the lack of identifying implementation issues which are recently evolved. To limit this, the demonstration is performed by interviewing an employee which was involved during the implementation at the corresponding case location, as denoted in the PIP. During the interview all factors of the framework are addressed one by one by questioning whether the factor was in place or not. Depending on the factor, additional questions could be asked to get a better understanding of the processes and difficulties at that time.
The focus of this demonstration are steps 3, 4 and 5 of the PIP. Steps 1, 2, 6 and 7 are less relevant as the location and stakeholders were already chosen and the implementation of DGAM itself is out of scope for this thesis.

The demonstration session is performed with two cases: a retrospective case at Lock Eefde and a (at time of writing) ongoing DGAM implementation at the Salland Twente Tunnel (STT). After these demonstrations an evaluation is made to identify possible flaws of the proposed PIP, if this is the case an iteration cycle will be performed.

8.1 Lock Eefde

Lock Eefde is part of the *Twentekanaal*, a canal running through the eastern part of The Netherlands. It is an important connection for shipping between North- and East Europe and the ports of Rotterdam, Amsterdam and Antwerpen. Yearly 70.000 containers and 60 million tonne of cargo passes the lock. The original lock is build in 1933 but was, due to the size of the lock and increase in traffic, not suitable to handle all the traffic. therefore, a new lock is build alongside the original one to boost the amount of traffic flow (Rijkswaterstaat, 2018).

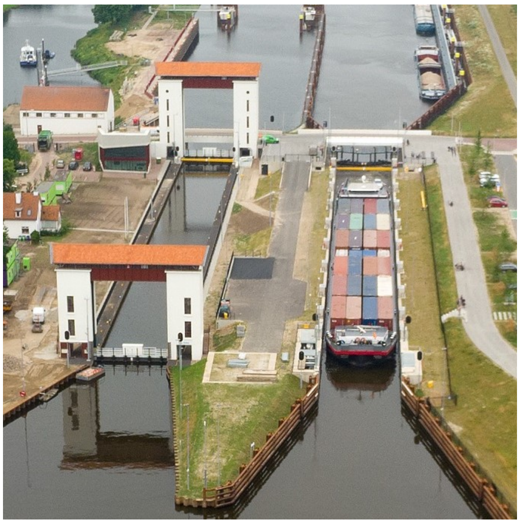

Figure 8.2: Lock Eefde Rijkswaterstaat, 2023d

From 2017 till 2020 lock Eefde was a so-called *proeftuin* for Smart Maintenance, a location where innovation with regard to Smart Maintenance could be tested. Smart Maintenance is an overarching term encompassing techniques aimed at operating in a more data-driven manner; an example being Predictive Maintenance. This *proeftuin* was part of the program *Vitale Assets* (English: Healthy Assets) of Rijkswaterstaat. This program focused on effective and durable upscaling of Smart Maintenance with specific topics for the individual locations. For lock Eefde the topics were: Energy consumption, corrosion forming, vibration/oil quality and data (Rijkswaterstaat, 2018).
Being a *proeftuin* location resulted in the interest of a substantial number of other parties to participate in the project. For example Mobilis, which is responsible for the maintenance of lock Eefde and EnerGQ, a company which provides 'plug & play'-energy sensors to detect abnormalities in energy consumption and use this information to observe patterns. According to World Class Maintenance foundation, which is the overall project manager of all the individually joined organizations and companies, this project is unique due the sheer number of cooperating parties (Rijkswaterstaat, 2018).

8.1.1 Demonstration results

The first demonstration is performed with the, at that moment, program member of the program *Vitale Assets*. As program member he was knowledgeable to comment on all the question. This demonstration is structured by addressing all factors from Framework 2.0 in sequence (see Appendix A.3 for the full set of factors) by asking semi-open questions if the factor was present during the implementation and secondly, if he believes that the factor was a facilitating factor (i.e. if the factor was present) or could be a facilitating factor (if the factor was not present). This in agreement with step 3 of the PIP.

The results can be seen below, note that a short definition of each category is given in de parenthesis:
Implementation climate (a supportive environment for implementation)
Lock Eefde was one of the first places at which Smart Maintenance was performed. therefore, there were little pre-defined requirements and most decisions were made in co-operation with the local engineers. These are for example topics with respect to the new procedures, which information (i.e. data) is needed and how this information is presented.
The, at that moment, program member of *Vitale Assets* commented that the factors from the framework are all relevant, but none of the factors were present at the start of the implementation due to the nature of this program. Relevant decisions were made on-the-go.

Innovation fit (will the innovation foster the organization?)
At the start of the implementation, there was little data available. Together with the local engineers and other external parties (for example the contractor) was decided which sensors should be placed. Due to the lack of data at the start, there was no dashboard or other visualisation product.
Because of the nature of this *proeftuin*, the joined members of this *proeftuin* (i.e. Program members, local engineers, contractors, suppliers etc.) were all very involved as they were voluntary joining this program. The program member mentioned that, despite the lack of data, this was one of the priorities of the project and was therefore a relevant factor. The lack of data at the start resulted in a slower start.

Skills (does the user have enough skills to use the innovation?)
Smart Maintenance is a new concept, certainly at the time this program was carried out. This resulted in a lack of skills needed to perform Smart Maintenance. As this program could be seen as 'Trial and error', this lack of skills did not harm the program much. However, it slowed down the pace.

Absence of obstacles (are there enough resources or support available?)
As part of the *proeftuin*, additional resources (i.e. budget and time) were available. Similar as the topic 'Skills' were things as training not provided beforehand and slowed down the pace. The joined members were voluntary joining the program which resulted in commitment from these partners, which was beneficial.
One item which was a major obstacle during this program was the fact that the program had little intervention possibilities in some areas. An example which occurred during this program was when they discovered that of the 4 pumps 2 performed more work than the other two, which is with respect to maintenance undesirable. Changing this (software) problem turned out to be very hard due to several stakeholders and the bureaucracy of Rijkswaterstaat.

Incentives (there are incentives to use the innovation)
The decision to implement Smart Maintenance at lock Eefde is decided together with the local engineers (among others the Asset Manager). This resulted in commitment from the Asset Manager, something which is vital for the implementation according to the program member.

Commitment (the user is motivated to use the innovation)
The program member mentioned that the commitment differs per person. The overall commitment was positive, probably because of the decision to implement Smart Maintenance was done together with the involved persons. The commitment resulted in a more effective implementation.

Benefits (benefits of the innovation are clear and measured)
As part of the *proeftuin* concept, a clear overview of the lessons learned is made. There were also no hard deadlines which should be met, as there was little to no experiences from previous implementations on what to expect. This resulted in little pressure to deliver and had advantages and disadvantages. The main advantage was the opportunity to do 'trial and error' and seek the best solutions for future implementation. The main disadvantage was the voluntary, this resulted sometimes in dis-aligned objectives, for example time management.

Summarized
The implementation at this location can be characterized as one where a majority of the factors were not fully in place. However, the unique external environment (i.e. being a *proeftuin* location) allowed for the swift resolution of the majority of challenges.
Furthermore, no agreements were made regarding the intended benefits of the implementation, and all new insights were considered valuable information for future implementations. This approach resulted in an implementation that would always be regarded as effective. However, the level of involvement of various parties and the flexibility observed may not be applicable to every implementation location.

8.2 Salland Twente Tunnel

The Salland Twente Tunnel is a combined rail and road tunnel which opened in 2013 and is part of the N35 highway. The tunnel is situated in Nijverdal, in the province Overijssel. It is the first combined rail and road tunnel in the Netherlands. The tunnel comprises of three tunnels tubes; one for trains and two for vehicles and measures 493 meters in length. Due to safety standards the tunnel is operated and monitored around the clock from the Traffic Control Center in Wolfheze. The tunnel serves as a solution for the previous route of the N35 highway, which used to pass through the village and facilitates improved traffic flow, reduced odor and noise pollution and enhances the safety within the village of Nijverdal (Rijkswaterstaat, 2023e).

Figure 8.3: Salland Twente Tunnel Rijkswaterstaat, 2023e

The Salland Twente Tunnel is one of the sites at which DGAM is being implemented. At the moment of writing, the implementation process is still ongoing but the first insights can be used for this demonstration. In contrast with lock Eefde the Salland Twente Tunnel is not part of a larger project and only the current contractor is involved.

8.2.1 Demonstration results

This second demonstration is performed with one of the current DGAM members and is therefore well informed about the situation at the Salland Twente Tunnel. This demonstration is structured in a similar way as the demonstration at lock Eefde. It is therefore used to analyze if the conclusions drawn from the first demonstration show similar patterns with this second demonstrations.

The results can be seen below, note that a short definition of each category is given in de parenthesis:

Implementation climate (a supportive environment for implementation)

The local Asset Manager believed that data could help to have a better insight in the condition of the asset. therefore is decided to incorporate STT in the DGAM project. This resulted in a combined decision of the local Asset Manager and the project team. The DGAM team member mentioned that he suspects that one of the reasons that STT is investigating the usage of data, beside the professional curiosity, is the fact that the management and maintenance of tunnels are more regulated that other infrastructures such as locks and bridges.

Consequence of this is that the new procedures and standards are being investigated and decided together and there is no official 'starting moment' seen from the program side. There were no demands from the program on what the deliverables should be and this was decided in cooperation with the local staff.

The local team is supported by the program members, consisting of (among other things): a group that realizes the information gathering (for example adding sensors and realizing the IT structure), a team which supports the implementation and could be seen as the contact person for the local team and a team which support with the interaction between Rijkswaterstaat and the contractor(s). An example of the support this latter team is providing is the help to rewrite contracts. The DGAM team member mentioned that currently most contracts with the contractors are based on performance (i.e. up time of the asset) and this adversely affect the urge to implement DGAM from the contractors' side.

With regard to reward emphasis, the DGAM team member indicated that the Asset Manager will not receive any appreciation when he is working according to the new DGAM standards. Occasionally a project will be written about in a (internal) magazine or website and the involved people are recognized for their work.

Innovation fit (will the innovation foster the organization?)
At the STT, there is currently no Object Data Services (ODS) which is a system that collects all data from the asset in an Rijkswaterstaat uniform way. Due to a scheduled overhaul over a year, they decided that the cost of implementing ODS now is too costly. However, a subcontractor found a detour to still be able to collect some data. The disadvantage of this is that it is not done according to Rijkswaterstaat standards and the lead time is 3 weeks, which means that time between data collection, processing and being available is 3 weeks.

Due to this temporarily fix, not all data could be logged and so the Asset Manager came up with three specific items he wanted information about to be able to do some analyses. The limited data resulting in the fact that a dashboard (or other way visualisation data) was not profitable.
The DGAM team member indicated that at other implementations they noticed that often the Asset Manager is not involved in the decision how to visualize the information and that this mostly decided by the IT'ers themself. He also noted that because of this lack of communication there is sometimes a misalignment on what is delivered by the IT department and desired by the Asset Manager.
At STT, the cooperation with the contractors is good. They are willing to invest resources to investigate what the benefits are for themselves.
One of the local members at the STT is a business analyst, according to the DGAM team member this is vital for a successful implementation.

Skills (does the user have enough skills to use the innovation?)
The local Asset Manager was already looking in the possibilities of using data to have a better insight in the condition of the asset. He was therefore aware (of some) of the techniques and is capable perform DGAM according to the DGAM program member.
The same is valid for the contractor, which has for example a dedicated data specialist.

Absence of obstacles (are there enough resources or support available?)
Due to the involvement of the DGAM project, there are additional resources available to help during the implementation. However, the DGAM program member is of the opinion that the Rijkswaterstaat culture is counteracting the implementation of DGAM. He described Rijkswaterstaat as a 'firefighting organization', with which he denoted that Rijkswaterstaat is excellent in making rapid decisions when there is urgency but is bad in making mid-term decisions. As DGAM revolves around using data to make decisions for the mid-term this is not beneficial.
To help the Asset Manager, a tool is made which can (based on data and statistic) indicate if it is financially beneficial to perform preventive or corrective maintenance.

Incentives (there are incentives to use the innovation)
The decision to implement DGAM at STT is decided based on the already enthusiast Asset Manager and the expectation that this provide a better understanding of the current condition of the asset. The result is commitment from the Asset Manager (and other local employees). A vital element according to the DGAM program member.

Commitment (the user is motivated to use the innovation)
The DGAM program member mentioned that all involved people are very committed. He suspects that this is because of the already positive attitude of the local Asset Manager and the willingness of the contractor. Additional actions to increase the commitment are not performed, as the level of commitment was found to be sufficient.

Benefits (benefits of the innovation are clear and measured

As the implementation of DGAM at STT is still ongoing, there is no clear overview of what the benefits will be. Both from the Asset Manager side as the DGAM program they are exploring the benefits and do not have any predetermined requirements. Both are also aware of the fact that the benefits of DGAM will not be visible in the short-term.

Summarized

This implementation has a large contrast with the previous implementation case. At STT the incentives and commitment were not the limiting factor, but the presence of obstacles. The absence of standard data gathering techniques (e.g. ODS) resulting in major challenges and resulting in less possibilities, a slower implementation process and decreasing commitment. Due to the limited involved parties, the challenges were hard to solve.

Chapter 9

Evaluation of PIP

9.1 Framework factors

In this chapter step four of the methodology will be discussed. The fourth step is an evaluation of the demonstration. The gathered information during the interviews will be used to evaluate the PIP and its components (i.e. the framework and factors).

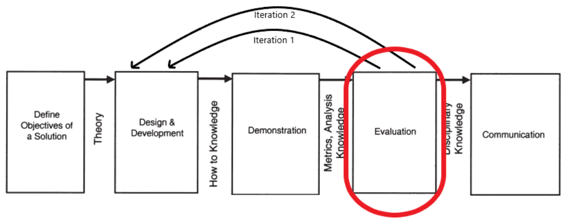

Figure 9.1: Current methodology phase

The first evaluation is regarding the effectiveness of the proposed PIP. Based on the results of the demonstration, it can be concluded that the proposed framework will foster the implementation. Examples are the commitment during the implementation at lock Eefde, as proposed in the framework is the commitment of the involved employees one of the conditions to foster the implementation. The presence of this commitment during the implementation was indeed an important factor during the implementation. An example which showed that the absence of a factor indeed resulted in a less effective implementation was the absence of ODS data at the STT. Due to the decision not to implement ODS, not all preferred data could be collected and data which could be collected was only available after 3 weeks. This resulted in a less effective implementation, which was as expected.

Moreover, a more in-depth exploration of the general atmosphere unveiled a notable difference between the two demonstration locations. Lock Eefde was positioned as a *Proeftuin* location, resulting in a sheer amount of freedom to explore and discover the opportunities within Smart Maintenance. A large group of external companies joined this project creating an almost perfect atmosphere for an explore and discover project. Providing almost limitless possibilities, but little to no obligations. This in great contrast to the Salland Twente Tunnel, which is part of the DGAM program. The current contractor is the only external partner and less involved compared to partners at lock Eefde. The atmosphere at the Salland Twente Tunnel can be characterized as considerably more strict and firmly focused on achieving the envisioned objective. Resulting in considerable less cooperation among the different teams, in contrast to the lesson learned at lock Eefde, which emphasized that clear communication and collaboration were essential for the success at lock Eefde (Rijkswaterstaat, 2018).

The demonstration at lock Eefde and STT also resulted in two areas at which the proposed factors were not in line with the conclusion drawn from the demonstrations at Eefde and STT. The first area is forced versus voluntary implementation. The second area concerns the baseline with regard to following standard procedures at Rijkswaterstaat and having a basis level knowledge of the asset.
The result is that the factors of the framework should be modified to adapt the findings. This modification will be explained in the following chapter.

9.2 Predictive Maintenance Implementation Process

The two demonstration cases were performed by interviewing an employee who was involved during the implementation at the corresponding case location. The interview was conducted by addressing all factors one by one to determine if the factors were present at the time of implementation.
This very structured interview approach proved to be suitable to assess the individual factors and decide whether they were in place, but lacked in effectively support the implementation of DGAM. By assessing the factors one by one, the majority of the answers will simply result in either 'yes' or 'no' and lack insights and reasoning why a factor is not in place. Resulting in the inability of deciding which action should be taken to make sure that the factor will be in place in the future (step 4 and 5 of PIP). In addition, this type of interviewing has a lot of similarities with available tools at Rijkswaterstaat. The consequence of this could be that the framework will be seen as 'just another tool' and will therefore not be used to it full potential.
To prevent both from happening, the PIP will be altered in the upcoming chapter.

Chapter 10

Re-design 1

As discussed in the evaluation, both the framework factors and the process itself should be modified to meet the desired outcome. To accomplish this, an iteration step is added in the methodology as illustrated in Figure 10.1. This iteration will involve revisiting steps two (Design and Development), three (Demonstration), and four (Evaluation). This iteration step is aligned with the intended application of the Design Science Research Methodology by Peffers et al., 2007.

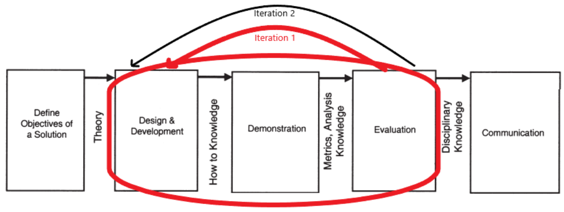

Figure 10.1: Current methodology phase

The demonstrations at lock Eefde and the Salland Twente Tunnel revealed that the proposed PIP showed differences with the situations at the demonstration locations. Two categories of the framework factors need further research as these proposed categories contain factors which should foster the implementation, but are not in accordance with the observed characteristics of the demonstration. These categories are related to forced versus voluntary implementation and following standard procedures. The second observation is regarding the process, as both demonstrations showed that the current 'box-ticking' assessment (step 3 in PIP) will not result in sufficient insight to be able to analyze missing factors. Both areas will be further explained in the following sections.

10.1 Design and Development

10.1.1 Framework factors

Forced versus Voluntary Implementation

The proposed framework is centered around a high degree of forced implementation. In other words, the proposed framework is based on the idea that forced implementation is the best option for an implementation at Rijkswaterstaat. This is based on the fact that there are fewer incentives for the regional teams to alter their processes and enhance the current procedures within a public organization, as discussed in Chapter 2. However, it can be concluded after both validations that the implementation at those assets where to a very high level, or even completely, voluntary and both interviewees commented that this aspect was a fostering factor during the implementation. A possible explanation for this difference in insight could be that both validation cases were at the time selected because they were already, to some degree, looking into the possibilities of usage of data to improve the insight of their assets. This would imply that both validation cases are not representative of the other implementations. This is supported by talks with Rijkswaterstaat employees at an earlier stage of this thesis, as they mentioned that the chosen locations are already have, to some extent, experience

with data driven techniques. Another observation from these discussions was the diversity in attitudes towards data, and consequently, DGAM.
To assess the necessity of modifying the framework, additional literature on forced or voluntary changes within public organizations was consulted.

Allthough increasing research on public sector innovation, the literature on the topic forced versus voluntary implementation in public organization is scarce (Demircioglu, 2020). Nevertheless, there is research performed on this topic in general (i.e. not necessarily public organization). For example by Dong et al., 2008 which performed an empirical examination of the innovation implementation model of Klein and Sorra.
Multiple hypothesis, based on the model of Klein and Sorra, were tested. Under which the following statements:

- Incentives are positively associated with implementation effectiveness.
- Affective commitment is positively associated with implementation effectiveness.

Both hypotheses were found to be supported by the research findings. Together with the statements from the employees and results from the demonstrations, it can be argued that a (partly) voluntary implementations will foster the innovation implementation. The current framework will be changed by rewriting the relating factors to enhance the collaboration and eliminate language that implies obligatory activities. For example by rewriting the sentence "The Asset Manager is told what to do with DGAM" to "Together with the Asset Manager is decided what the opportunities of DGAM are".

Following standard procedures

The second area concerns following standard procedures at Rijkswaterstaat. DGAM is an innovation at Rijkswaterstaat which continues on already gathered information but also on standard procedures which should be followed to perform the current defined methods to perform asset management. The proposed framework assumed that this baseline was at the desired level according to Rijkswaterstaat standards. However, both demonstrations led to the conclusion that this assumption was incorrect.
The standard procedures outlined by Rijkswaterstaat for conducting asset management were not consistently followed. This included both technical as managerial items. Examples are the non-standard ways of data collection or the lack of certain mandatory investigation plans.
The lack of a standard baseline at the different implementation locations resulted in heavy delays and lost opportunities. It is therefore a key factor to start the implementation with a decent baseline. As it is nearly impossible to get all assets at a certain baseline within a realistic time, the proposed framework is modified by adding an extra topic: Following standard procedures (Dutch: *Basis op orde*. This topic consist of the following factors:

1. Maintenance plans are available.
   (Dutch: *Er zijn instandshoudingsplannen beschikbaar.*)
2. The failure mechanisms of the asset are known.
   (Dutch: *De faalmechanismen van het kunstwerk zijn bekend.*)
3. There is an understanding of what data is available and who has access to it.
   (Dutch: *Er is inzicht in welke data er beschikbaar is en voor wie dit toegankelijk is.*)

These factors were the main limitation according to program members. The insight of the state of these limitations before the start of implementation should reduce the delays and foster the implementation as the implementation manager could decide to first resolve the absent factors.
Both adaptions regarding voluntariness and following standard procedures are incorporated into a new version of the framework: Framework 3.0. The list of corresponding factors can be seen in Appendix A.5.

10.1.2 Predictive Maintenance Implementation Process

The previously used 'one by one interviewing method' proved to be ineffective to fully support the intended objectives. To solve this problem, step 3 of the PIP will be altered. As the majority of the problems were the result of the manner in which the framework is conducted, the step will be changed to a more open question method. By questioning the presence of the framework categories (e.g. *Mededelingen* and *Vaardigheden*) instead of the individual factors, it is expected that the analyses of the new PIP will contain more valuable information to support the implementation process. Step 3 of the PIP will be altered in: "Perform an assessment of the factors by questioning the presence of the framework categories (e.g. *Mededelingen* and *Vaardigheden*)."

The new PIP (version 2) is as follows:

1. Identify the location at which DGAM will be implemented and responsible DGAM implementation manager.

2. The DGAM implementation manager identifies and select the relevant stakeholders. Examples of stakeholders are: Local Asset Manager and the maintenance contractor.

3. Perform an assessment of the factors by questioning the presence of the framework categories (e.g. *Mededelingen* and *Vaardigheden*), see Appendix A.4 for a complete set of the categories and factors..

4. The DGAM implementation manager analyzes with relevant stakeholders the results of the assessment; which factors are in place?

5. The DGAM implementation manager and relevant stakeholders decide if there is a need for improvement to increase the amount of present factors. It is advised to assure that the factors from category A.2 (*Innovatie fit*) are predominately present. If there is a need for improvement, a plan should be made to accomplish this improvement. Afterwards, step 4 should be performed to re-check if the improvement is indeed accomplished.

6. Perform the implementation of DGAM (note: out of scope for the PIP)

7. Perform an evaluation to improve the PIP in the future.

A process diagram of the PIP can be seen in Figure 10.2.

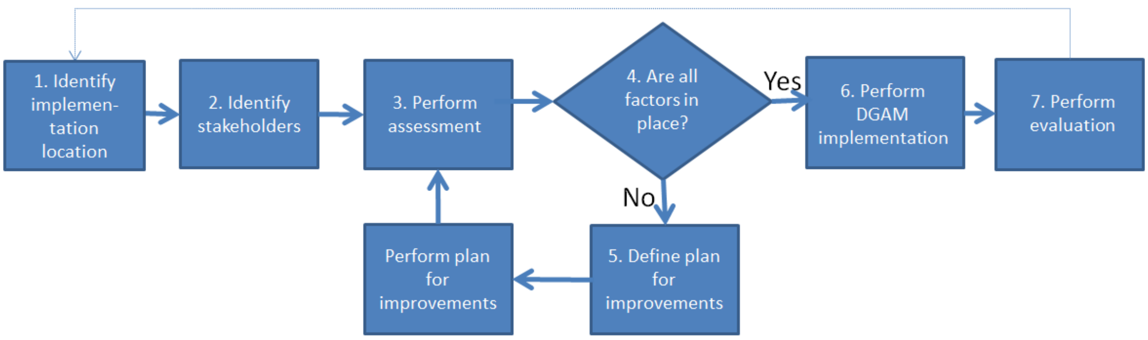

Figure 10.2: Process diagram PIP version 2

10.2 Demonstration

The modified version of the PIP, as proposed in the previous section, is demonstrated at lock Delden. The demonstration is performed with the *Senior Adviseur Asset Management (SAAM)* responsible for the assets in the Twentekanaal. The lock in Delden is chosen as the location for the demonstration as the SAAM committed that he is most knowledgeable about this asset. Lock Delden is part of the DGAM program.

Lock Delden is part of the *Twentekanaal* and shares a lot of similarities with lock Eefde. The lock went into service in 1933 and is designed in the same architectural style as the complex in Eefde. One uncommon difference is the fact that the lift towers are not interconnected. in 2018 the lock underwent significant refurbishment, ensuring its operational durability for at least another 30 years (Rijkswaterstaat, 2023a).

Figure 10.3: Lock Delden (Rijkswaterstaat, 2023a)

Demonstration

This third demonstration is performed with the *Senior Adviseur Asset Management*, responsible for lock Delden. The demonstration process is modified as elaborated on in the previous section.

The primary objective of this third demonstration is to validate the modifications made to the PIP. Additionally, the demonstration is used to verify if the conclusions drawn from the previous demonstrations align with the findings of this third demonstration.

The results can be seen below, note that a short definition of each category is given in de parenthesis:

Implementation climate (a supportive environment for implementation)

The *Senior Adviseur Asset Management (SAAM)* started with this role 3 months prior to this demonstration session, this means that the implementation of DGAM was already ongoing at the moment he started. His predecessor made sure that all information was passed on and he is still available if there is a need for information about something which happened before he started. However, during earlier talks with the predecessor it was mentioned that the implementation of DGAM was decided together with the local team.

One of the current problems mentioned by the SAAM is when a decision made in the past is not clear but the previously involved people are not always available to clarify the decision due to, for example, people transferring to other jobs or departments.

When talked about objectives, the SAAM told that he is of the opinion that the objectives of the DGAM program members and the regional departments are in general not aligned. There is also no clear ultimate goal for the DGAM program. Another issue is the support for the regional departments; as the implementation of DGAM results in more work, extra resources are allocated to the region, but they are supervised by the national DGAM program. For example with the help of an extra employee. However, the SAAM mentioned that he did not noticed any positive effects. The same goes for the contractors, which are not fully cooperative.

In the period he worked as SAAM, he is not asked to help with the development of a design. So he could not comment on the question if the region is involved in the design process. At the moment he is making a mock-up for a tactical dashboard himself. The mock-up is build around which information is useful according to the SAAM and his direct colleagues and will be sent to another department to create this dashboard.

Innovation fit (will the innovation foster the organization?)
At lock Delden the basis with respect to maintenance plans, failure mechanism, data availability and accessibility is at an adequate level. Object Data Services (ODS) is available, allthough there are some minor issues (wrong date stamps for example) and no additional sensors are placed. However, the amount and quality of the data is sufficient. The data is accessible via the *Centrale Informatie Voorziening (CIV)*, this leads to delays as each request requires manually handling. Another option is to use the already existing dashboard from the contractor, in which real-time data available. To avoid delays and not have to rely on information from the contractor the SAAM has done a proposal for a dashboard as mentioned in the previous section.
The information extracted from the data is not always trusted. A reason for this are the minor issues such as wrong data stamps. However, in general there are little issues with the data. The SAAM mentioned that he expects that the reason of this high level of data availability and accessibility is attributable to his predecessor which had a strong focus on this topic.
When talked about the contractor, it was concluded that the contractor will only fully be cooperative when they have an incentive. As contractors are commercial companies, they mostly resulted in incentives which are related to money. As contractors are mostly concerned about short-term profit, among other things due to the fact that they have contracts for a certain period, this results in a conflict of interest as Rijkswaterstaat is not concerned about short-term profit. However, some contracts between the contractor and Rijkswaterstaat contains specific agreements with respect to this topic. Moreover, a group of contractors have recently signed a letter of intent to put effort in the development of predictive maintenance techniques.

Skills (does the user have enough skills to use the innovation?)
The SAAM has already a background in maintenance and asset management. Together with the existing data sources and the adequate level of it, there are no constraints in that respect.

Absence of obstacles (are there enough resources or support available?)
If needed, there are enough colleagues or departments who can assist. For example assisting with gathering a list of all available sensors. The SAAM did not need to contact the DGAM program members, but he expects that they are available for assistance if needed.
An obstacle mentioned by the SAAM is that lock Delden is an essential asset for maintaining a certain water level in the rivers and channels. This means that in period of drought the lock should always be operational and that they should be very confident about any predicted failure to avoid unnecessary downtime.

Incentives (there are incentives to use the innovation)
The decision to implement DGAM at the lock in Delden was already made, but the SAAM is convinced of the benefits of DGAM, mainly on the long-term as he mentioned that the main disadvantage of DGAM is that it will take a long time and a lot of resources before the investments are payed back.

Commitment (the user is motivated to use the innovation)
As already mentioned, the SAAM is very committed to further implementing DGAM. However, the commitment of the contractor is less present despite this being part of the contract.

Benefits (benefits of the innovation are clear and measured)
The SAAM and his colleagues are aware of the facts that the majority of the benefits of DGAM will not be visible in the short-term. As there already is a dashboard build by the contractor, there is some impression what the benefits could be and which information they need to achieve this.

Summarized
This demonstration highlights the importance of ensuring the presence of all factors. Despite the commitment of SAAM, the availability of necessary skills, and the presence of only minor obstacles, relatively small challenges led to a less effective implementation. For example, issues such as corrupt data and misalignment between the teams regarding the offered extra help for the regional teams created challenges.

10.3 Evaluation

The focus during the demonstration were the modifications which were made during the iteration phase. From the demonstration with the *Senior Adviseur Asset Management* it can be concluded that the non modified factors are indeed relevant for an innovation implementation at Rijkswaterstaat. All present factors resulted in an (more) effective implementation and factors which were not present are considered as having an adverse effect on the implementation.
The implementation of DGAM was already ongoing when the SAAM started with his role at Rijkswaterstaat, so he could not comment on the exact manner the implementation is introduced in the region. However, it can be concluded that it is vital to have a good interaction during the start of the implementation. For example; misalignment in the objectives are devastating for the results for the program and the incentives and commitment of the involved persons. This and other statements of the demonstration at lock Delden are consistent with the literature review performed in Section 10.1.1. Which was regarding to forced versus voluntary implementation and concluded that the preferred approach for the implementation of DGAM is (predominately) voluntary implementation.

The other modification was related to following standard procedures. The interview clearly confirmed the need for a solid baseline to improve the implementation results. The baseline at lock Delden is at a relatively high level, with several data sources of good quality and an understanding of the fundamentals of the asset such as an overview of the failure mechanisms. The high baseline level resulted in less interruption due to lack of information or data and is therefore beneficial for the implementation of DGAM.

It can be concluded that the modified factors foster the implementation process. Furthermore, the improved PIP proved to yield more in depth insight in the current status of the asset location. Resulting in an improved ability to analyze the needed action to be able to effectively implement DGAM. Despite this modified PIP, it was concluded that this process was still not able to extract the full potential of the framework.

A conclusion that can be drawn from the demonstrations is that the current format is (still) less desirable for Rijkswaterstaat as organization. Rijkswaterstaat is an organization with a multitude of processes, models and visualization tools. The current process format, an organized list of succesfactors to support the implementation of DGAM could be regarded as 'just another tool'. This would be fatal for effectiveness of the PIP. To ensure that this research will reach it desired potential, the format of the design will be changed. As the contents (i.e. factors) of the framework are validated during the demonstration phase, only the format needs to be changed and the factors can be used as 'building blocks'.

The decision is made based on the following conclusions:
Firstly, despite the substantial support that the PIP is poised to offer during the course of the implementation of DGAM, the process will be employed alongside other tools. This raises the potential for an abundance of resources at the disposal of the implementation team, which could lead to a decision not the utilize them. The current design format is very information dense and not visually appealing to use. Allthough the format is designed around the intended users, which are the employees responsible for the implementation, the implementation phase is a collaboration between the implementation team and the team where DGAM is implemented. Consequently, the process should support both

teams. It is expected that this is not the case with the current design format.

Secondly, during the demonstration is emerged that there is a high amount of collaboration between the implementation team and the team where DGAM is implemented. While collaboration was anticipated, its extent surpassed initial expectations. Consequently, the focal point for the design has shifted from solely the implementation team to both teams. As denoted earlier, the current PIP is expected to be less suitable for this higher level of collaboration.

Lastly, the regional teams have a high level of authority as already touched on in Chapter 1 and Section 10.1.1. This high level of authority demands that the teams are having a high level of commitment. This high level of commitment is sought to achieved by altering the PIP to one that is equally centered on the regional teams and will support both teams with the implementation. This high level of authority will also underscore the significance of collaboration between the teams. This is particularly essential for factors related to commitment and incentives, as these factors cannot be imposed but necessitate cooperation from all involved members as discussed in Section 10.1.1.

Chapter 11

Re-design 2 (Final design)

Based on the insights retrieved from the evaluation in Section 10.3, the framework format will be modified. This results in adding a second iteration step, as can be seen in Figure 11.1. The steps Design and Development, Demonstration and Evaluation will therefore be completed again. It was concluded that the framework factors support the implementation of DGAM and therefore only the format will be changed in the upcoming section.

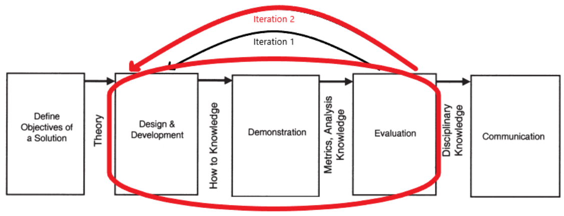

Figure 11.1: Current methodology phase

11.1 Design and Development

To determine the optimal choice for the new design format, two resources are consulted. Firstly, research is performed on literature regarding effective visualization of information and secondly, a Senior Advisor Asset Management (SAAM) is consulted to elaborate on his personal preferences regarding the visualization.
Research resulted in information on effective visualization principles, such as the book "Design for Information" by Meirelles, 2013 which gives an introduction to the theory and best practices behind effective information visualization or "On the role of design in information visualization" by Moere and Purchase, 2011 in which the requirements of attractiveness in visualization is investigated.
Additionally, the SAAM is consulted. During this consultation some advice was given based on experiences within the case organization and personal preferences. The SAAM recommended the inclusion of the benefits associated with the ability to execute specific factors. This addition aims to provide users with a clearer understanding of the rationale behind the innovation implementation. The SAAM also advised to only use the sub-categories (e.g. Mean emphasis, skills etc.) with an (short) explanation of this sub-category and supply the factors in a handout for further specific explanation of the factors. This to avoid an overload of information. Another advise was to divide the (sub-)categories into parts which would be executed consecutive. The SAAM mentioned 'Stage-gate' as possible method to separate the parts and give focus to the implementation team. In line with the suggestions provided by the SAAM and literature research, the framework will be changed into a roadmap to support the PIP. The roadmap is divided into three parts: 1) Innovation fit, 2) pre-implementation climate and 3) implementation climate. The parts are based on the different phases in the implementation of DGAM (or other related innovations). The innovation fit consist of the factors which should be present to start a successful implementation. Absence of this factors could mean that the innovation is not the right fit

for the organization. Pre-implementation climate consist of factors which foster the implementation and are factors which are mostly harder to accomplish in a short period of time. Absence of these factor will therefore result in either a less successful implementation or would delay the implementation. The last part consist of factors which will either be executed during the implementation or could be accomplished in a shorter time.

The roadmap can be seen in Figure 11.2. An enlarged version can be found in Appendix A.6.

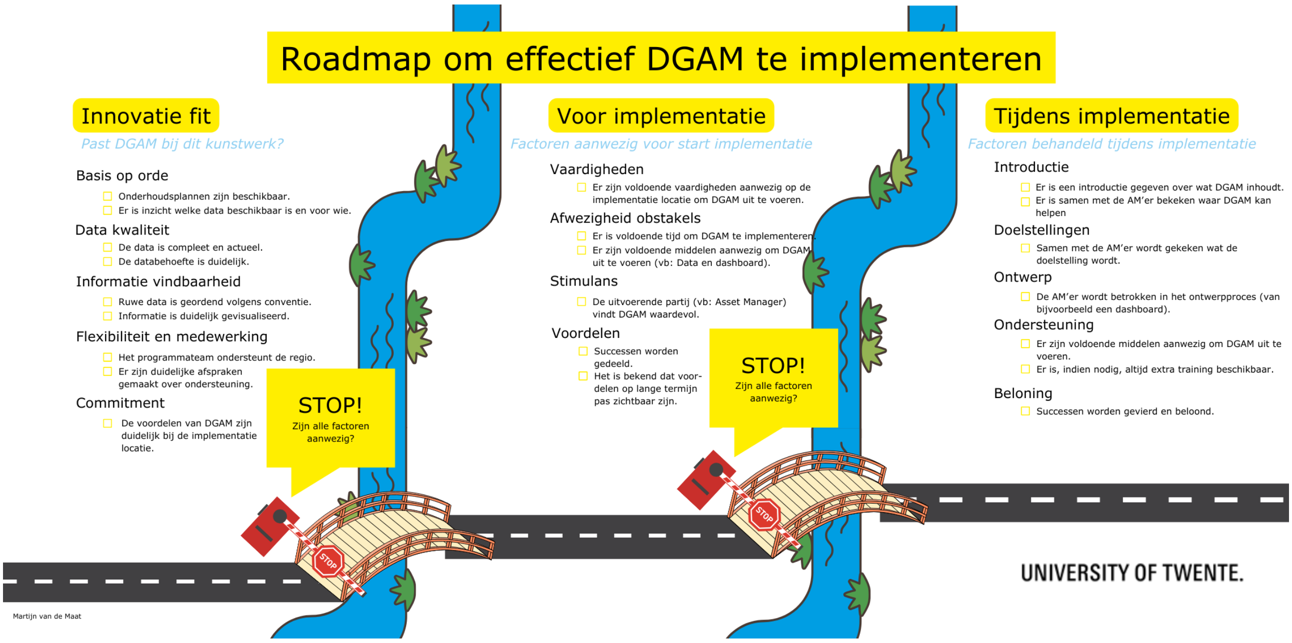

Figure 11.2: Designed PIP supporting roadmap

Due to the format change, the PIP should also be changed to align with the new format. The change to a roadmap results in two major modifications of the PIP. Firstly, the assessment process is now based on a collaboration between the implementation manager and the local team. Secondly, the roadmap is divided into three phases (Innovation fit, pre-implementation and implementation). First phase one will be assessed by analyzing the presence of the factors associated with phase one. If a sufficient amount of factors are in place, the implementation can proceed to the next phase. If this is not the case, a plan should be devised to accomplish the presence of more factors.

The new steps of the PIP are:

1. Identify the location at which DGAM will be implemented and responsible DGAM implementation manager.

2. The DGAM implementation manager identifies and select the relevant stakeholders. Examples of stakeholders are: Local Asset Manager and the maintenance contractor.

3. The DGAM implementation manager performs an assessment if the factors of the first phase are present, see Table 11.1. This assessment should be done in collaboration with the stakeholders. Use the roadmap to check off the factors which are in place.

4. The DGAM implementation manager analyzes with relevant stakeholder the results of the assessment; are there sufficient factors in place to proceed to the next phase? If not, devise a plan to accomplish the presence of more factors.

5. The DGAM implementation manager and relevant stakeholders perform an assessment of the factors of the second phase, see Table 11.1.. Analyze the results of the assessment; are there sufficient factors in place to proceed to the next phase? If not, devise a plan to accomplish the presence of more factors. Use the roadmap to check off factors which are in place.

6. At the start of the implementation of DGAM, the factors of the third phase should be assessed, see Table 11.1.. These factors should be put in place as expeditiously as possible to facilitate the implementation. Use the roadmap to check off factors which are in place and ensure that the roadmap is physically present during meetings to ensure that the stakeholders are aware of the factors which need attention.

7. Perform an evaluation to improve the PIP in the future.

A process diagram of the PIP can be seen in Figure 11.3.

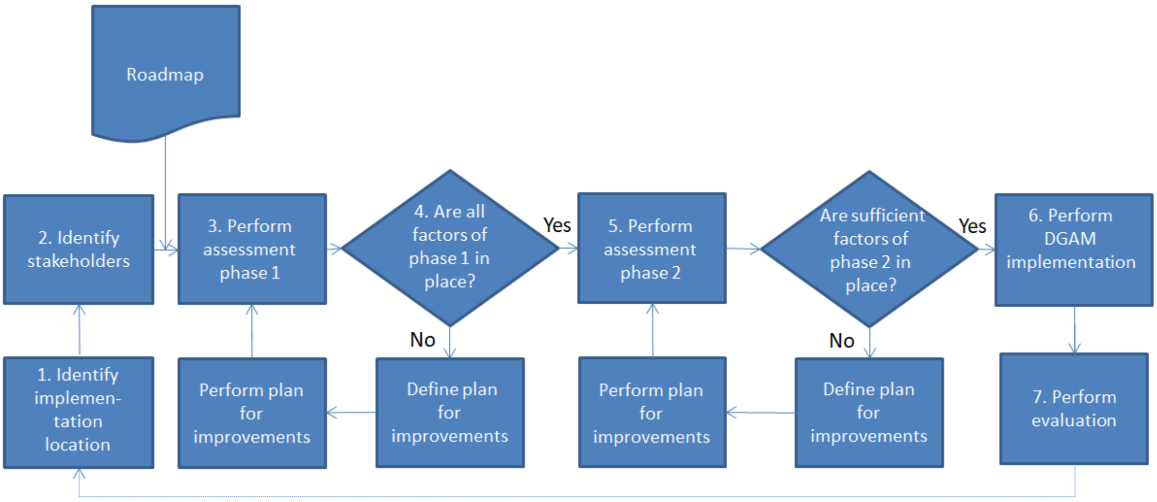

Figure 11.3: Process diagram PIP (final version)

Table 11.1: Framework factors (final version)

Fase 1:
A2. Innovatie fit
Basis op orde
Er zijn instandshoudingsplannen beschikbaar.
Er is inzicht in relevante onderhoudsgegevens van het kunstwerk, bijvoorbeeld faalmechanismen.
Er is inzicht in welke data er beschikbaar is en voor wie dit toegankelijk is.
Data kwaliteit
Het programmateam cq. RWS zorgt ervoor dat de data 'Actueel Beschikbaar Compleet' is.
Het programmateam cq. RWS zorgt ervoor dat, op basis van de informatiebehoefte, de data beschikbaar is die nodig is voor de AM'er om DGAM uit te voeren.
Asset Manager krijgt door (bijna realtime) data beter inzicht in zijn behoefte.
Informatie vindbaarheid
De ruwe data is goed geordend en er is een duidelijke dataconventie
De informatie is goed geordend en is makkelijk doorzoekbaar voor de AM'er
De informatie is duidelijk gevisualiseerd. Bijv: Door het gebruik van duidelijke diagrammen en grafieken
Flexibiliteit en medewerking
Het programmateam cq. RWS ondersteunt DGAM
DGAM ondersteund de coöperatie tussen de verschillende stakeholders uit de AM keten (Landelijk, Regio en Markt)
DGAM zorgt ervoor dat de AM'er beter zijn werk kan doen (lees: Beter inzicht).
A6. Commitment
De Asset Manager vindt DGAM persoonlijk waardevol.
De Asset Manager geniet van het delen van zijn ervaringen omtrent DGAM (i.e. hij is trots op DGAM).
De Asset Manager heeft het gevoel dat hij onderdeel is van DGAM (cq. Eigenaarschap)
De Asset Manager maakt tijd vrij om zich verder te verdiepen in DGAM.
Fase 2:
A3. Vaardigheden
De Asset Manager heeft de vaardigheden om DGAM uit te voeren.
De Asset Manager heeft de vaardigheden en mogelijkheden om ervoor te zorgen dat de data 'Actueel Beschikbaar Compleet' is.
De verschillende gebruikers (bijv: Asset Manager en Markt) zijn gekoppeld en de data wordt gedeeld.
Het is duidelijk wie welke rol heeft en wie welke informatie nodig heeft/gebruikt.
De Asset Manager heeft de vaardigheden om grafieken te lezen, makkelijk informatie te vinden in dashboards etc.
A4. Afwezigheid obstakels
Het programmateam zorgt ervoor dat er voldoende organisatorische middelen zijn (tijd, training etc.) om de AM'er te ondersteunen.
Het programmateam zorgt ervoor dat de middelen beschikbaar zijn (i.e. de data/dashboards zijn altijd te bereiken).
De Asset Manager heeft voldoende stuurmaatregelen om het proces te beïnvloeden die nodig zijn om DGAM uit te voeren. Bijv: Het aanpassen van onderhoudsplanningen.
A5. Stimulans
De Asset Manager ziet voordelen van DGAM.
De Asset Manager vindt DGAM zinvol en is gemotiveerd om DGAM uit te voeren.
A7. Voordelen
Het programmateam houdt er rekening mee dat het de voordelen van DGAM moeilijk te meten zijn. Bijvoorbeeld door niet te sturen op harde eisen.
Het programmateam houdt er rekening mee dat het verzamelen van data middelen (o.a. tijd en geld) kost, zonder dat deze data directe positieve invloed heeft.
Het programmateam houdt een 'wall of fame' bij waar alle successen van DGAM zichtbaar zijn.
Fase 3:
A1: Implementatie klimaat
Introductie
De Asset Manager wordt uitgelegd wat DGAM kan verbeteren in de Asset management proces (afhankelijk van het niveau van de AM'er).
Samen met de Asset Manager wordt bekeken welke processen veranderd moeten worden.
De markt wordt geïnformeerd over de implementatie van DGAM.
Doelstelling
De Asset Manager wordt uitgelegd hoe hij/zij DGAM kan uitvoeren. Bijv: Storingen zien aankomen, juiste gebruik van data etc.
De Asset Manager wordt meegenomen in de bestaande standaards. Bijv: Standaard naamgevingsconventie.
Samen met de Asset Manager wordt bekeken waar DGAM van toevoegde waarde kan zijn voor het proces.
Ondersteuning
Het programmateam zorgt ervoor dat alle benodigde technologie aanwezig is zodat de AM'er DGAM kan uitvoeren. Bijv: Er is een dashboard opgeleverd. De benodigde technologie is o.b.v. de behoefte van de Asset Manager.
Het programmateam zorgt ervoor dat er handleidingen en naslagwerk beschikbaar is.
De Asset Manager krijgt voldoende tijd om te wennen aan DGAM. Bijv: Door het toekennen van extra (tijdelijke) hulp.
Het programmateam zorgt ervoor dat er een 'helpdesk' beschikbaar is voor Asset Mangers met vragen over DGAM.
Het programmateam zorgt ervoor dat, indien nodig, er extra training beschikbaar is voor de Asset Manager.
Binnen RWS zijn er voldoende resources (budget en mensen) vrijgemaakt voor de implementatie van DGAM.
Beloning
Asset Manager krijgt waardering voor gebruik van DGAM. Bijv: door het benoemen van behaalde prestaties via een nieuwsbrief.
Ontwerp
Tijdens het ontwerpen van (bijvoorbeeld) een dashboard wordt er rekening gehouden met de wensen van de gebruiker.
Tijdens het ontwerpen van (bijvoorbeeld) een dashboard wordt er rekening gehouden met het feit dat ontwerpkeuzes invloed hebben op de gebruiksvriendelijkheid.
Tijdens het ontwerpen van (bijvoorbeeld) een dashboard wordt er rekening gehouden met de flexibilieit van het dashboard, zodat deze makkelijk aangepast kan worden op (veranderende) wensen van de gebruiker.

11.2 Validation

To meet time constraints, a validation is conducted instead of a full demonstration. The modified PIP was presented to the implementation manager of the DGAM program. He was asked to assess the roadmap and determine whether this format and associated PIP could have a positive impact on the implementation of DGAM at Rijkswaterstaat. The implementation manager concurred that this format could be beneficial, particularly in enhancing the collaboration between the Nationwide and Regional branches. Moreover, he mentioned that the subdivision (Innovation fit, pre-implementation and implementation) could help with guiding the implementation process and keep focus on which parts are most important at a given time. The implementation manager provided feedback regarding the potential usability of the PIP across all assets slated for DGAM implementation, since the assets of Rijkswaterstaat are characterized by unique technical and operational features. This feedback will be further on elaborated in Chapter 12.

11.3 Evaluation

Allthough the framework and the corresponding factors are being demonstrated and found to be in accordance with the intended use, the last step is to verify if the design meet the set of objectives formulated during the first step of the Design Science Research Methodology (see Chapter 5).
The formulated objectives are:

1. The design should be focused on the organizational implementation aspects of DGAM. The technical aspects of the implementation of DGAM are out of scope for this thesis.
2. The users of the design are the members of the DGAM program who are in charge of the implementation of DGAM at the assets of Rijkswaterstaat (i.e. Members of work package: "6-implementations").
3. The design should be supported by a platform which is already used by Rijkswaterstaat. I.e. Excel, PowerPoint, etc.
4. The design should be easy to use and it should be possible to incorporate it within the program team.
5. The design should be Rijkswaterstaat specific, for example: abbreviations should align with those used by Rijkswaterstaat employees.

Objective 1 is met, as the design and corresponding factors are focused on the organizational aspects of an innovation implementation. Objective 2 is met, as the design is focused on the members in charge of the implementation and two out of three demonstration cases were performed with the intended users. Objectives 3,4 and 5 are met as the design is supported by a platform already in use at Rijkswaterstaat, easy to incorporate within the program teams and is Rijkswaterstaat specific.

11.4 Final design

As the last iteration of the Predictive Maintenance Process correspond with the defined objectives for the thesis, this will be the final deliverable of this thesis.
The final design solution is the Predictive Maintenance Implementation Process, this design consists of 2 parts; 'how' and 'what'. The 'what' gives answer on what factors need to be taken care off to ensure an effective innovation implementation. The 'what' consist of a conceptual framework (see Figure 11.4) and framework factors (See Table 11.1). The conceptual framework is the theoretical foundation of this design and provides the different categories. The framework factors provide interpretation to the conceptual framework by giving definitions (i.e. the factors) to the categories.
The 'how' gives answer on how to use the conceptual framework and framework factors and consist of the step-by-step plan as can be seen in Figure 11.3. The 'how' is supported with the roadmap, which supports the collaboration between the nationwide and regional teams and is a visual representation of the framework factors and the step-by-step plan. The roadmap can be seen in Figure 11.5.

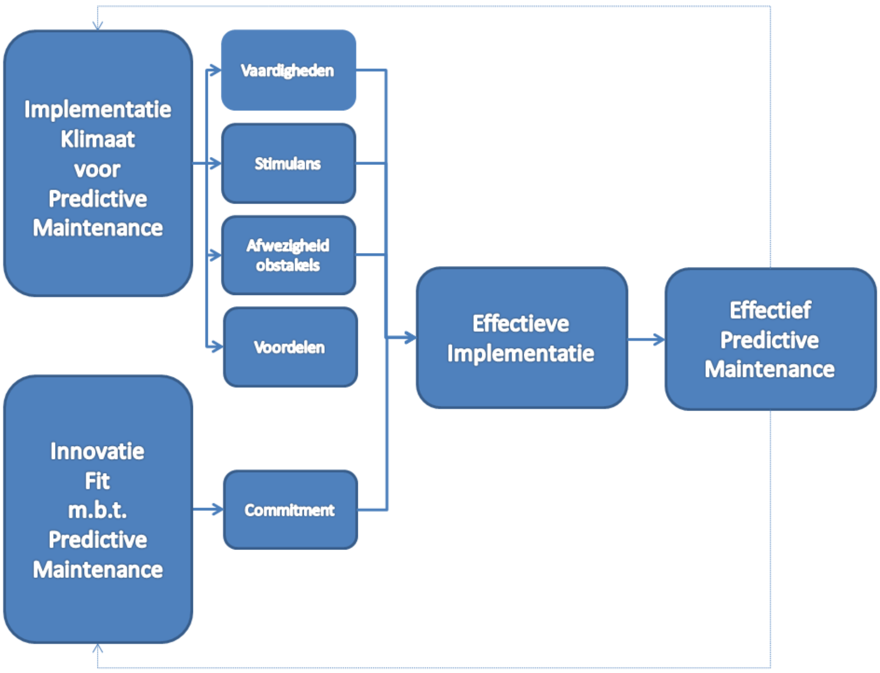

Figure 11.4: Conceptual model framework 3.0

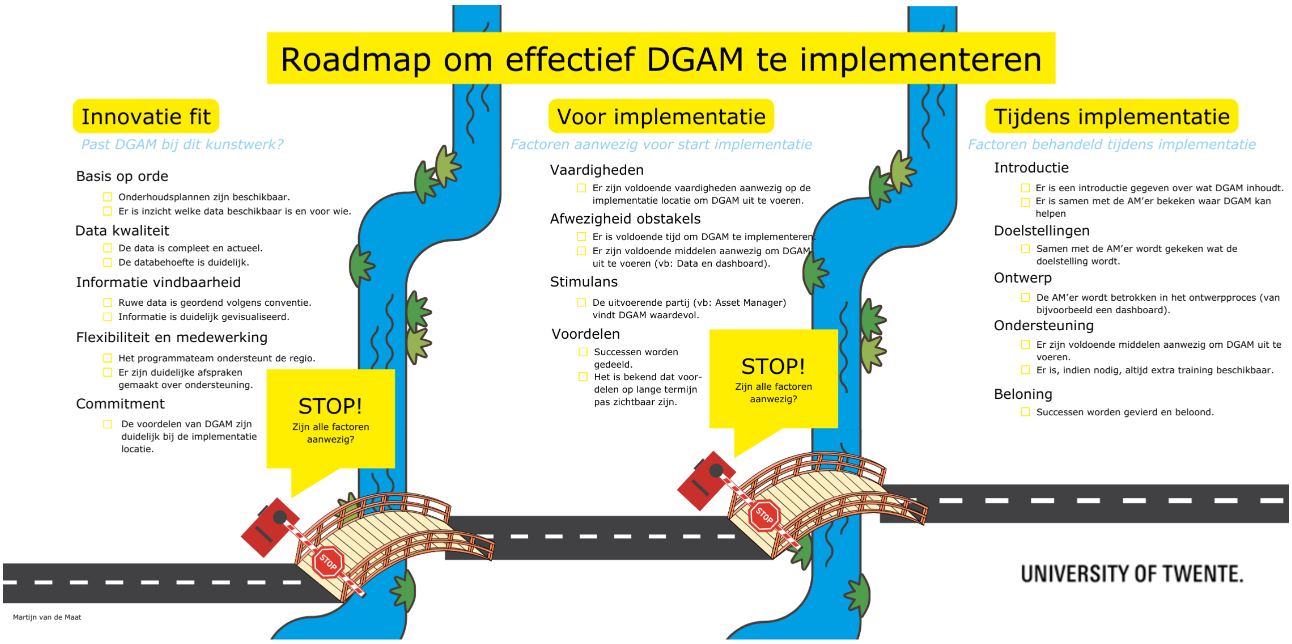

Figure 11.5: Designed PIP supporting roadmap. See Appendix A.1 for an enlarged version.

11.5 Communication

The final step of the Design Science Research Methodology is communication. Throughout the demonstration phase, it was reinforced once again that clear and transparent communication is vital for any implementation. This is particularly crucial in organizations with a structure similar to Rijkswaterstaat, where different divisions not only serve distinct functions but are also physically separated from each other.

This thesis will serve as an extensive explanation of the development of the Predictive Maintenance Implementation Process. In addition to the thesis, the development process and results will be shared during a presentation at the case organization Rijkswaterstaat.

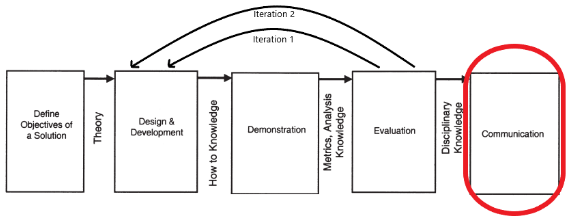

Figure 11.6: Current methodology phase

Chapter 12

Conclusion, Discussion and Managerial implications

12.1 Conclusion

In this section the research question of this thesis will be answered: 'How can a DGAM implementation manager be supported with a fitting DGAM implementation process to enable maintenance towards Predictive Maintenance?'. Before this question can be answered, it is important to realize that the implementation of Predictive Maintenance comprises of two distinct areas. Firstly, the implementation of a new maintenance strategy, such as Predictive Maintenance, results in a transformative shift in various organizational aspects including processes, data collection, maintenance planning and much more. Concurrently to this is the implementation of an innovation, as the new maintenance concept is never used before. This innovation implementation results in even more complexity during the combined implementation.
Each of these domains presents its own set of challenges and results frequently in the inability to achieve the intended benefits of an innovation, as mentioned by Klein and Sorra, 1996.

To improve the effective implementation of Predictive Maintenance at Rijkswaterstaat, which is an asset-intensive public organization, the PIP is designed. This process offers the personnel tasked with overseeing the implementation of DGAM at Rijkswaterstaat with a process. The PIP is constructed by consolidating key-factors for innovation implementation and Predictive Maintenance implementation. The key-factors for an effective Innovation Implementation are based on the Determinants and Consequences of Implementation Effectiveness model by Klein and Sorra, 1996 and supplemented with the definitions from "Testing Klein and Sorra's innovation implementation model: An empirical examination" by Dong et al., 2008. This resulted in a framework with a set of factors to support the implementation of an innovation, see Appendix A.3. This framework comprises of key-factors relevant for an implementation of a general innovation at organizations. To tailor the framework to its designated context, which is Predictive Maintenance implementation at an asset-intensive public organizations such as Rijkswaterstaat, the framework is further enriched with distinctive factors for Predictive Maintenance, Condition Based Maintenance and Information Technology. Informed by a literature review, two specific sources have been integrated to augment the existing framework: Knowledge Lost in Data: Organizational Impediments to Condition-Based Maintenance in the Process Industry by Kerkhof et al., 2016 and Technology Acceptance Model 3 and a Research Agenda on Interventions by Venkatesh and Bala, 2008.
As anticipated, certain factors are already encompassed within the existing framework. These factors are either omitted or integrated into existing factors to circumvent excessive similarity. This consolidation resulted into a new version of the framework, see Appendix A.4. This new version comprises of key-factors relevant for the implementation of Predictive Maintenance at organizations.
In order to arrive at a conclusion to the research question, a final modification must be made. This entails specifying the factors for use within the context of Rijkswaterstaat. This process involves an

evaluation if the factors are applicable for use at Rijkswaterstaat, which is conducted by two DGAM program members during an Expert Session. Furthermore, the factors are subsequently rephrased to harmonize with the lexical preferences and abbreviation usage within Rijkswaterstaat. Lastly, the factors are translated into Dutch as this is the spoken language at Rijkswaterstaat resulting in Framework 3.0, see Appendix A.5. A comprehensive explanation is available in Section 7.6.
The factors outlined in Framework 3.0 contribute to addressing the research question, as they provide essential support to the implementation team by highlighting factors crucial for the successful implementation of innovations, particularly in the context of DGAM. However, the intended design format proved to be less favourable for the case organization as elaborated in Section 11.1. Based on further research and consultation of a Senior Advisor Asset Management at Rijkswaterstaat is chosen to change the design format in a roadmap which visualizes the framework, see Figure 11.2.
This roadmap is poised to enhance collaboration between the national and regional teams. It serves as an easily accessible tool that both teams can utilize to visualize the necessary factors for facilitating the implementation. Additionally, it helps identifying areas that may require further development to ensure the presence of all essential factors. It can also be used as tool to emphasize the goal, to ensure focus as suggested by the Senior Advisor Asset Management.

To conclude with an answer on the research question: 'How can a DGAM implementation manager be supported with a fitting DGAM implementation process to enable maintenance towards Predictive Maintenance?'. The implementation manager can be effectively supported by using the PIP developed in this research. This process is build upon a set of decisive factors for the implementation of DGAM. The factors can be employed either as guidance during the implementation process to identify factors that require attention, or as a means to assess the current status and level of implementation (i.e. a type of maturity assessment). The roadmap, based on the factors, support the implementation primarily during the collaboration between national and regional teams. The roadmap will foster a shared goal and provide focus throughout the implementation process.

12.2 Discussion

The PIP and the corresponding factors and roadmap are proposed to support the implementation of Predictive Maintenance at an asset-intensive public organization, for example Rijkswaterstaat, by presenting the essential factors in a useful manner and providing a guideline on how to use it. The process is based on well founded literature regarding innovation implementation, supplemented with literature specific for the innovation; Predictive Maintenance. The resulting factors are demonstrated and evaluated with the help of experts. Although the factors are validated and missing factors were added with the help of experts, It can be argued that certain essential factors for innovation implementation are still missing. As the proposed objective for this research is to investigate how to support the innovation implementation, the PIP is expected to be a very applicable tool to do so.
Next to the intended function, supporting the implementation with a set of essential factors, the roadmap proved to be an opportunity to bridge the gap between the national and regional teams. During the demonstration session with the Senior Advisor Asset Management, but also other prior interviews, it became evident that the perception of the implementation of DGAM was not aligned. The national team can focus on long-term plans and should have the ability to drive the regional teams. The regional teams are mainly concerned with the day-to-day business of making sure that their assets are in adequate condition and have a high level of authority over the assets they maintain. The result is less focus on long-term project, such as the implementation of DGAM. The conceptual framework is therefore also a very suitable tool to foster the collaboration, keep track of the factors which need attention and keep focus by visually be able to see the factors and their progress.

The framework is developed with the input from different employees of Rijkswaterstaat. The expectations and opinions with regard to Predictive Maintenance cq. DGAM were very various. The members of the national DGAM team were all very positive about the implementation of DGAM, which was to be expected. However, other employees' opinions were overall less positive. The majority expected the implementation of DGAM to be beneficial for Rijkswaterstaat, but were more concerned about the practical implications. The meetings, interviews and other talks have been of great importance for this research. The amount of knowledge accumulated during these moments were invaluable, in particular because of the different backgrounds. By talking to a great number of employees with different backgrounds, I could develop a better understanding of the perceptions and processes within Rijkswaterstaat.

Nevertheless, the framework has limitations. The first limitation is the fact that the framework is partly demonstrated and validated with historical cases. Although these cases can be assumed to be a good representation of current cases, there is a possibility that either the employees or Rijkswaterstaat as organization has evolved rapidly and drawn conclusions are not valid. Secondly, one of the demonstration locations was part of the *Proeftuin* project and other locations were chosen based on, among other things, already having some experience with Predictive Maintenance (or similar tools). This could for example be a local Asset Manager which was already knowledgeable about this maintenance type. The result is that those locations could possibly be less representative for other locations, and the proposed framework a lesser fit is for other locations. Lastly, the change to a roadmap format is based on limited input as it is based on comprehensive literature research and the input from a Senior Advisor Asset Management at Rijkswaterstaat. However, the roadmap is build upon the factors which were demonstrated and validated extensively.

Reflecting on the chosen methodology, the modified Design Science Research Methodology was a good fit for this research. Specifically, the iteration step was an important step during this research as this step forced to evaluate the current design. In retrospect, the two iteration steps were an essential part of the end result. Another important factor during this research was the ability to consult different employees with different (working)backgrounds. The opinions and perceptions regarding Predictive Maintenance cq. DGAM varied substantially. To be able to combine those resulted in the ability to finding out which would be the decisive factors during the implementation of DGAM. The downside of these variation of opinions and perceptions was the necessity to fully understand the reasoning behind their opinions and perceptions. A DGAM program member would, obviously, wish that the implementation of DGAM would gain advantages for Rijkswaterstaat and could therefore have a favoured opinion about DGAM. Contrarily, regional employees could have an adverse opinion as they are primarily focused on the day-to-day business and the benefits of DGAM are, mostly, long-term centered.

12.3 Managerial Implication

It is important for Rijkswaterstaat to realize that the success of the PIP for the implementation of DGAM are not only subject to a strict 'ticking off' attitude. Using the roadmap as a 'talking board' to create awareness and improve the attitude towards DGAM proved to be an essential part of the implementation success rate. Is it therefore advised to incorporate the process, and particularly the roadmap, into the implementation meetings. This to align the objectives between the nationwide and regional teams and keep focus.

Besides the incorporation of the PIP, it is advised to follow the division made in the roadmap by first assessing the innovation fit, followed by the achievement of the pre-implementation factors and lastly, completing the set of factors. This sequence will prevent the initiation of an implementation at locations that are not prepared (i.e., some factors are still missing) or where the innovation is not suitable (i.e. there is no innovation fit). This approach prevents the waste of valuable resources and, more importantly, avoids attempting to implement an innovation at locations that are not prepared, which can lead to low commitment and resistance to the innovation.

In addition to adhering the suggested PIP, it is advisable to establish well-defined objectives and establish goals for what should be achieved with the DGAM implementations. Predictive Maintenance, and other related maintenance categories, is often used as a collective term for more data driven techniques. As a result, the implementation of Predictive Maintenance leads to a wide array of goals, many of which may not be achievable within the proposed timeframe. This could, in turn, lead to disagreements about which goals should be the primary focus. One of the important factors of a successful implementation is the commitment of the employees at the locations at which DGAM is implemented. However, this commitment is equally important for the implementation managers. Losing focus or confidence in the implementation of DGAM would not only result in a slower and less effective implementation, but could also result in less commitment at the implementation locations.

Lastly, Rijkswaterstaat is currently implementing DGAM at 'existing businesses' (i.e. at teams which are also engaged in the daily operation). According to research, this project structure is less favorable as it mostly result in unsuccessful implementation. therefore, Rijkswaterstaat is advised to investigate the possibilities to change their project team organization as denoted by O Reilly and Tushman, 2004.

12.4 Research Implications

This thesis tried to close the research gap identified in Section 3.3; it was found that there is no research performed about the decisive factors for an effective Predictive Maintenance implementation at public organizations. With the development of the Predictive Maintenance Implementation Process this gap is partially closed. The PIP is demonstrated an evaluated at Rijkswaterstaat, which is a public organization. However, more research should be performed to be able to conclude that the PIP will also be effective at other public organizations. The PIP serves as a perfect starting point for such researches.
Moreover, this thesis gave valuable insight in the difficulties associated with the implementation of an innovation at asset-intensive public organization. This insights could be used to further improve innovation implementation processes.

12.5 Future work

In this thesis a process is developed for the implementation of Predictive Maintenance at an asset-intensive public organization. As already committed in Section 12.2, the process is partly demonstrated at locations at which an implementation is performed in the past. As future work, it is suggested to use the proposed PIP at a location where an implementation is planned to start in the near future and follow this implementation process through to completion. This 'real time' monitoring of an implementation could result in valuable insight for the PIP, as it could lead to an extra validation for the relevance of the PIP or the suggestions for possible adaptions to improve the PIP.
Despite the PIP being developed for asset-intensive public organizations, it is expected to be useful as a blueprint for other similar implementation processes. The design is build upon a set of factors derived from Innovation Implementation and is therefore very usable for other fields. Using the PIP in other fields could gain valuable insight in the differences with respect to Innovation Implementation in other fields.

12.6 Reflection

The development of this thesis has been a complex process. During the formulation of the problem statement, it became evident that there were significant differences in opinions and attitudes towards DGAM/Predictive Maintenance. Segregating personal opinions and facts was therefore a major challenge, but important to perform meticulous to ensure that the solution of this thesis represents facts and not solely personal opinions. After the formulation of the problem statement and the drafting of a plan, it became clear that is was hard to reach the required employees. This was mainly due to the high workload and the gap between the nationwide and regional branches within Rijkswaterstaat, resulting in a change of plan.
An additional challenge is the increasing trend of remote work, with many employees now working from home for part of the week. This makes it harder as intern to fully incorporate in a program,

such as DGAM. The balance between keeping informed about the developments of the program and working on this thesis proved to be challenging at times.
Regardless of having written dozens of reports, they were mainly focused on very technical subjects. The subject of this thesis is less technical and required a different set of skills and competencies. However, as an engineer, it is essential to have the ability to handle both types of subjects, and this thesis provided a perfect opportunity to demonstrate such versatility.

Despite the challenges, I am confident that the developed PIP holds significant value for both the literature and Rijkswaterstaat. This demonstrates not only my possession of the requisite knowledge but also my perseverance in addressing complex issues.

Appendix A

Appendix

During the preparation of this work, I used ChatGPT to rephrase sentences in formal educational English. After using this tool/service, I thoroughly reviewed and edited the content as needed, taking full responsibility for the final outcome.

A.1 Factors Empirical Examination by Dong et al.

A.1. Implementation climate (CLIMATE)
Mean emphasis
Employees were told about the new work procedures for using the system.
Employees were told about the changes in the work procedures due to the implementation of the system.
Employees were told about the methods for using the system.
Goal emphasis Employees were told that what they needed to accomplish in using the system.
Employees were told the standards they had to meet in using the system.
Employees were told the types of outcomes that they needed to accomplish in using the system.
Task support
Employees were provided all computer technology (e.g., hardware and software) necessary to perform their tasks with the system.
Helpful books, manuals, and online documents were available when employees had problems with the new system.
Employees were given sufficient time to learn the new system before they had to use it.
A "Help Desk" was available whenever people needed help with the system.
Additional training for the new system was available on request.
Money was readily available to support activities related to the implementation of the system.
Reward emphasis
Employees were told the potential risk if they did not use the new system.
Employees perceived that the more they knew about the new system, the better their chances were of getting a job promotion.
Employees perceived that the better they were at using the new system, the more likely they were to get a bonus or raise.
Employees knew how their individual performances in using the new system was evaluated.
Employees perceived that they were going to be recognized for time and effort they spent in learning the system.

A.2. Innovation-values fit

Fit re: Quality (FITQL)

The system keeps data up-to-date for my task.
The system is missing critical data that would be very useful to my task.
The system helps me to get data that is current enough to meet my business needs.
The system maintains data I need to carry out my task.
Sufficiently detailed data are maintained by the system.
The system keeps data at an appropriate level of details so that I can complete my tasks.

Fit re: Locatibility (FITLO)

The definition of data fields relating to my task is easy to find out in the system.
The system helps me locate corporate or department data very easily.
It is easy to find out what data the system maintains on a given subject.
The system helps me understand the meaning of data very easily.

Fit re: Flexibility and cooperation (FITFC)

The system supports the repetitive and predictable work processes.
The system supports cooperation between departments.
The system assists me in developing diverse abilities and capabilities that are required to complete my job.

A.3. Skills

I am very knowledgeable about how the system works.
I understand all of the special features of the system.
I can enter data into the system whenever I need to.
I know how data in my functional department links to data in other departments.
I know which departments receive the information I input into the system.
I can interpret the data shown in the system without problems.

A.4. Absence of obstacles

Due to the lack of organizational resources (e.g., time, training), I have faced a lot of difficulties in learning to use the system.
Due to the lack of technical support, I have found the system difficult to use.
There are a lot of organizational barriers that prevent me from using the system effectively.

A.5. Incentives

I am discouraged from using the system.
I am motivated to use the system.

A.6. Commitment

Using the system is personally meaningful to me.
I enjoy discussing my experiences in using the system with my colleagues.
I really feel as if the system is my system.
I like to spend time mastering the system.

A.2 Supplementing factors

The factors for a successful implementation derived from knowledge Lost in Data: Organizational Impediments to Condition-Based Maintenance in the Process Industry by van de Kerkhof, 2020 are:

- Knowledge lack of the team
- Corrective and legally obligatory maintenance get priority (budget wise)
- Visionary managers
- Engaged managers that believe in CBM/PdM
- Internal knowledge of CBM/PdM/Data
- Internal knowledge of (new) techniques
- Standards for data collection and storage (ISO based)
- Wall of fame
- Strategic partnership with innovative maintenance contractors
- Working together is necessary (asset owner, OEM and maintenance contractor)
- Continuous collection of data takes time, but the benefits are not directly noticeable
- Data overload is an issue
- Increased variability in maintenance planning requires extra time
- It is hard to measure the impact of CBM/PdM

The factors for a successful implementation derived from Technology Acceptance Model 3 and a Research Agenda on Interventions by Venkatesh and Bala, 2008 are:

- Design can positively influence acceptance
- Design can help better decisions
- Reliable, flexible and user friendly is better
- User participation in development phase is better
- Top management support
- User should benefit from new system
- Training
- Peer support

A.3 Framework 1.0

Table A.1: Framework 1.0

A.1. Implementation climate (CLIMATE)	**II**[1]	**PdM**[2]	**IS**[3]
Mean emphasis			
Employees were told about the new work procedures for using the system.	X		
Employees were told about the changes in the work procedures due to the implementation of the system.	X		
Employees were told about the methods for using the system.	X		
Goal emphasis			
Employees were told that what they needed to accomplish in using the system.	X		
Employees were told the standards they had to meet in using the system.	X		
Employees were told the types of outcomes that they needed to accomplish in using the system.	X		
Task support			
Employees were provided all computer technology (e.g., hardware and software) necessary to perform their tasks with the system.	X		
Helpful books, manuals, and online documents were available when employees had problems with the new system.	X		
Employees were given sufficient time to learn the new system before they had to use it.	X		
A "Help Desk" was available whenever people needed help with the system.	X		X
Additional training for the new system was available on request.	X		
Money was readily available to support activities related to the implementation of the system.	X	X	
Reward emphasis			
Employees were told the potential risk if they did not use the new system.	X		
Employees perceived that the more they knew about the new system, the better their chances were of getting a job promotion.	X		
Employees perceived that the better they were at using the new system, the more likely they were to get a bonus or raise.	X		
Employees knew how their individual performances in using the new system was evaluated.	X		
Employees perceived that they were going to be recognized for time and effort they spent in learning the system.	X		
Design			
Keep in mind that the acceptance of DGAM can be positively influenced by the design			X
Keep in mind that the design can influence decision making			X
A reliable, flexible and user friendly design is better			X
A.2. Innovation-values fit			
Fit-Quality (FITQL)			
The system keeps data up-to-date for my task.	X		
The system is missing critical data that would be very useful to my task.	X		
The system helps me to get data that is current enough to meet my business needs.	X		
The system maintains data I need to carry out my task.	X		
Sufficiently detailed data are maintained by the system.	X		
The system keeps data at an appropriate level of details so that I can complete my tasks.	X		
Fit-Locatibility (FITLO)			
The definition of data fields relating to my task is easy to find out in the system.	X	X	
The system helps me locate corporate or department data very easily.	X	X	
It is easy to find out what data the system maintains on a given subject.	X		
The system helps me understand the meaning of data very easily.	X		
Fit-Flexibility and cooperation (FITFC)			
The system supports the repetitive and predictable work processes.	X	X	
The system supports cooperation between departments.	X		
The system assists me in developing diverse abilities and capabilities that are required to complete my job.	X		
A.3. Skills			
I am very knowledgeable about how the system works.	X	X	
I understand all of the special features of the system.	X		
I can enter data into the system whenever I need to.	X		
I know how data in my functional department links to data in other departments.	X		
I know which departments receive the information I input into the system.	X		
I can interpret the data shown in the system without problems.	X		
A.4. Absence of obstacles			
Due to the lack of organizational resources (e.g., time, training), I have faced a lot of difficulties in learning to use the system.	X		X
Due to the lack of technical support, I have found the system difficult to use.	X		
There are a lot of organizational barriers that prevent me from using the system effectively.	X		
A.5. Incentives			
I am discouraged from using the system.	X		X
I am motivated to use the system.	X		
A.6. Commitment			
Using the system is personally meaningful to me.	X		
I enjoy discussing my experiences in using the system with my colleagues.	X		
I really feel as if the system is my system.	X		
I like to spend time mastering the system.	X	X	
A7. Benefits			
Keep in mind that it is hard to measure the benefits of DGAM		X	
Keep in mind that data collecting takes time and resources without having direct positive influence		X	
Make a wall of fame with all the benefits that were a result of DGAM		X	

[1]: Innovation Implementation. This set of factors are derived from Testing Klein and Sorra's innovation implementation model: An empirical examination by Dong et al., 2008. The categories (mean emphasis, goal emphasis etc.) are derived from the Determinants and Consequences of Implementation Effectiveness Model by Klein and Sorra, 1996. Dong et al. gave meaning to these categories by defining a set of definitions for each category.
[2]: Predictive Maintenance. The factors are derived from Knowledge Lost in Data: Organizational Impediments to Condition- Based Maintenance in the Process Industry by van de Kerkhof, 2020.
[3]: Information Systems. The factors are derived from Technology Acceptance Model 3 and a Research Agenda on Interventions (TAM3) by Venkatesh and Bala, 2008.

A.4 Framework 2.0

Table A.2: Framework 2.0

A1: Implementatie klimaat
Mededeling
De Asset Manager wordt verteld hoe de nieuwe procedures van DGAM werken
De Asset Manager wordt verteld hoe deze nieuwe procedures in praktijk eruit gaan zien
De markt wordt geïnformeerd over de implementatie van DGAM
Doelstelling
De Asset Manager wordt verteld hoe hij/zij DGAM moet uitvoeren. Bijv: Storingen zien aankomen, juiste gebruik van data
De Asset Manager wordt verteld aan welke eisen hij/zij moet voldoen. Bijv: Standaard naamgevingsconventie
De Asset Manager wordt verteld wat hij/zij moet opleveren. Bijv: Rapportages over inspecties
Ondersteuning
Het programmateam zorgt ervoor dat alle benodigde technologie aanwezig is zodat de AM'er DGAM kan uitvoeren. Bijv: Er is een dashboard opgeleverd. De benodigde technologie is o.b.v. de behoefte van de Asset Manager
Het programmateam zorgt ervoor dat er handleidingen en naslagwerk beschikbaar is.
De Asset Manager krijgt voldoende tijd om te wennen aan DGAM. Bijv: Door het toekennen van extra (tijdelijke) hulp.
Het programmateam zorgt ervoor dat er een 'helpdesk' beschikbaar is voor Asset Mangers met vragen over DGAM.
Het programmateam zorgt ervoor dat, indien nodig, er extra training beschikbaar is voor de Asset Manager
Binnen RWS zijn er voldoende resources (budget en mensen) vrijgemaakt voor de implementatie van DGAM.
Beloning
Asset Manager krijgt waardering voor gebruik van DGAM. Bijv: door het benoemen van behaalde prestaties via een nieuwsbrief.
Ontwerp
Tijdens het ontwerpen van (bijvoorbeeld) een dashboard wordt er rekening gehouden met de wensen van de gebruiker.
Tijdens het ontwerpen van (bijvoorbeeld) een dashboard wordt er rekening gehouden met het feit dat ontwerpkeuzes invloed hebben op de gebruiksvriendelijkheid.
Tijdens het ontwerpen van (bijvoorbeeld) een dashboard wordt er rekening gehouden met de flexibilieit van het dashboard, zodat deze makkelijk aangepast kan worden op (veranderende) wensen van de gebruiker.
A2. Innovatie fit
Data kwaliteit
Het programmateam cq. RWS zorgt ervoor dat de data 'Actueel Beschikbaar Compleet' is.
Het programmateam cq. RWS zorgt ervoor dat, op basis van de informatiebehoefte, de data beschikbaar is die nodig is voor de AM'er om DGAM uit te voeren.
Asset Manager krijgt door (bijna realtime) data beter inzicht in zijn behoefte.
Informatie vindbaarheid
De ruwe data is goed geordend en er is een duidelijke dataconventie
De informatie is goed geordend en is makkelijk doorzoekbaar voor de AM'er
De informatie is duidelijk gevisualiseerd. Bijv: Door het gebruik van duidelijke diagrammen en grafieken
Flexibiliteit en medewerking
Het programmateam cq. RWS ondersteunt DGAM
DGAM ondersteund de coöperatie tussen de verschillende stakeholders uit de AM keten (Landelijk, Regio en Markt)
DGAM zorgt ervoor dat de AM'er beter zijn werk kan doen (lees: Beter inzicht).
A3. Vaardigheden
De Asset Manager heeft de vaardigheden om DGAM uit te voeren.
De Asset Manager heeft de vaardigheden en mogelijkheden om ervoor te zorgen dat de data 'Actueel Beschikbaar Compleet' is.
De verschillende gebruikers (bijv: Asset Manager en Markt) zijn gekoppeld en de data wordt gedeeld.
Het is duidelijk wie welke rol heeft en wie welke informatie nodig heeft/gebruikt.
De Asset Manager heeft de vaardigheden om grafieken te lezen, makkelijk informatie te vinden in dashboards etc.
A4. Afwezigheid obstakels
Het programmateam zorgt ervoor dat er voldoende organisatorische middelen zijn (tijd, training etc.) om de AM'er te ondersteunen.
Het programmateam zorgt ervoor dat de middelen beschikbaar zijn (i.e. de data/dashboards zijn altijd te bereiken).
De Asset Manager heeft voldoende stuurmaatregelen om het proces te beïnvloeden die nodig zijn om DGAM uit te voeren. Bijv: Het aanpassen van onderhoudsplanningen.
A5. Stimulans
De Asset Manager ziet voordelen van DGAM.
De Asset Manager vindt DGAM zinvol en is gemotiveerd om DGAM uit te voeren.
A6. Commitment
De Asset Manager vindt DGAM persoonlijk waardevol.
De Asset Manager geniet van het delen van zijn ervaringen omtrent DGAM (i.e. hij is trots op DGAM).
De Asset Manager heeft het gevoel dat hij onderdeel is van DGAM (cq. Eigenaarschap)
De Asset Manager maakt tijd vrij om zich verder te verdiepen in DGAM.
A7. Voordelen
Het programmateam houdt er rekening mee dat het de voordelen van DGAM moeilijk te meten zijn. Bijvoorbeeld door niet te sturen op harde eisen.
Het programmateam houdt er rekening mee dat het verzamelen van data middelen (o.a. tijd en geld) kost, zonder dat deze data directe positieve invloed heeft.
Het programmateam houdt een 'wall of fame' bij waar alle successen van DGAM zichtbaar zijn.

A.5 Framework 3.0

Table A.3: Framework Version 3.0

A1: Implementatie klimaat
Introductie
De Asset Manager wordt uitgelegd wat DGAM kan verbeteren in de Asset management proces (afhankelijk van het niveau van de AM'er).
Samen met de Asset Manager wordt bekeken welke processen veranderd moeten worden.
De markt wordt geïnformeerd over de implementatie van DGAM.
Doelstelling
De Asset Manager wordt uitgelegd hoe hij/zij DGAM kan uitvoeren. Bijv: Storingen zien aankomen, juiste gebruik van data etc.
De Asset Manager wordt meegenomen in de bestaande standaards. Bijv: Standaard naamgevingsconventie.
Samen met de Asset Manager wordt bekeken waar DGAM van toevoegde waarde kan zijn voor het proces.
Ondersteuning
Het programmateam zorgt ervoor dat alle benodigde technologie aanwezig is zodat de AM'er DGAM kan uitvoeren. Bijv: Er is een dashboard opgeleverd. De benodigde technologie is o.b.v. de behoefte van de Asset Manager.
Het programmateam zorgt ervoor dat er handleidingen en naslagwerk beschikbaar is.
De Asset Manager krijgt voldoende tijd om te wennen aan DGAM. Bijv: Door het toekennen van extra (tijdelijke) hulp.
Het programmateam zorgt ervoor dat er een 'helpdesk' beschikbaar is voor Asset Mangers met vragen over DGAM.
Het programmateam zorgt ervoor dat, indien nodig, er extra training beschikbaar is voor de Asset Manager.
Binnen RWS zijn er voldoende resources (budget en mensen) vrijgemaakt voor de implementatie van DGAM.
Beloning
Asset Manager krijgt waardering voor gebruik van DGAM. Bijv: door het benoemen van behaalde prestaties via een nieuwsbrief.
Ontwerp
Tijdens het ontwerpen van (bijvoorbeeld) een dashboard wordt er rekening gehouden met de wensen van de gebruiker.
Tijdens het ontwerpen van (bijvoorbeeld) een dashboard wordt er rekening gehouden met het feit dat ontwerpkeuzes invloed hebben op de gebruiksvriendelijkheid.
Tijdens het ontwerpen van (bijvoorbeeld) een dashboard wordt er rekening gehouden met de flexibilieit van het dashboard, zodat deze makkelijk aangepast kan worden op (veranderende) wensen van de gebruiker.
A2. Innovatie fit
Basis op orde
Er zijn instandshoudingsplannen beschikbaar.
Er is inzicht in relevante onderhoudsgegevens van het kunstwerk, bijvoorbeeld faalmechanismen.
Er is inzicht in welke data er beschikbaar is en voor wie dit toegankelijk is.
Data kwaliteit
Het programmateam cq. RWS zorgt ervoor dat de data 'Actueel Beschikbaar Compleet' is.
Het programmateam cq. RWS zorgt ervoor dat, op basis van de informatiebehoefte, de data beschikbaar is die nodig is voor de AM'er om DGAM uit te voeren.
Asset Manager krijgt door (bijna realtime) data beter inzicht in zijn behoefte.
Informatie vindbaarheid
De ruwe data is goed geordend en er is een duidelijke dataconventie
De informatie is goed geordend en is makkelijk doorzoekbaar voor de AM'er
De informatie is duidelijk gevisualiseerd. Bijv: Door het gebruik van duidelijke diagrammen en grafieken
Flexibiliteit en medewerking
Het programmateam cq. RWS ondersteunt DGAM
DGAM ondersteund de coöperatie tussen de verschillende stakeholders uit de AM keten (Landelijk, Regio en Markt)
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De verschillende gebruikers (bijv: Asset Manager en Markt) zijn gekoppeld en de data wordt gedeeld.
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Het programmateam houdt er rekening mee dat het verzamelen van data middelen (o.a. tijd en geld) kost, zonder dat deze data directe positieve invloed heeft.
Het programmateam houdt een 'wall of fame' bij waar alle successen van DGAM zichtbaar zijn.

A.6 Enlarged version roadmap

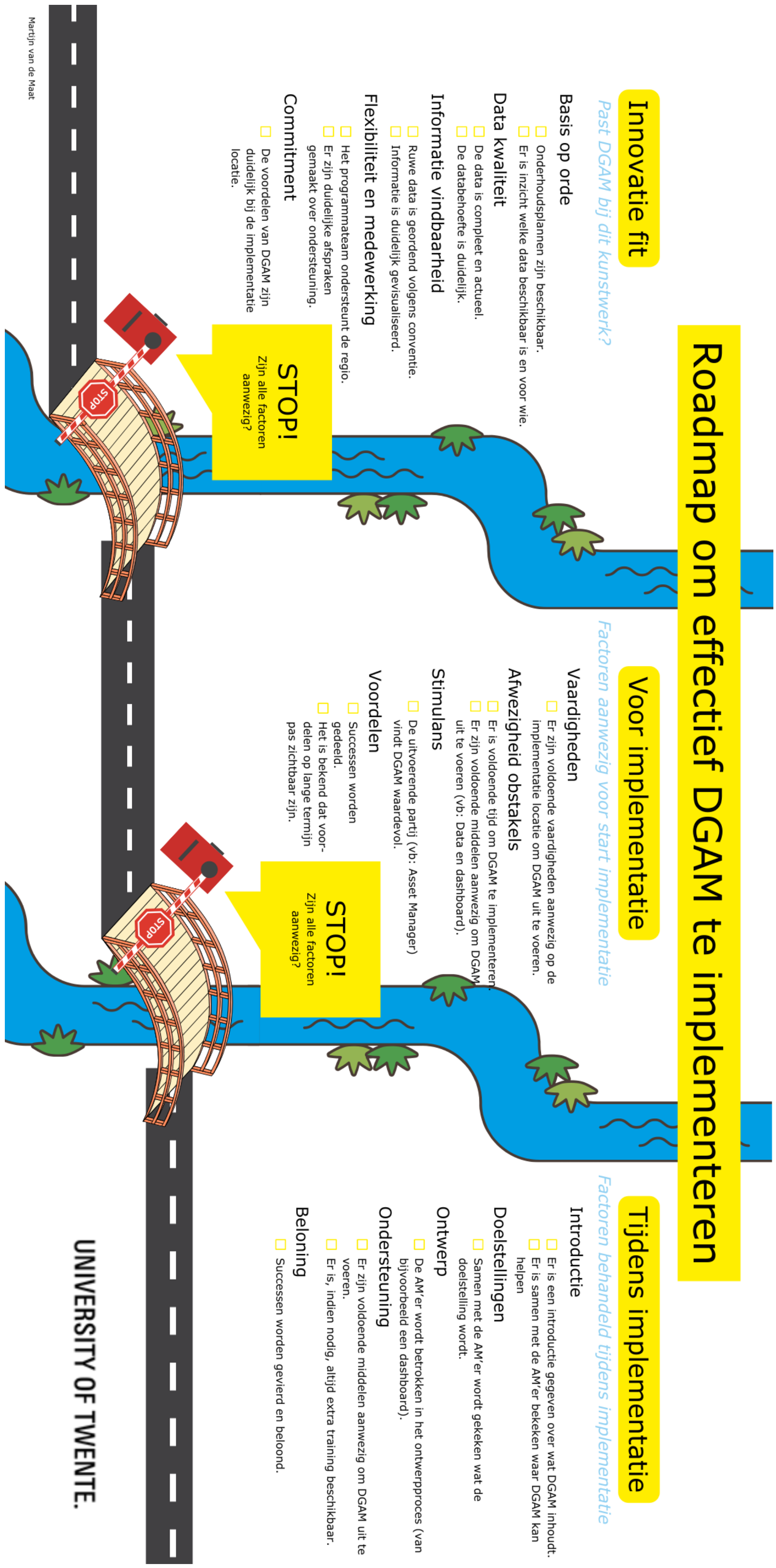

Figure A.1: Designed PIP supporting roadmap - enlarged version

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