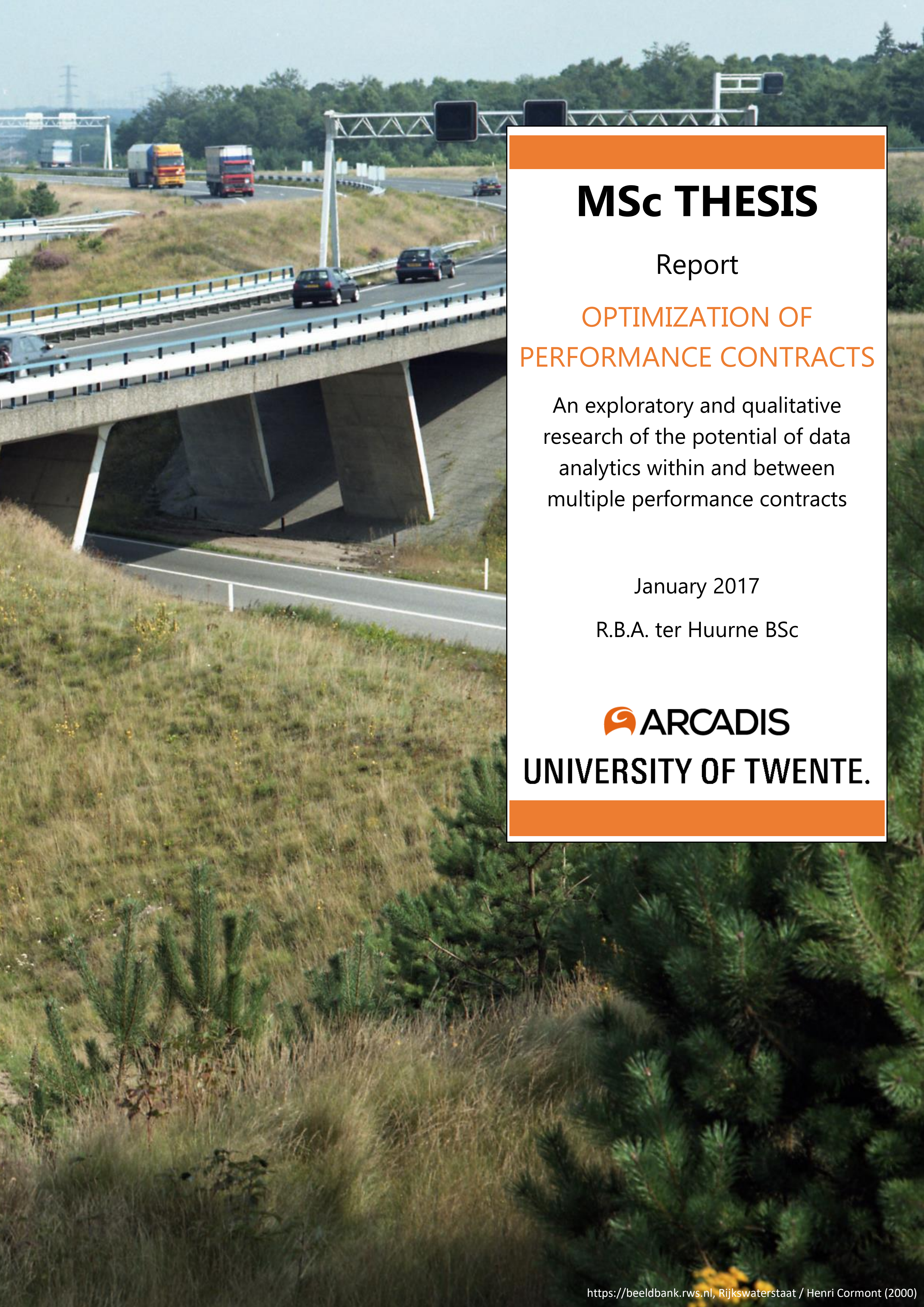

MSc THESIS

Report

OPTIMIZATION OF PERFORMANCE CONTRACTS

An exploratory and qualitative research of the potential of data analytics within and between multiple performance contracts

January 2017

R.B.A. ter Huurne BSc

ARCADIS

UNIVERSITY OF TWENTE.

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OPTIMIZATION OF PERFORMANCE CONTRACTS

By:

R.B.A. (Ramon) ter Huurne BSc.

A Master Thesis presented to the faculty of Engineering Technology of the University of Twente to apply for the title of Master of Science in Construction Management and Engineering.

Enschede, January 26, 2017

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LIST OF ABBREVIATIONS

Abbreviation:	Meaning:
BI:	Business Intelligence
BIM:	Building Information Modeling
BVP:	Best Value Procurement
DISK:	Data Informatie Systeem Kunstwerken (Data Information System Civil Structures)
DTB:	Digitaal Topografisch Bestand (Digital Togographical File)
FMECA:	Failure Mode, Effect and Criticality Analysis
GIS:	Geographical Information System
ICT:	Information and communication technology
IDS:	Information Document System
I&V proposal:	Investerings- en verbeter (investment and improvement) proposal
Kerngis:	Kern Geographic Information System
KPI:	Key Performance Indicator
LCC:	Life-Cycle Costing
MEAT	Most Economically Advantageous Tender
OMS:	Onderhoud Management Systeem (Maintenance Management System)
OTL:	Object type library
RAMS:	Reliability, Availability, Maintainability, Safety
RAMSSHEEP:	Reliability, Availability, Maintainability, Safety, Security, Health, Economy, Environment, Political
ROI:	Return on Investment
RUPS:	Rijkswaterstaat Uniforme Programmering Systeem
RWS:	Rijkswaterstaat
SE:	Systems Engineering
SMART:	Specific, Measurable, Achievable, Relevant and Time-bound
TM-planning:	Technical management planning

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PREFACE

In front of you lies an exploratory and qualitative research of the potential of data analytics within and between multiple performance contracts (the appendices are provided in a separate report). The research serves two purposes: on the one hand answering the research questions initiated by Arcadis and on the other hand the closure of my Master Construction Management and Engineering at the University of Twente.

I would like to make use of the opportunity here to thank people for their help during my research. At first my supervisors A. M. Adriaanse, A. Hartmann, F. J. Broersma and F. van Ruth, for their input and constructive feedback during the research. I also want to thank the interviewees for their input and the other colleagues at Arcadis Amersfoort for their time and support.

Moreover, I want to thank my parents, family, friends and my girlfriend for support and distraction during the period of my research. In special I want to thank my parents and girlfriend. I want to thank my parents for giving me the opportunity to follow this Master in the first place. I want to thank my girlfriend for being a listening ear and supporting me throughout the whole process of this final period of my Master.

I wish you a pleasant reading.

Ramon ter Huurne

Enschede, January 26, 2017

SUMMARY

Within the field of operations and maintenance, performance contracts are becoming more and more popular (Deng, Zhang, Cui, & Jiang, 2013; Sols, Nowicki, & Verma, 2007). A performance contract focuses on the maintenance of an object. Within a performance contract, (performance) criteria are prescribed which have to be met during the contract period. This contract therefore does not focus on what maintenance should be done (as in the traditional way), but about what results (in terms of performance) should be achieved (Gruneberg, Hughes, & Ancell, 2007). Reason of this increasing popularity of performance contracts is the increasing awareness of the high costs of the operations and maintenance phase, which can even add up to 60% of the total costs of objects over their complete lifespan (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013). Performance contracts perform more efficiently and effectively compared to traditional contracts, because these establish an environment in which contractors can fully use their expertise.

Three developments have been going on influencing performance contracting. First one is the adoption of Best Value Procurement (BVP) by many agencies and governments. As a result of this shift towards BVP, contractors no longer can focus only on having the lowest bid, but also need to incorporate factors such as quality, past performance, technical and managerial merit, financial health and durability (Gransberg & Elicott, 1997). More pragmatically, the factor durability may address energy consumption or CO_2 emissions within the period of the contract. Past performance may address previous performance contracts, whereas technical and managerial merit can involve the capability of developing an effective and efficient maintenance regime. A second development is the requirement of applying Building Information Modeling (BIM) more often within performance contracts and the increasing adoption of BIM by organizations themselves. BIM is a method often used for the integration and coordination of information and data throughout a set of policies, processes and technologies. In other words, BIM can facilitate a shared knowledge resource. BIM is more often used as a consequence of the increasing complexity of projects (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013). A third development is the exponential growth of data due to factors such as cloud computing, increased mobile and electronic communication and the decreased costs relating to compute and store data (O'Donovan, Leahy, Bruton, & O'Sullivan, 2015). This explosion is also called 'Big Data'. Big data is becoming crucial for companies to outperform their peers, and in most industries already data-driven strategies to innovate, compete and capture value are seen.

The three developments together have led to a bigger emphasis on the analytics of data. BVP asks for additional factors to be made clear by contractors, such as past performance and technical and managerial merit. Contracts need to be able to transform their data into useful information they can use in their tender addressing the BVP factors and increase their provability on these. To do so, data however needs to be readily available and well managed, which can be facilitated by BIM. Here the implementation of BIM thus directly supports data analytics. Even more, having integrated and coordinated information between multiple contracts, may facilitate cross-project analytics, creating more data to analyze possibly retrieving extra insights and an increase of the reliability of the outcomes. Integrated and coordinated data and information between multiple project facilitated by BIM therefore also enables extra cross-project analytics opportunities. In this research, BIM therefore not only counted as a future requirement organizations should take into account, but also as an important driver for BI, facilitating the shared knowledge resource required to perform cross-project analytics.

The ability to capture, access, understand and convert data into active information in order to improve the business is called Business Intelligence (BI) (Azvine, Cui, Nauck, & Majeed, 2006). What is seen however, is that despite having more data and the existing need of proving their capabilities regarding the BVP contracts, without having a proper data management system and analytics capabilities organizations are often not able to leverage the advantages the data has to offer (Gandomi & Haider, 2015). They lack the BI maturity and understanding required to do so. Furthermore, the construction industry is characterized by a lot of fragmentation (Adriaanse, 2014), which is also seen within performance contracts (Deng, Zhang, Cui, & Jiang, 2013; Sols, Nowicki, & Verma, 2007), indicating a lack of integrated and coordinated information.

As a result of the lacking BI maturity and understanding within and between performance contracts, it remains unclear for organizations how to leverage the advantages of the available data in order to adapt to the upcoming BVP and BIM contracts and make the maintenance planning process more efficient and effective. Within this research, this problem has been elaborated by answering the following research question:

How should organizations fill in the gaps within their Business Intelligence capabilities to increase their provability concerning future BVP contracts and leverage the potential of the data generated within and between performance contracts?

The research started with analyzing how the BI and BIM capabilities can be measured based on an extensive literature review. A theoretical framework was developed involving an integrated BI maturity and BIM level matrix. The BI maturity was based on the maturity levels of Williams & Thomann (2003) and Puget (2015), which are 'descriptive analytics', 'diagnostic analytics', 'predictive analytics' and 'prescriptive analytics'. Necessary capabilities for BI were found to be a scalable and extensible information foundation combined with a proper data warehousing configuration, to have sufficient analytics capabilities involving query and reporting, data mining, data visualization and to have a strict and uniform registration of data (facilitating topical, reliable and complete data). The BIM level was based on the maturity levels of Adriaanse (2014), which are 'mono-disciplinary BIM', 'multi-disciplinary BIM' and 'multi-project BIM', focusing on the organizational scale of application addressing on which level shared knowledge resources are found. The necessary capabilities for BIM were found to be an integrated and coordinated infrastructure, a uniform way of working and transparent and accessible data for all involved parties. To be able to map performance contracts within this matrix, an information system perspective was used, involving the components (1) hardware and software, (2) activities and processes and (3) data (Bourgeous, 2014).

To map the three components of the information system of performance contracts within this matrix and identify the current gaps within the BI, an explorative and qualitative case study has been performed. Four performance contracts were analyzed at Arcadis, a global design, engineering and managing consultancy company. At Arcadis, BVP and BIM is asked by clients in future performance contracts. Rijkswaterstaat (executive agency of the Ministry of Infrastructure and the Environment), the client within the analyzed contracts within this research, will already ask for the use of BIM in their upcoming performance contracts. Furthermore, Arcadis itself is an innovative company seeing potential in using data analytics within their contracts. The case study existed of analysis on case documents, ten semi-structured expert interviews and a validation and evaluation workshop involving four experts. For the cases it has been determined what their BI maturity and BIM level is for each of the components, reflecting on the defined capabilities within the theoretical framework. Thereafter, the future opportunities of the contracts addressing the BVP factors were mapped within this matrix, enabling a comparison of the required BI maturity and BIM level of these opportunities with the existing ones seen defining the gaps to be filled.

The analysis showed that the **hardware and software** possess descriptive analytics as a BI maturity together with a multi-disciplinary BIM level. An equal and common framework was seen in every contract, though with a shattered configuration of multiple databases around it. Furthermore, the hardware and software enabled veracity in the data, especially in the central data management system used. Visualization techniques were not seen. How future proof the central data management system is, in terms of dealing with the higher volume, velocity and variety within the data is also questionable. Within single projects though, data was made relatively transparent and accessible by the use of a central data management system accessible for all involved parties. The main systems used were furthermore based on the same decomposition. However, because of having separate workspaces for each single project, the collaboration and integration cross-project was very limited.

The **activities and processes** possess descriptive analytics as a BI maturity level together with a multi-disciplinary BIM level, except for one activity being on the BI maturity of predictive analytics and multi-disciplinary BIM level. The analyses mainly focus on that what has happened. Most concrete problems found were the lack of uniformity in reporting and processing of data, and lack of sharing of trends, developments and optimization between contracts. Furthermore, several BI capabilities were lacking such as simulations, visualization techniques and analysis on unstructured and semi-structured data (except for some video analytics). Also activities were not picked up collaboratively cross-project wise, and despite the fact that the same activities and processes were performed in the multiple projects, differences did exist due to individual preferences and different portfolio managers decreasing the uniform way of working.

The **data** possess diagnostic analytics as a BI maturity level together with a multi-disciplinary BIM level, except for the data within Atrium (faults register, defects register, condition scores, surveillance and inspection data), the attribute data and the GIS spatial data who possess descriptive analytics together with a multi-disciplinary BIM level. Though the data in general is perceived of good quality, most concrete problems are the poor registration of the data, resulting in a lack of topical, reliable and complete data. Area and spatial data is often not complete or missing, the GIS (area) data is not topical and a lacking data management mindset was seen at the contractor (Van Doorn). Veracity in the data within the maintenance management system used is furthermore allowed by the hardware and software. Data overall lacks the strictness and uniformness it needs for proper data analytics. Also concerning cross-project collaboration, no data exchange is seen, limiting the cross-project learning opportunities.

Concerning the future BVP and BIM contracts, seven opportunities were defined that will increase the chance of organizations to be awarded of the contract during tender phases. These seven opportunities address the several factors BVP addresses, being costs, quality, technical and managerial merit, past performance and durability. Financial health was not covered within any of the opportunities, though this factor more relates to the management of a(n) organization/department itself, then to the performance contracts. Within the cases, the first five opportunities addressed are applicable to single contracts. First one involves the measuring of the overall quality of the area within the performance contracts, by analyzing the number of faults and defects and the RAMSSHEEP scores. Second, there is a great opportunity in adding the costs within the performance contracts, to measure what the costs are of the chosen maintenance measures and maintenance regime. A third opportunity involves measuring the effectivity of the maintenance regime based on how the chosen maintenance regime does succeed in maintaining the functionalities within the area. Fourth opportunity is the determination of error prone objects and sections within the area, through analysis of the faults and defects coupled to GIS locations and a uniform decomposition (NEN2767 in this research). Fifth, another opportunity is to measure the durability of the maintenance regime. The sixth and seventh one involve cross-project opportunities. Sixth opportunity is cross-project combining datasets for analysis, combining the datasets of the multiple contracts to enlarge the dataset on which analyses are done, increasing the reliability of the outcomes. Most important datasets that have the potential to be combined turned out to be the faults register, the defects register and the degradation behavior data of objects. Seventh opportunity is cross-project benchmarking, showing most potential in comparing the area's quality, the effectivity, costs and durability of the maintenance regime, the error prone sections and the effectivity of optimizations made.

The seven opportunities were prioritized during a held workshop among three employees of Arcadis and one of Van Doorn. This prioritization was based on the added value of the opportunity. Feasibility and costs of the opportunities were not analyzed within this research, making it hard to prioritize on these. Based on the prioritization, most important was considered the measuring of the cost of the maintenance regime. In none of the contracts, costs were registered, leaving no insights in how costs actually are spread over the contract. In order to do so, the costs of the maintenance measures should be put in the data management systems. Knowing beforehand what the costs of a chosen maintenance regime are, requires prescriptive analytics, though it can be established in a multi-disciplinary BIM environment. At the second place the cross-project opportunities were placed, addressing cross-project combining datasets for analysis and cross-project benchmarking. Here a multi-project BIM level is required, not seen in any of the contracts, especially in order to combine the datasets. A shared knowledge resource is required on the level of multi-project. The remaining opportunities were considered of equal importance, giving the choice which to implement first to the organizations themselves.

Comparing the existing BI maturities and BIM level to the required ones by the opportunities leaves a lot of room for improvements. The focus initially should be on increasing the BI capabilities to prescriptive analytics, and thereafter to increase the BIM level to multi-project BIM. This will make it possible to leverage all opportunities, having acquired the highest BI maturity level and BIM level. Improving the BI maturity level towards prescriptive analytics requires strict and uniform data facilitating topical, reliable and complete data, though organizations should keep in mind that a data management mindset might be lacking among their employees, as was seen at the contractor Van Doorn within the analyzed cases. The hardware and software should have a scalable and extensible information foundation as well as a proper data warehousing configuration that supports the increasing volume, velocity and variety of the data, though it should decrease the veracity within the data. The activities and processes need to focus on increasing the data mining techniques towards on what should happen, including data visualization, uniform query and reporting and analysis on unstructured and semi-structured data. To improve the BIM level towards multi-project BIM, the focus should be on creating an integrated and coordinated infrastructure, where it is important to have at least a shared workspace where collaboration and exchange of data is stimulated concerning the hardware and software. For the activities and processes, it is of importance to create uniform way of working cross-project, in which collaboration is stimulated. The data at last should be transparent and accessible between the multiple projects.

These outcomes of the research thus involve steps to be taken within the analyze cases concerning the improvement of their BI maturity and BIM level regarding the upcoming BVP and BIM contracts. Within the held workshop, where also the opportunities were prioritized, the steps were presented in a framework. This framework was evaluated and validated during this workshop on completeness and practical applicability. Together with the prioritization of the opportunities, the concretizations from the workshop resulted in the final framework, as presented within this research.

A critical footnote though is that within the research, only four contracts at one organization, being Arcadis were analyzed. This means that the findings are not likely to be representative for the whole industry. However, it is also not likely that within the field of performance contracts, companies have their BI maturity and BIM level a lot better developed than at Arcadis, the biggest consultancy in the Netherlands, known worldwide, and above all an innovative player in their field. Therefore, it is assumable that other consultancies in the Netherlands have BI maturities and BIM levels comparable to those of Arcadis, though likely to be even lower. The recommendations and steps within this research therefore might prove beneficial to other consultancies as well. The many opportunities within this research do illustrate the impact BI and BIM can have on performance contracts, especially regarding future BVP contracts.

Another critical footnote is that the opportunities developed within this research might not cover all of the possible opportunities. Questions also remain on how the actual modeling of the data should find place if the BI maturities and BIM level are achieved. This research did not focus on the statistical models that should be used for the data analytics itself. Furthermore, the information system chosen within this research did not involve the component ‘people’. Though not being part of the scope of the research, the human behavior can influence the success of data analytics greatly, by for example a lack of understanding or personal preferences. At last, no quantitative measures were provided concerning costs and benefits of adopting a higher BI maturity and BIM level. All of the above provides input for follow-up studies, from which the leads of this research could be used as input.

This research as concluding has provided insights in how performance contracts score in terms of BI maturity and BIM level, and how this does compare with the required BI maturity and BIM level of the opportunities performance contracts have regarding future BVP and BIM contracts. The research provided insights in what gaps existed between this existing BI maturity and BIM level and the required ones for the opportunities to be realized. Even though the research has an explorative character, and was focused on a single organization, it is the assumption that within the industry, many organizations are characterized by equal or even lower BI maturities and BIM levels, making the research also very relevant to them. Most important lesson this research can learn, is that in the field of performance contracting and data analytics, there is no time to lay back, as many opportunities lie ahead ready to be realized.

INTRODUCTION

Chapter 1 **Introduction** **Page 1**

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1. INTRODUCTION

Within this chapter, the introduction of the research is elaborated. This chapter starts with the motivation in paragraph 1.1. Paragraph 1.2 and 1.3 then discuss the research problem and research objective. The research questions are elaborated in paragraph 1.4 followed by the research cases and scope in paragraph 1.5. In paragraph 1.6 the structure of this report is provided. Paragraph 1.7 discusses the research methodology and at last in paragraph 1.8 the research quality is elaborated.

1.1. Motivation

Performance contracts have been emerging lately and data analytics becomes more and more desirable within these type of contracts, being triggered by several developments.

1.1.1. Performance contracts

We become aware of the fact that the maintenance of a constructed work often involves more cost than the construction of it. According to Eadie et al. (2013) the maintenance phase can even add up to 60% of the total costs of objects over their whole lifespan. This awareness of costs has been one of the triggers for performance contracts to emerge. A performance contract focuses on the maintenance of an object. In a performance contract certain (performance) criteria are prescribed concerning the objects, which have to be met during the contract period. A performance contract does not focus on what maintenance should be done (traditional contracts), but about what results should be achieved (Gruneberg, Hughes, & Ancell, 2007). A performance contract follows after completion of the construction phase.

Performance contracts have several advantages over traditional maintenance contracts, such as a more uniform level of quality of the maintenance and a higher level of efficiency and coordination. By providing freedom in the maintenance design and process the contractor is able to come up with its own ideas to make his maintenance process more efficient and effective (Straub, 2009). According to Humphries (2003), the contractor can because of his broader and more efficient knowledge about maintenance, better tune the final result to the required predefined performance demands, increasing the overall quality and decreasing the costs. Performance contracts establish an environment in which the contractors can fully use their expertise.

With these type of contracts, it is important that the prescribed criteria can be objectively measured or controlled (Pianoo, 2016; Joostdevree, 2016). Often models such as RAMSSHEEP (reliability, availability, maintainability, safety, security, health, economy, environment and political) are used as a basis to control whether or not the object does still function properly by scoring the aspects (Movares, 2013). During performance contracts, communication between the client and the contractor is a vital aspect. The contractor should be able to prove he delivers the right performance. The client on the other hand should provide the contractor of the right information and data about the maintainable object in the first place (Straub & Van Mossel, 2007).

Performance contracts become more and more popular nowadays around the world. They are already seen in the commercial shipping, the aviation industry, the oil industry, the IT Sector, the Military, public transport, healthcare, energy companies and of course the construction industry (Deng, Zhang, Cui, & Jiang, 2013; Sols, Nowicki, & Verma, 2007).

1.1.2. Best Value Procurement

Many agencies and governments start with adopting Best Value Procurement (BVP). The objective of the transition from the old practice of lowest bid procurement to BVP is to increase the value that is added for each extra dollar or other monetary unit. It aims to enhance the long-term performance through selection of the contractor with the most advantageous offer (Abdelrahman, Zayed, & Elyamany, 2008). Price and other selection factors are considered in the selection of the offer. These other factors can vary but often include past performance, technical and managerial merit, financial health and durability (Gransberg & Elicott, 1997).

As a result of this shift towards BVP, contractors no longer can focus only on having the lowest bid. The low bid system did encourage contractors to implement cost-cutting measures instead of quality enhancing ones. This made it therefore less likely that the contract was eventually awarded to the best performing contractor with the higher quality (Scott, Molenaar, & Smith, 2006). BVP stimulates contractors to focus on more than costs, by forcing them to think of and incorporate other factors such as those mentioned before.

1.1.3. Building Information Modeling

Besides BVP, Building Information Modeling (BIM) is also more often required in future performance contracts by agencies such as Rijkswaterstaat (RWS), the executive agency of the Ministry of Infrastructure and the Environment in the Netherlands, for example. Organizations themselves however also start with adaptation of BIM. BIM is often used for the integration and coordination of information and data throughout a set of policies, processes and technologies. In other words, BIM can facilitate a shared knowledge resource. Many definitions of BIM exist, but within this research the following definition of BIM by the ISO Standard 29481 (ISO Standard, 2010) is followed, being provided below:

> *"A shared digital representation of physical and functional characteristics of any built object, which forms a reliable basis for decisions."*

By using BIM, the involved parties achieve better insights in the project as information becomes more transparent and better accessible (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). The use of BIM has been rapidly increasing as a consequence of the increasing complexity of projects (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013).

1.1.4. Maintenance and the use of data

Data has become a common thing in today's world. The world is inundated with data every minute of every day, growing in size like never before. Everywhere we look, some sort of data is generated that can be used for a certain purpose. It is estimated that by the year of 2020, yearly 44 zettabytes (a zettabyte is a billion terabyte) of data is generated, almost four times as much as now in 2016 (11 zettabytes) (Hagen, et al., 2013). Contributing factors to this exponential growth of data are both technological as economical, including the emergence of cloud computing, increased mobile and electronic communication and the decreased costs relating to compute and store data (O'Donovan, Leahy, Bruton, & O'Sullivan, 2015). This explosion of data has resulted in what is called 'Big Data'.

Big data is becoming crucial for leading companies to outperform their peers (Rajteric, 2010). In most industries, data-driven strategies to innovate, compete and capture value are already seen. Data from sensors is something very often used, to determine how products/objects/assets are used or perform actually in the real world (TechAmerica Foundation's Federal Big Data Commission, 2012). Such information creates new insights on the particular project/object/asset, supporting the decision-making processes. As a result of big data, data has become more accessible and ubiquitous (Lee, Edzel, & Kao, 2013).

Concerning maintenance, there is a huge increase of real-time data through sensors and mobile data, such as insight in the functioning of the lightning (light output) and in the degradation of the asphalt, providing a solid ground for the planning of the maintenance, besides the statistical data from the past (Gandomi & Haider, 2015). In theory, big data can leverage the following advantages concerning maintenance and performance contracts (Quang, Sachin, & Girish, 2014; Gandomi & Haider, 2015; Van Dongen, 2014; McGuire, Manyika, & Chui, 2012):

- Unlock significant value by making information transparent improving decision-making;
- Being able to better predict and plan maintenance activities;
- A more efficient maintenance process with less downtime;
- Saving costs;
- Increasing the overall quality of the maintainable area;
- Increasing client satisfaction.

1.1.5. A bigger emphasis on data analytics

BVP asks contractors not only to deliver a higher quality, but also asks them to prove they are capable of actually delivering it. BVP contracts ask for a higher provability of organizations, in terms of the several factors BVP includes within their contracts, being mentioned previously. More pragmatically focusing on performance contracts, the factor durability for example can address the CO_2 emissions or energy consumption during the contract period, whereas financial health can address debt and profitability ratios of the organization. Past performance addresses previous performance contracts at the organizations, whereas technical and managerial merit can for example address the capability to develop an effective and efficient maintenance regime.

To be able to prove that organizations possess the required factors, data and information is needed, nowadays being provided by the increasing amount of data that is generated. The adoption of BIM furthermore facilitates the creation of coordinated and integrated information out of all the data. A situation is thus seen where organizations need to prove their capabilities for BVP contracts, from which the insights can be retrieved from the increasing amount of data available, supported by the use of BIM facilitating integrated and coordinated information.

However, to be able to prove the capabilities to clients within the tender phase, organizations need to be able to retrieve the required insights from the data first. The discussed developments have therefore led to a bigger emphasis on data analytics. It has led to a situation where organizations involved in performance contracts, especially those involving BVP, require proper data analytics capabilities. Data analytics is necessary to improve the provability within performance contracts, but also leverages multiple advantages in the maintenance process as defined previously. The freedom granted to the contractors in performance contracts stimulates innovative thinking, making the field highly competitive. Data analytics will become a core capability to survive, stressing the importance for those organizations being immature in the domain of analytics.

1.2. Research problem

The increase of BVP contracts demands organizations to a greater extent to prove they possess the sufficient capabilities. The increasing amount of available data can be of great help, though only after having the proper capabilities to make use of the data.

1.2.1. Lacking analytics capabilities

Having a lot of data doesn't directly mean organizations are able to leverage the potential of this data. Data itself is namely worthless in a vacuum. Data is a value, but without placing it in a context, it acquires no meaning. The potential of big data is therefore only unlocked when leveraged to drive decision-making. To be able to do so, organizations need efficient processes. Processes that are able to turn high volumes of fast-moving and diverse data into meaningful insights (Gandomi & Haider, 2015). The evolution of data has been visualized by the scheme of Cooper (2014), showed in Figure 1.

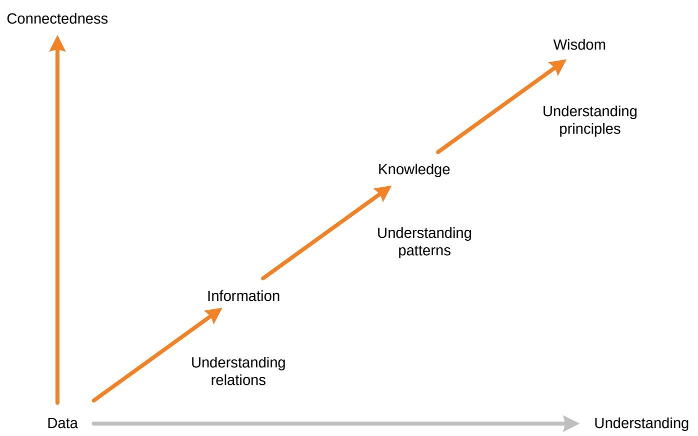

Figure 1 – The evolution of data (Cooper, 2014)

To be able to transform data into information, knowledge and wisdom, many companies have invested a lot of money into the renewal of their business processes and the improvement of their information system, in order to gain competitive advantage over competitors and/or reduce costs. Correct and in-time business decisions are of crucial importance for organizations and companies to survive. In order to make correct decisions, reliable, accurate and punctual information is required (Rajteric, 2010). This process of investing into the renewal of the business process and the improvement of the information system is also described as 'Business Intelligence' (BI). BI is defined by Azvine et al. (2006) as the following:

"Business Intelligence is the capturing, accessing, understanding, analyzing and converting of one of the fundamental and most precious assets of the company, represented by the raw data, into active information in order to improve business."

Within performance contracts the question remains how the data available should be leveraged towards a successful maintenance regime fulfilling to the requirements as stated within BVP contracts. The huge amount of data has the potential of a great information source, though many companies not yet have the right analytics capabilities and knowledge to access it. What is therefore seen, is that despite having more data and the existing need of proving their capabilities for the BVP contracts, without having a proper structured data management system and the required analytics capabilities, often organizations aren't able to leverage the advantages the data has the offer (Gandomi & Haider, 2015). There was also no literature found addressing the successful appliance of data analytics within performance contracts, possibly as a result of performance contracting, big data and data analytics being all fairly new phenomenon, especially in a combination.

1.2.2. Fragmentized contracts and lack of BIM

The construction industry is recognized by a lot of fragmentation. Projects are individually managed and there is limited integration of information and data between them. A nice imagining of Adriaanse (2014) is that he characterizes the construction industry in general as an archipelago, in which projects form individual separated island with no integration between them. This imaging is also seen in the field of performance contracting. The current way of working within performance contracts is merely individual (Deng, Zhang, Cui, & Jiang, 2013; Sols, Nowicki, & Verma, 2007).

Fragmentized contracts indicate a lack of BIM. BIM is used for the integration and coordination of information and data as mentioned before. As also said before, BIM is of great help in facilitating an environment in which data is transparent and accessible, supporting BI. An interesting link between BI and BIM is cross-project analytics. BIM can facilitate integrated and coordinated information between multiple projects, creating an integrated knowledge resource/dataset to be used/analyzed. Having a bigger dataset can improve the reliability of the outcomes. BIM therefore is not only useful in creating transparent and accessible data, but also in supporting the opportunity of cross-project analytics. This means the improvement of BI might go hand in hand with BIM adoption. Besides knowing what BI capabilities performance contracts possess, the BIM capabilities are therefore relevant to analyze as well. This will be all explained in more detail later in the theoretical framework.

Based on the previous, the following research problem has been defined:

Through lacking Business Intelligence capabilities and understanding within performance contracts and cross-project, it remains unclear for organizations how to leverage the advantages of the available data in order to increase their provability concerning BVP and make the maintenance planning process more efficient and effective.

1.3. Research objective

The research problem addresses the lacking BI maturity and understanding in the performance contract. Based on the research problem, the following research objective has been defined:

Develop a step-wise framework to better use, analyze and integrate the data within and between multiple performance contracts, which increases the Business Intelligence capabilities of organizations and the overall maintenance planning process efficiency and effectiveness.

The developed framework will be a step-wise one. This means that the framework will provide the steps necessary to be followed, in order to increase the BI maturity and leverage the potential of the data within the performance contracts. The framework discusses how the gaps within the existing situation should be resolved. This step-wise framework aims to provide a guideline on how to increase the analytics capabilities.

1.4. Research questions

Based on the research problem and objective, the following research question is defined:

How should organizations fill in the gaps within their Business Intelligence capabilities to increase their provability concerning future BVP contracts and leverage the potential of the data generated within and between performance contracts?

The research question will be answered by answering multiple sub questions, shown below.

1. How can the BI and BIM capabilities within the performance contracts be analyzed and measured?
2. What bottlenecks and problems are found within the performance contracts in regard to the improvement of the BI and BIM capabilities?
3. What BI and BIM capabilities are seen within the performance contracts?
4. What BI and BIM capabilities do the future BI opportunities require?
5. How can the steps organizations should take to increase their BI and BIM capabilities be modeled in order to implement the future opportunities?

In order to answer the research question together with the multiple sub questions, a case study has been conducted. The cases are analyzed to find the current problems and future needs performance contracts face. The next paragraph elaborates these cases.

1.5. Research cases and scope

Within this chapter the cases analyzed within this research as well as the research scope are discussed.

1.5.1. Cases

The increasing amount of available data as well as the increasing requirements from clients through BVP and BIM contracts are also developments seen at Arcadis. Arcadis is a global design, engineering and managing consulting company, which has over 300 offices in 40 countries. The company was founded in the Netherlands and has its origins in the Nederlandsche Heidemaatschappij, which was also the name of the company until 1997. Within their section of Information Management, Arcadis focuses on the management of all types of information, of which the management of information and data of performance contracts is one. Arcadis is performing the data and information management of performance contracts for several clients, such as Defence, Provinces, Municipalities, industries and RWS. Arcadis is by far the biggest consultancy of the Netherlands and known worldwide. They already have a lot of expertise in the field of performance contracts. As an innovative company in a competitive market, Arcadis always strives to improve their business. They see a lot of potential in data analytics within performance contracts, striving to have the maintenance regime better in control leading to the increase of the likelihood of winning future contracts, connecting to the provability required by BVP.

In this research, four performance contracts at Arcadis of RWS are analyzed. RWS, being one of the bigger clients of Arcadis, especially concerning performance contracting, already stated that their future performance contracts will be based on the BVP format as well as BIM. To objectively define which plan offers the highest quality for the best price within their BVP contracts, RWS makes use of MEAT (Most Economically Advantageous Tender) criteria. The MEAT criteria connect to the factors of Gransberg and Elicott (1997). These criteria focus on both the price and quality, though the emphasis lies on quality (75% of the total weighting) (Rijkswaterstaat, 2015). The outsourcing of the performance contracts is furthermore done by public tendering. As being a big client, it is for Arcadis of great importance to also win these future contracts involving BVP and its criteria. RWS is a big player in the Netherlands, being the executive agency of the Ministry of Infrastructure and the Environment, taking care of the management and development of the infrastructural works. The four performance contracts focus on the maintenance of the highways of RWS. Within the whole process of these performance contracts, multiple parties are involved which are the Ministry of Infrastructure and the Environment, RWS, Van Doorn (the contractor), Arcadis themselves and Spie (performing management of electrical installations).

Reason why is chosen for the performance contracts between Arcadis, Van Doorn and RWS, is in the first place that RWS prescribes the use of BVP and BIM within their future performance contracts, being representative for the overall industry. Secondly, the cooperation between Van Doorn and Arcadis is a fruitful relation, in which both parties are willing to invest in a more effective and efficient way of data management. They both see the advantages of data analytics in the long term concerning the competitiveness of the market.

1.5.2. Scope

Within the performance contracts of Arcadis with RWS, the cooperation with Van Doorn will act as the scope of this research, as within this cooperation the actual data and maintenance process is managed. Also the information flow between Van Doorn and RWS is incorporated, as RWS provides the contractual requirements (asking for provability) and (may) provide(s) data and information for the maintenance and maintenance planning process. Furthermore, RWS is kept up-to-date of the latest developments within the area during the period of the contract. The scope is seen in Figure 2 by the black dotted line. The Ministry of Infrastructure and the Environment, RWS and Spie are within the broader context of the research, but won't act as the areas to be investigated.

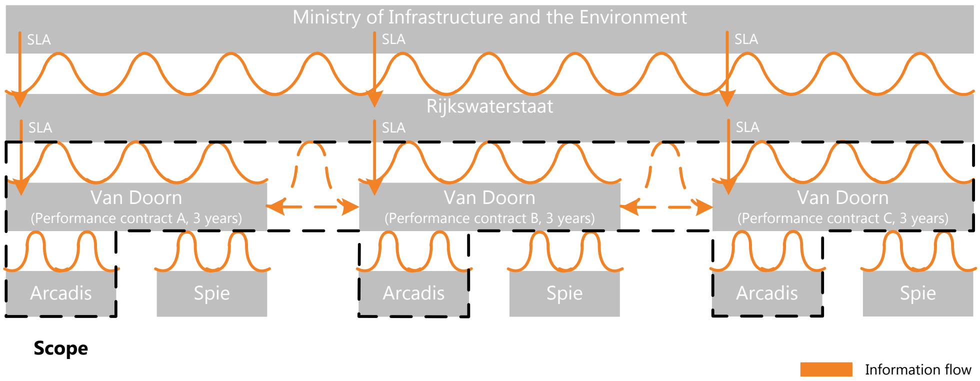

Figure 2 – Hierarchical scheme of performance contracts with RWS including research scope

Within performance contracts, the whole process is executed within an information system. To discover the potential of data analytics, the different components of the information system all have to be analyzed. According to Bourgeous (2014) an information system can be divided into four components which are: (1) hardware and software, (2) activities and processes, (3) data, and (4) people. The components of the information system that are analyzed within this research are: hardware and software, activities and processes, and data.

The component 'people' is left out. Within this research the focus lies on the data component and the actual system in which the data is processed. The component 'people' is important to analyze involving human behavior, but will therefore not be part of this research.

The research furthermore only addresses the gaps concerning BI and how these should be filled. This research does not provide the statistical models eventually needed to perform the actual analytics. The research provides the underlying problems that should be resolved first before modeling of data can take place.

1.6. Structure of report

The structure of the report can be divided into five sections, shown in Figure 3. This figure also shows what kind of material was used in the sections, being either information retrieved from the literature or the case study.

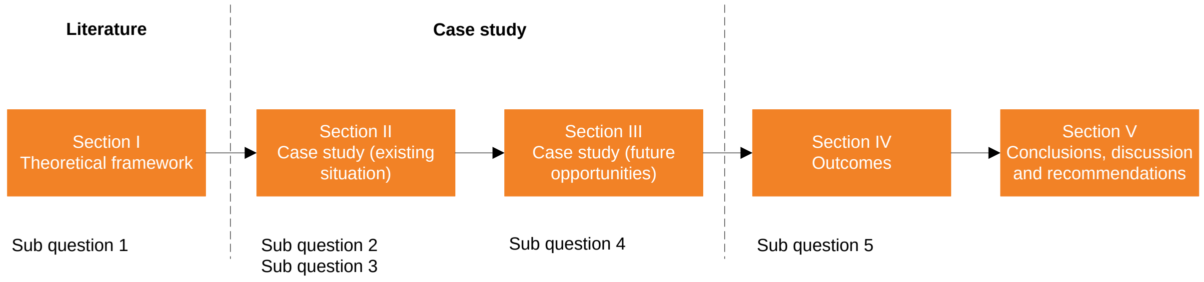

Figure 3 – Research model

Section I elaborates the theoretical framework that is used within the report, providing a framework of how to analyze and measure the BI maturity in the performance contracts. Therefore, sub question 1 is placed within this section.

Section II starts with the multiple case study at Arcadis. This section is explorative, meaning the performance contracts themselves are analyzed into detail, focusing on the components hardware and software, activities and processes and data. This section elaborates the existing bottlenecks and problems of the performance contracts for each of the information system's components regarding data analytics and translates these to the current BI and BIM capabilities. Sub question 2 and 3 are placed in this section.

Section III continues with the case study, though focusing on the future opportunities. In this section, it is analyzed what opportunities of data analytics within the performance contracts exist, especially concerning BVP and BIM. Having both the existing BI and BIM capabilities of the information system and the ones required for the opportunities within the performance contracts, a comparison can be made between the two. The gap between these two forms the input for section IV, where it is analyzed what concrete steps are then necessary to fill this gap. Sub question 4 is placed in this section.

Section IV provides the outcomes of the research in the form of the step-wise framework. This framework is initially specifically developed for the performance contracts at Arcadis, making a generalization to the broader industry not possible. However, assumptions possibly reflecting to the broader industry were provided in the discussion of this research, part of section V. The last sub question, 5, is placed in this section.

The last section, section V, contains the conclusions, discussion and recommendations.

1.7. Research methodology

In this section, the research methodology followed throughout the research is explained, involving the type of research, the research design, the data collection and data analysis.

1.7.1. Type of research

The research can be classified as prescriptive. A prescriptive research is focused on the development and application of strategies, methods, techniques and tools (Reymen, 1999). Within this research this is the development of a step-wise framework for organizations and in specific Arcadis for the improvement of the BI and BIM capabilities. The research is furthermore both descriptive and explorative. On the one hand, it's descriptive because it's analyzed what the current BI and BIM capabilities are. On the other hand, it's explorative because it's analyzed what the opportunities are and the potential is of data analytics.

Besides a prescriptive research, this research is also a qualitative one. Qualitative research considers the focus on phenomena in natural settings. In qualitative research, the complexity of these phenomena is captured and studied, which is done in this research by investigating the required steps for proper data analytics. Furthermore, qualitative approaches are very useful in cases when interpretation is needed (Leedy & Ormrod, 2014). For this research, new insights in the phenomenon of performance contracts are gained, by developing new concepts, theoretical perspectives and management approaches in the form of the step-wise framework.

1.7.2. Research design

Qualitative research can be done in many ways like a case study, ethnography, phenomenological study, grounded theory study and content analysis (Leedy & Ormrod, 2014). Within this research, a case study fits best. Within the research the current situation and the current bottlenecks and opportunities within performance contracts concerning data analytics are analyzed. It is analyzed what is required for organizations to improve their BI and BIM capabilities in their performance contracts in order to fulfill to the future BVP and BIM contracts and leverage the advantages of the increasing data bulk they have access to. Four performance contracts at Arcadis were therefore chosen to provide the answers to these questions. This research is because of the multiple cases, a multiple case study. A multiple case study in general is more robust than a single case study, because the multiple cases can be compared to each other (Leedy & Ormrod, 2014).

1.7.3. Data collection

Data during the research was collected through a literature review and a case study. Below for each of these is described how this was done.

Literature review

The literature review was performed to develop the theoretical framework, forming section I of the report and involving sub question 1. For a literature review, it's important to know where the literature is gathered and what keywords are used. For the literature review, the several search engines and keywords which were used are written down below. The keywords mentioned were combined to get better findings during the literature review.

- **Search engines:** FindUT (search engine of the University of Twente), Scopus, Google Scholar, ScienceDirect.
- **Keywords:** Performance contracts, performance contracting, information management, operations and maintenance, maintenance, life-cycle management, Building Information Modeling, BIM, facility management, construction industry, civil infrastructure, data quality, data quality dimensions, data integration, data analytics, Business Intelligence, analytics maturity, data mining, data visualization.

Case study

In a case study, the researcher collects extensive data on the particular event(s). This collection of data can be done in many ways with different measurement techniques, such as observations, interviews, documents, past records and audiovisual materials (Leedy & Ormrod, 2014). To be able to place the cases within the theoretical framework, information from case documents, software databases and interviews was used. The case study forms the section II and III of the research.

Within the research, different types of documents were used and analyzed. The list of the documents that were used is shown below in Table 1.

Table 1 – Use of documents during research

Document type	Developed by	Content
Project Management Plan	Van Doorn	Describes how Van Doorn arranges the work for the maintenance of the prescribed area.
Work instructions	Arcadis	Work instructions for the use of databases and other systems such as DTB, Kerngis and Ultimo.
Work plans data management	Arcadis	Discusses contract demands as well as data management procedures of Arcadis.
Verification and control documents	Arcadis	Documents used to verify and control the information gathered and processed during the activities done by Arcadis.
Others	-	Other documents that might come in handy, such as PowerPoints about the projects and previous developed process schemes.

During the research, access was granted by Arcadis to Atrium, a data management system. Atrium provided a lot of information about the actual data registration and data registers that are saved. Atrium can therefore be seen as a big database, where a lot of data of the performance contracts is saved. Examples of data that is stored within Atrium are the faults and defects registers and surveillance and inspection data. This was especially useful for determining what types of data are processed within the performance contracts.

At last interviews with the involved people of Arcadis and Van Doorn were held to gather more in depth information about the particular cases. To support the findings from the other sources, interviews were held among ten employees of both Arcadis (six) and Van Doorn (four) concerning questions about the three components of the information system of Bourgeous (2014). The interview itself is provided within Appendix III. The interview consisted of two parts. The first part involved questions about the information system and its bottlenecks, problems and needs recognized here. The second part of the interview involves questions about the actual quality of the data used within the performance contract. The people to be interviewed did have the following roles: project manager, project leader, data specialist, portfolio manager, technical specialist, contract specialist, and maintenance and technical manager. This broad field of roles gave a higher certainty that of all of the different aspects within the performance contracts could be captured. The first part of the interview was semi-structured, to give the interviewees the opportunity to freely speak about it and get real in-depth information. For the second part of the interview a structured interview was held, to ensure that the data quality could be objectively measured.

Within the case study, the answers on the sub questions 2, 3 and 4 were found. For sub question 2, addressing the bottlenecks and problems within the performance contracts, all the different measurement techniques from the case study were used. Project documents, Atrium and the interviews all provided important input for this question. For sub question 3 also all measurement techniques within the case study were used to find the existing BI and BIM capabilities. The answer on sub question 4 was mainly retrieved from the interviews, though the case documents and the software databases also did provide some input.

1.7.4. Data analysis

The function of analysis is to apply order to unstructured qualitative data (Yin, 1989). Data retrieved from the documents and interviews have been analyzed in a specific way. Furthermore, the outcomes of the research were evaluated and validated.

Case documents and interviews

Case documents were arranged by different document types. The interviews were transcribed and filtered on the relevant information. For both the case documents and the interviews, the retrieved data then got connected to the components of the information system by Bourgeous (2014). Having mapped the data within a specific component, it was analyzed what kind of bottlenecks/problems or opportunities could be found regarding the implementation of proper data analytics. During the interviews, data quality was assessed as well, based on the data quality criteria accuracy, completeness, timeliness, accessibility and reliability. These criteria were determined after a thorough literature review.

Based on all bottlenecks/problems and needs, an overall portrait of the cases could be constructed in terms of BI and BIM capabilities for each of the information system's components. The same was done with the needs and opportunities required for the future BVP contracts. These were analyzed based on capabilities defined in the theoretical framework defined for each of the components. The gap between existing maturity and required maturity for the future opportunities, provided the input for the step-wise framework.

Evaluation/validation
The outcome of this research is a step-wise framework specifically developed for the performance contracts analyzed at Arcadis. An important part of the research was an evaluation and validation workshop held at Arcadis evaluating this framework. The workshop was held among four people who also were part of the interviews. These four people involved four employees of both Arcadis (three) and one of Van Doorn (one). The functions of these employees were project manager, senior project leader, maintenance manager and portfolio manager. It was chosen to also incorporate people from Van Doorn, to make clear what the added value of this research could be for them and incorporate their final comments on the framework. The workshop was held to evaluate and validate the developed step-wise framework yet without prioritization of the opportunities. A brief overview of the workshop is provided in Appendix IX.

During the workshop the finished step-wise framework was evaluated on completeness, practical applicability and the developed opportunities were prioritized within the framework. This evaluation and validation workshop started with a short presentation from the researcher, focusing on the developed framework. Thereafter, the audience could ask questions and the outcomes of the research were briefly discussed. However, most important of this workshop was the discussion that followed thereafter, guided by a couple of predefined questions given to the audience. These questions were also send to them a week before the workshop, so they were able to prepare these.

The questions discussed the completeness of the framework and prioritization of the opportunities in terms of importance. It was asked how the framework matched with the expectations and how the practical applicability was perceived. The opportunities were thereafter prioritized to make specific what steps the developed framework should start with and what opportunities were perceived as most beneficial to incorporate. The prioritization was done on the added value of the opportunity and made it possible to adjust the developed step-wise framework in the desired order. This provided input for a last concretization to make the final step-wise framework.

The workshop therefore functioned as a final evaluation moment for the developed step-wise framework. Based on the workshop, the opportunities were prioritized and last concretizations could be applied to the framework, resulting in the final framework as presented within this research.

1.8. Research quality

For qualitative research the role of the researcher is very important. The researcher needs to be able to get the core out of all the information that is gathered during the research. Therefore, involvement is necessary, though the researcher should beware of 'getting native', which means the researcher gets too involved. During the research, the researcher will namely be part of the phenomena and people he is observing and can be seen as a measurement instrument itself. This means that the researcher should be aware of the fact that bias in data may occur, especially during the interviews, where only the way of how questions are asked already can change the way how people answer. The researcher should therefore try to be as objective as possible (Leedy & Ormrod, 2014).

To measure the quality of the research, the validity and reliability have been elaborated. Validity of a research shows whether or not the measurement techniques measured what was meant to be measured (Leedy & Ormrod, 2014). The reliability of a research ensures that when repeating the research with the same instruments, the research will grant the same results (Leedy & Ormrod, 2014).

1.8.1. Validity

Internal validity means that the conclusions drawn are truly warranted by the data (Leedy & Ormrod, 2014). To ensure the internal validity of the research, it's necessary to eliminate other possible explanations of the results observed. This is done by having multiple sources of data in the hope they will all converge to support a certain outcome. This instrument is called 'triangulation' (Leedy & Ormrod, 2014). During the research, information and data was gathered through a literature study, case documents, software databases and in-depth interviews. The results were furthermore evaluated and validated in the workshop at the end of the research. In qualitative research such as this, triangulation is common used and very popular to ensure the internal validity.

The selection of the people interviewed is done based on their function. This to have multiple views on the subject and preventing a tunnel vision. Furthermore, both from Arcadis and Van Doorn people are interviewed. Here Arcadis has the more specific view on the projects, concerning data management and process management. Van Doorn on the other hand develops maintenance plans and executes the maintenance. Knowing how both of them experience the current situation provides a better insight in the overall process of the performance contracts. The interviews themselves are semi-structured for the first part and structured for the second part. For the components of the information system it is important that the interviewees speak openly about it, and provide as much useful information as possible. A structured interview would limit the answering possibilities and would increase opportunistic answering. For the questions about data quality however, a structured interview is set up, as objective data is needed to be able to compare the outcomes of the interviews with each other. In total ten interviews were held, shared between Arcadis (six) and Van Doorn (four), to get the views from both of these organizations on the analyzed performance contracts. With an amount of ten, all the different roles concerned important could be interviewed.

The selection of the people within the workshop was also based on their function. Here it was chosen to involve people with a broader vision on the performance contracts, to be able to discuss about the overall impact of the developed framework. The in-depth information was already retrieved from the interviews. Concerning the literature review, literature was gathered and analyzed from multiple perspectives, to avoid tunnel vision. Literature was gathered from a wide domain of authors to ensure the appropriateness and validity of their findings and theoretical concepts. At last, information from people at especially Arcadis was used. Within the daily work routines, with a lot of people was spoken, gathering feedback, increasing the validity of the research even more.

External validity ensures that the results obtained can be used to make generalizations about the world beyond the specific research context (Leedy & Ormrod, 2014). The external validity of a research is the extent to which its results apply to situations beyond the situation itself. In this research, a framework is developed for specifically Arcadis. As mentioned previously, this means no generalizations can be made for the broader industry, limiting the external validity. However, based on this research, assumptions were made that could apply to the broader industry, though these can't be proved and are just based on suspicions. It is thus not proven that the outcomes of this research are seen at other performance contracts within the industry.

1.8.2. Reliability

Reliability of the research involves the influence of accidental errors that had influence on the retrieved data and information. It describes the extent to which the results remain stable if the research is performed by a different researcher (Yin, 1989). According to Leedy and Ormrod (2014), the reliability can be increased if standardized measurement techniques are used. In this research, the interviews form some kind of standardization, although not all questions can be repeated exactly the same, especially concerning the semi-structured part of the interview.

To increase the reliability of the research, Yin (1989) furthermore states that it is helpful to use a protocol on how to collect and manage the retrieved data during the case study. Within this research, beforehand a research proposal has been written including an outline of the structure of the interviews and how data in general should be collected. The reliability of the research was increased by having written down how the interviews and workshop took place. A structure is provided within the appendices of both of them (Appendix III and IX) which makes it easier to reproduce them. It therefore can be said that the reliability of the research is reasonably assured.

SECTION I

THEORETICAL FRAMEWORK

2. THEORETICAL FRAMEWORK

Within this chapter, the theoretical framework that is used within this research is elaborated. This starts in paragraph 2.1 with BI and data analytics, followed by BIM and data analytics in paragraph 2.2. Paragraph 2.3 then discussed the role of the information system within the research. Paragraph 2.4 discusses the required BI and BIM capabilities for each of the components of the information system. In paragraph 2.5 these capabilities are mapped for each of the components in the BI maturity and BIM levels. At last in paragraph 2.6 these four paragraphs come together in an integrated matrix, being the basis for the whole research.

2.1. BI and data analytics

As mentioned, BI facilitates an organization away from being 'ignorant' and having a lack of understanding about a system and the data it produces. Within the context of data integration and analytics, BI offers four levels of analytics of the data. These are descriptive (what happened?), diagnostic (why did it happen?), predictive (what will happen?), and prescriptive (how can we make it happen?) analytics (Cook & Nagy, 2014). Based on these different types of analytics, BI maturity levels are identified by Williams et al. (2003) and Puget (2015). These levels are schematized in Figure 4. For level 1 the business value is the data, for level 2 the insights in the data and for level 3 the support of the data for future decision-making. The higher the business value, the less human input is required for the decision-making, as data becomes increasingly helpful.

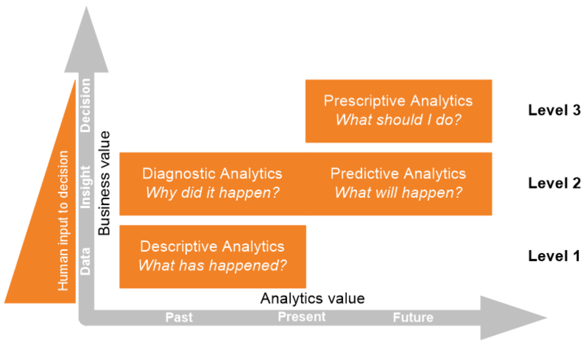

Figure 4 – BI maturity levels (Williams & Thomann, 2003; Puget, 2015)

2.2. BIM and data analytics

Data analytics does relate strongly with BIM. BIM has many common interfaces with the integration of multiple data and information sources and streams. The integration of data across organizational and department silos has been a business challenge for many years (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). BIM is often used for the integration and coordination of information and data throughout a set of policies, processes and technologies as defined earlier on. BIM can be used to facilitate a shared knowledge resource (ISO Standard, 2010).

By using BIM, the involved parties achieve better insights in the project as information becomes more transparent and better accessible. The use of BIM has been rapidly increasing as a consequence of the increasing complexity of projects (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013). Within these projects a lot of data, information and stakeholders are present, which makes it difficult to coordinate and manage, without having a proper management model. As a result, information and communication technology (ICT) has been developing on a very fast pace (Taxén & Lilliesköld, 2008). The proliferation of BIM is one of the major shifts ICT has made. BIM has been utilized on many large scale projects due to their complexity, such as the constructed London 2012 Olympic Velodrome (Bryde, Broquetas, & Volm, 2013).

An upcoming development within the field of BIM is 'multi-BIM'. Whereas BIM in the last years mainly has been used within a single organization (mono-disciplinary BIM) or within a single project involving multiple disciplines (multi-disciplinary BIM), it now is seen that BIM is shifting towards 'multi-project'. This involves the use of BIM over multiple projects, which means multiple projects can leverage advantages from the data from each other. Organizations involved within multiple projects for example can use multi-BIM to optimize logistics and plan based maintenance. These three levels of BIM can be seen as organizational levels, where the implementation of BIM increases from a single purpose to a multi-project one (Adriaanse, 2014).

Concerning data management, BIM mainly focuses on making data more transparent and accessible for all the parties involved within a project, where data analytics focuses on new insights/patterns/relationships that can be discovered within the data. As briefly discussed earlier on, the implementation of data analytics together with multi-project BIM, is very interesting. Having a BIM orientated data and information structure, helps data analytics greatly in analysis of the data by facilitating integrated and coordinated data, being transparent and accessible as well. Multi-project BIM in specific greatly stimulates cross-project analytics. A BIM friendly environment is within this research therefore seen a great driver for successful data analytics and improving the possibilities of BI. However, this does not mean data analytics cannot exist without BIM.

2.3. Data analytics within an information system

To make the process of data analytics more clear, the processing of data within this research is viewed from an 'information system' perspective. The information and data used for the maintenance process and maintenance planning within performance contracts are collected, processed and distributed within an information system. For information systems, the following definition of Laudon and Geurcio Traver (2011) is used within this research:

"Information systems are interrelated components working together to collect, process, store and disseminate information to support decision-making, coordination, control, analysis, and visualization in an organization."

Information systems consist of multiple interrelated components. According to Bourgeous (2014) the following components of an information system can be defined, though the component people isn't included as defined within the scope of the research:

Hardware and software: The system does consist of hardware and software. Hardware is the part of an information system you can actually touch. It is the physical component of the technology. Examples are computers, keyboards, servers and flash drives. Software on the other hand is a set of instructions that tells the hardware what to do. Software is not tangible like hardware. The two main categories of software are operating-system software and application software. Operating-system software makes the hardware usable and examples are Microsoft Windows or Google's Android. Application software is software that is used to perform functions, tasks or activities for the benefit of the user. Examples are Microsoft Access or Microsoft Excel (Bourgeous, 2014).

Activities and processes: Activities and processes can be seen as a series of steps that are undertaken to achieve a desired outcome or goal. As information systems become more integrated with the organizational processes, more productivity and better control of these processes is brought. However, simply automating activities using technology is not enough. Organizations are always striving to make the processes more effectively together with the information system. A buzzword such as "business process management" all has to do with the goal of continuing improvement of the businesses procedures and the integration of technology with them. When hoping to gain advantage over their competitors, business is highly focused on this component of an information system (Bourgeous, 2014).

Data: Data can be seen as a collection of facts, which are intangible. Without having data, the system won't function, but data in itself it not really useful as well. Integrated, indexed and organized in for example a database, makes data a very powerful tool for business. Organizations collect and process all kinds of data to support their decision-making process. Data on these decisions can then even be analyzed to try to improve the decision-process itself (Bourgeous, 2014).

A well developed and defined information system is the foundation of being able to collect, process and distribute data leveraging decision-making, control, analysis and visualization in an organization.

2.4. BI and BIM capabilities

Data doesn't create value until it is put to use to solve important business challenges. This involves the use of more and different kinds of data, all resulting in the need of strong analytics capabilities. This not only includes the right tools to do so, but also the skills to operate these tools (TechAmerica Foundation's Federal Big Data Commission, 2012; Gandomi & Haider, 2015). Within this paragraph it is defined what kind of capabilities each of the components require regarding the BI maturity and BIM levels. The capabilities are translated to the information system perspective.

2.4.1. BI capabilities

As mentioned, BI facilitates an organization away from being 'ignorant' and having a lack of understanding about a system and the data is produces. It tries to leverage knowledge out of data and information, to support the decision-making process (Cook & Nagy, 2014). To do so, organizations need to possess certain BI capabilities.

Hardware and software

The hardware and software requires a scalable and extensible information foundation. To be able to use data analytics, first the information foundation of the organization should support the rapidly growing volume, variety and velocity of the data. Big data is dependent upon a scalable and extensible information foundation. In order to get such an information foundation, certain core components should be met. The first one is integrated information, a characteristic of BIM as well (Azhar, Hein, & Sketo, n.d.). Integrated information is a core component of analytics, and very important for big data. For analytics, the data should be readily available and accessible for the people and systems that need it. The integration of data across organizational and department silos has been a business intelligence challenge for many years. Big data makes this challenge even more complex (Gandomi & Haider, 2015; Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012).

A common phenomenon that does address integrated data is data warehousing. Data warehousing is basically nothing more than a central database in which all data and information is stored, so organizations can run data analysis applications and obtain information that is of strategic and tactical importance for their business (Kim, Choi, Hong, Kim, & Lee, 2003). Very important for the storage of data, is to remove the veracity, data uncertainty, one of the V's of big data (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012).

Furthermore, it is necessary to have a scalable storage infrastructure and to have a high-capacity data warehouse. Because of the growth of information and data more storage capacity is needed, for example in the form of servers (Schommer, 2008). However, not only adding more storage capacity is important, also to understand how to anticipate and to support the ebb and flow of data to enable users to access data when needed and be able to analyze the data within the business' time constraints. This balance results in a more optimized infrastructure, not only dealing with the higher volume of the data, but also with the higher velocity. For many organizations this is the first big data priority, followed by the expanding variety of the data (Gandomi & Haider, 2015; Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). The hardware and software together form the foundation on which data analytics is executed. Therefore, an important aspect of the hardware and software is to facilitate the required activities and processes.

Activities and processes

Within the world of big data and data analytics, it is seen that many organizations start building on a strong core of analytics capabilities designed to address structured data. Next they start with developing capabilities able to handle semi-structured and unstructured data. Capabilities that are concerned as the core capabilities are especially query and reporting and data mining (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). Query and reporting involves how data is requested and reported. Data mining is the process of discovering meaningful correlations, patterns and trends by sifting through a large amount of data (Gartner, n.d.). It is the extraction of implicit, previously unknown, and potentially useful data (Frawley, Piatetsky-Shapiro, & Matheus, 1993). These two capabilities are the foundational capabilities to start interpreting and analyzing big data.

Big data furthermore increases the need for more advanced visualization capabilities, as datasets often become too large for business or data analysts to view and analyze with the traditional reporting and data mining tools. Most of the organizations can't handle the amount of data generated with the existing visualization tools (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). Whereas data mining involves the specific extraction of potentially useful data, data visualization is the processing of turning this data into meaningful charts or graphs. These make it easier for the human being to understand the large amounts of complex data, normally often stored in spreadsheets. Data visualization therefore makes it quite easy to experiment with the data, as changes can easily be seen within the charts and graphs, in contrary to a spreadsheet. Data visualization thus allows retrieval of new insights/patterns/relationships by the human being through visualization from the data mined (Ware, 2012).

Being a type of data mining, predictive modeling is also often used, to predict future outcomes based on historical and current data (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). It seeks to uncover patterns and captures relationships in data, which is in relation with data mining. To do so, the predictive modeling techniques are primarily based on statistical methods (Gandomi & Haider, 2015). Together, predictive modeling is defined by Quang, Sachin and Girish (2014) as the process of using statistical data and data mining techniques to analyze historic and current data sets, create rules and predictive models and predict future events.

Furthermore, optimization and simulation techniques are also often used. Optimization involves the optimization of current analytics models after better understanding of the key business processes. Simulation involves analysis of the myriad within the variables available in the dataset, checking how the variables behave when simulated. These capabilities mentioned so far mostly focus on structured data. However, to be able to use big data and data analytics to their full potential, organizations also start with the adoption of capabilities facilitating the analysis of semi-structured and unstructured data, for example geospatial location, voice, text and video data.

Data

Data is intertwined with the hardware and software and the activities and processes. However, concerning data, data analytics requires strict and uniformly registered data. Analysis on data is only possible if the data is uniform and doesn't consist errors. This mainly means the data needs to be topical, reliable and complete (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). This counts for both structured and unstructured data, which means the way how data is collected, processed and distributed within the activities and processes is of high importance.

2.4.2. BIM capabilities

BIM is used for the integration and coordination of information and data. It tries to make data and information more transparent and better accessible for the involved parties, making the managing of it more convenient (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). This integration and coordination facilitates the three different BIM levels this research focuses on.

Hardware and software

The hardware and software involves the foundation of where data and information is collected, processed and distributed. Concerning BIM, it is of great importance that the hardware and software facilitate the integration and coordination of multiple data and information streams in such a way that for all the involved parties the data is transparent and accessible (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). Hardware wise this involves for example the use of a shared database, but also the use of the same processing devices. Software wise this involves may the use of a common model in a shared application. More pragmatically, object oriented models facilitate for example an unambiguously way of how to define and communicate about the objects of concern. By having equal object models between multiple disciplines, it becomes possible to even exchange and integrate the data and form a common shared model (Bouw Informatie Raad, 2014), facilitating integrated and coordination information. The hardware and software furthermore facilitate communication. This means specific communication systems are necessary to ensure that data not only is communicated in a uniform way, but that the send information and data also needs to be of a common format that can be read and used by all the involved parties. Interchangeability of data and information is crucial (Azhar, Khalfan, & Maqsood, 2012).

Activities and processes
Concerning the integration and coordination of data and information between multiple parties, and making the data transparent and accessible for everyone, it is necessary that the activities and processes are arranged in such an order that they are uniform (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). This for example requires that data is uniformly registered through the use of common principles and guidelines. It is crucial that the involved parties know how to actually collect, process and distribute the data. A shared decomposition within object oriented systems for example, as discussed within the hardware and software, can create such uniformity.

Data
Data is, just as at the BI capabilities, intertwined within both the hardware and software and the activities and processes. As mentioned, for BIM it is necessary to have a well-integrated and coordinated system in which all the involved parties know how to collect, process and distribute data. Data needs to be transparent and accessible, which needs to be facilitated by both the hardware and software and the activities and processes.

2.4.3. Overview of BI and BIM capabilities
An overview of the discussed BI and BIM capabilities of the previous two paragraphs is summarized in Table 2.

Table 2 – Overview of BIM and BI capabilities

Component	BIM capability	BI capability
Hardware and software	Integrated and coordinated infrastructure	A scalable and extensible information foundation
		A proper data warehousing configuration
Activities and processes	A uniform way of working	Uniform query and reporting
		Data mining
		Optimizations and simulation
		Data visualization techniques
		Analytics on semi-structured and unstructured data
Data	Transparent and accessible data for all involved parties	Strict and uniform registration of data, facilitating topical, reliable and complete data

2.5. Translation of capabilities to BI maturity and BIM levels
In the previous paragraph for each of the information system's components the BI and BIM capabilities were defined. In this paragraph, these capabilities are translated to the BI maturity and BIM levels. For each of the components it is defined what is required to be in a certain BI maturity or BIM level, reflected against the performance contracts.

2.5.1. BI maturity
The BI capabilities are translated to the maturity framework as defined by Williams & Thomann (2003) and Puget (2015). For each increasing level, less human input is required for the decision-making, as data becomes increasingly helpful. Below the three BI maturity levels (four types of analytics) are discussed for the performance contracts.

Level 1 (descriptive): What has happened? Within this level, organizations only think about what **data** is needed to support their decision-making processes and how to make this visible. This level focuses on the past. Concerning the performance contracts, descriptive analytics mainly focus on maintenance tasks and services from the past, which describe what has happened or has been detected. A consequent action might be corrective maintenance. The following capabilities are required within this BI maturity level.

- Hardware and software: A scalable and extensible information foundation is required, as well as a proper data warehousing configuration. Data should be readily available and accessible for those who want to analyze it. The hardware and software furthermore need to support the activities and processes required.

- Activities and processes: No real data mining activities are here performed, as this level only does a simple analysis of historical data. Uniform query and reporting though is required. Data visualization is not a necessity here. Analysis of semi-structured and unstructured data might prove useful.
- Data: Strict and uniform registration of data is required, to be certain about what has happened in the past. However, as only describing what has happened, data often doesn't require to have all the details about the event. If the data can describe what has happened, it is here considered complete enough. The data should be reliable however.

Level 2 (diagnostic): Why did it happen? Within this level, users not only want to know what data is needed and what happened with the data, but also want **insights** in why this happened. Diagnostic analytics focuses here on the past by analyzing historical data to get insights. Concerning the performance contracts, diagnostic analytics tries to identify why certain events happened. This could for example be why a certain fault happened within the area, instead of only describing that it happened. Knowing why some events happen is useful input for predictive analytics, explaining the same level these analytics have (both trying to retrieve new insights). This level does require some analytics capabilities, because a connection needs to be made between an event and the cause of the event. This may require sifting through data about the particular event. The following capabilities are required within this BI maturity level.

- Hardware and software: A scalable and extensible information foundation is required, as well as a proper data warehousing configuration. Data should be readily available and accessible for those who want to analyze it. The hardware and software furthermore needs to support the activities and processes required.
- Activities and processes: Diagnostic analytics focus on the past by analyzing historical data to get insights in why certain events happened. This addresses relative simple data mining. Furthermore, uniform query and reporting is required. Data visualization might have a bigger role on this level, visualizing these insights. Optimization of business processes could be seen at this level, by knowing what has happened in the past. Analysis of semi-structured and unstructured data might prove useful.
- Data: Strict and uniform registration of data is required, to be certain and have a complete view about why things happened in the past. Especially reliability and completeness of the data here is important, to analyze why events happened.

Level 2 (predictive): What will happen? Within this level, users not only want to know what data is needed and what happened with the data, but also want **insights** in why this happened and how this could be predicted. Predictive analytics focuses on applying insights to data to predict new data about present and future. Concerning the performance contracts, predictive analytics mainly focuses on preventing objects from failing. Predictive analytics makes it possible to determine when and where maintenance is needed. Predictive analytics furthermore can provide insights in what consequences changes in the maintenance regime will have on for example the quality of the area. This level requires high analytics capabilities, where data from the present and past is analyzed to predict the future. The following capabilities are required within this BI maturity level.

- Hardware and software: A scalable and extensible information foundation is required, as well as a proper data warehousing configuration. Data should be readily available and accessible for those who want to analyze it. The hardware and software furthermore needs to support the activities and processes required.
- Activities and processes: This addresses predictive modeling and more complex data mining, involving more complex statistical models (not further elaborated within this research). Furthermore, uniform query and reporting is required. Data visualization is very useful by visualizing the predictions and experimenting with how changes in the data can influence these. Optimizations can be seen at this level. By having predictive modeling capabilities, it will be more convenient to optimize certain processes. Analysis of semi-structured and unstructured data might prove useful.
- Data: Strict and uniform registration of data is required, to be certain and have a complete view about what could happen in the future. Data should be reliable, topical and complete, in order to be able to do predictions for the nearby future.

Level 3 (prescriptive): What should I do? So far, users know what data they want, why they want this data and what they can expect from this data to happen. It is strived to fully understand how the data can be best used to optimize the business processes and **decision-making** once that data is delivered. Therefore, users need to know how they can achieve the desired outcomes of the data together with the steps to be taken. Prescriptive analyses here thus focus on what should be done to achieve the certain desired outcomes. This level focuses on the future. Concerning the performance contracts, prescriptive analytics can be applied to know how to react to certain developments within the area, but also how certain required outcomes can be met. It is then known beforehand what to do in order to reach those outcomes. Prescriptive analytics requires very strong analytics capabilities. The following capabilities are required within this BI maturity level.

- Hardware and software: A scalable and extensible information foundation is required, as well as a proper data warehousing configuration. Data should be readily available and accessible for those who want to analyze it. The hardware and software furthermore needs to support the activities and processes required.
- Activities and processes: This requires all BI capabilities. Uniform query and reporting is required. Data mining is of the highest level here, also involving predictive modeling as a part of the analyses. Data visualization is of high importance, not only by visualizing the complex data, but also by enabling an experimental setting in which it can be easily visualized how changes in data influence the outcomes. In this way it will be easier to fine tune the data in order to achieve the desired future outcome. Having prescriptive analytics furthermore makes it more convenient to optimize current processes. Simulation here is also important in order to check that the desired outcomes are really met by the proposed optimization. Analysis of semi-structured and unstructured data might prove useful.
- Data: Strict and uniform registration of data is required, to be able to achieve the desired outcomes out of the data. Data should be reliable, topical and complete.

2.5.2. BIM levels

The BIM capabilities are translated to the framework as defined by Adriaanse (2014). This framework focuses on what scale BIM is used or should be used within an organization, starting with BIM within a single organization towards BIM between multiple projects. This connects to the definition of BIM used within this research, provided by the ISO Standard 29481 (ISO Standard, 2010), which elaborates on shared knowledge resources facilitated by BIM. Within this research, it is analyzed on what BIM levels such shared knowledge resources are seen within the performance contracts. Below the three BIM levels are defined for the performance contracts.

Mono-disciplinary BIM: Involves the use of BIM within a **single discipline**. This means BIM is only applied within a model accessible for one party. No data exchange finds place with other disciplines, delimiting the integration and coordination of data and information overall seen. The following capabilities are required within this level.

- Hardware and software: Integrated and coordinated infrastructure is required within a single discipline and a single project.
- Activities and processes: A uniform way of working is required within a single discipline and a single project.
- Data: Transparent and accessible data is required within a single disciplines and a single project.

Multi-disciplinary BIM: Involves the use of BIM between **multiple disciplines**. Data here is shared between multiple parties through for example a common database or server. This is however within a single project. The following capabilities are required within this level.

- Hardware and software: Integrated and coordinated infrastructure is required between multiple disciplines but within a single project.
- Activities and processes: A uniform way of working is required between multiple disciplines but within a single project.
- Data: Transparent and accessible data is required between multiple disciplines but within a single project.

Multi-project BIM: Involves the use of BIM **cross-project**, enabling multiple projects to use each of their others data and information. Data is integrated and coordinated between multiple projects. To be on this level, projects need to be able to share their data and information with the others, in such an order that the data and information is transparent and accessible as well. The following capabilities are required within this level.

- Hardware and software: Integrated and coordinated infrastructure is required between multiple disciplines and multiple projects.
- Activities and processes: A uniform way of working is required between multiple disciplines and multiple projects.
- Data: Transparent and accessible data is required between multiple disciplines and multiple projects.

2.6. Synthesis: an integrated BI and BIM matrix

Within the previous paragraphs it has been determined what capabilities each of the information system's components need to possess to be within a certain BI maturity or BIM level. To map and visualize both the BI maturity and the BIM level, an integrated matrix has been developed which makes it possible to visualize these in a simple way. This matrix contains the BI maturities as well as the BIM levels. This matrix is shown in Table 3.

Table 3 - Integrated BIM and BI maturity matrix (X belongs to example provided below)

		BI maturity			
		Level 1 Descriptive	Level 2 Diagnostic	Level 2 Predictive	Level 3 Prescriptive
BIM levels	Mono-disciplinary BIM	X	X	X	X
	Multi-disciplinary BIM	X	X	X	X
	Multi-project BIM	X	X	X	X

Within this table it will be possible to map the different components of the information system, being hardware and software, activities and processes and data. Based on the required capabilities for each of these BI maturities and BIM levels defined in the previous paragraph, it is possible to map these within the matrix. To make this clearer, an example is given below:

In case a specific dataset is only used in a descriptive way, this means its BI maturity can be defined as level 1. If this dataset furthermore is only used within single contracts, though between multiple parties, the BIM level can be defined as multi-disciplinary BIM. This means this specific dataset can be placed within the integrated BI maturity and BIM level matrix on the spot of X (see Table 3).

The components don't need to be fixed at one position in the matrix. Hardware for example can be on a different level than software, but also a specific type of data might be used on a different level than the remaining data. This therefore means within a certain component, different BI maturities and BIM levels can be recognized. The mapping of the components is done in the chapters 4, 5 and 6 (each chapter addressing one component), part of section III. Besides the components of the information system, the future opportunities in terms of BVP will also be mapped, to identify the current gap between the existing and required BI maturity and BIM level. The mapping and analysis of these is performed in chapter 7, part of section III.

SECTION II

CASE STUDY

(EXISTING SITUATION)

3. INTRODUCTION ON THE PERFORMANCE CONTRACTS

This first section involves an introduction on the performance contracts analyzed, discussing the main characteristics, to provide the necessary background information on the performance contracts within this research. Within this chapter, first of all a brief introduction on the performance contracts within this research is provided in paragraph 3.1. Thereafter, an overview is provided of the characteristics of the analyzed performance contracts in paragraph 3.2. In paragraph 3.3, the contractual objectives within the performance contracts with RWS are discussed, followed by a brief explanation of the roles of the involved parties in paragraph 3.4. At last, in paragraph 3.5, the importance of the performance contracts for each of the involved parties is discussed.

3.1. Introduction on the analyzed performance contracts

Within this research, four performance contracts at Arcadis are analyzed, in which all of them RWS is the client. Within these performance contracts, the main process is of course the maintenance planning process. Broadly seen, the maintenance planning process consists of the development of a 'Failure Mode Effect and Criticality Analysis' (FMECA) which is a structured and systematic technique for failure analysis. Here for each of the objects/components within the area, it is determined what its failure modes together with its criticality and probabilities are. Based on the outcomes of the FMECA, maintenance measures are determined within a maintenance regime and maintenance is planned within the 'Technical Management' (TM) -planning. Based on the TM-planning, maintenance tasks and services are executed, which are thereafter evaluated and analyzed, possibly resulting in adjustments and optimizations within the FMECA and TM-planning.

A lot of data is collected, processed and distributed within the performance contracts of Arcadis in order to support the maintenance planning process. The analysis done on the data however is falling behind and doesn't deliver the potential it has, especially regarding BVP contracts, where it becomes increasingly important for organizations to improve their provability of factors as those mentioned previously. The analytics capabilities are not sufficient to deliver this provability. Analysis are namely most of the times only performed on data that directly relates to the condition and functioning of an object, such as condition scores or the number of faults and defects of an object. Past performance is monitored not consequently enough, costs are not incorporated and the quality and effectivity of the maintenance measures are unknown. Durability is not analyzed either. The BI maturity and consequently the data analytics capabilities are falling behind therefore as well. Arcadis however acknowledges that they do have a lot of data, though they do not know yet how to make fully use of it, a common problem for many organizations as stated earlier on. In other words, many opportunities of data analytics are still waiting to get applied. Furthermore, fragmentized projects is another issue at Arcadis. Even though they are involved in multiple performance contracts for RWS, all of these contracts are mostly managed individually at the moment. This lack of communication and collaboration between the contracts limits the opportunity of cross-project learning and improvement.

3.2. Characteristics analyzed performance contracts

Arcadis is involved within multiple performance contracts, both for 'wet and dry' areas. The differences between the areas of these contracts is basically nothing more than whether or not the objects within the area are 'wet' (coastal/river areas) or 'dry' (rural/urban areas). The four performance contracts analyzed within this research are all 'dry'. Van Doorn is a big player concerning the dry performance contracts Arcadis is dealing with. From the in total seventeen dry performance contracts, Van Doorn takes up four in total, almost a quarter of all the dry performance contracts. The main characteristics of these four contracts are shown below in Table 4.

Table 4 – Performance contracts analyzed within research

	East Netherlands, district South (ONZ)	Mid Netherlands, district South (MNZ)	West Netherlands, district North (WNN)	South Netherlands, district Mid (ZNM)
Start of contract	01-01-2013	01-01-2016	01-01-2016	01-01-2014
End of contract	31-12-2017	01-03-2019	01-03-2019	01-01-2017
Version of contract	1.0	3.1	3.1	1.0
Area	Highways RWS East Netherlands, district South (Arnhem / Nijmegen)	Highways RWS, Mid Netherlands, district South (Utrecht)	Highways RWS, West Netherlands, district North (Alkmaar)	Highways RWS, Noord-Brabant (Eindhoven)
Maintainable objects	Oil- and gasoline separator Traffic signs and signage Road banks Road ditches Greening Wildlife crossing infrastructure Buildings (toilet, CVR) Guidance constructions Drainage Portals and brackets Playsets Area furniture Road surface Road markings	Oil- and gasoline separator Traffic signs and signage Road banks Road ditches Greening Wildlife crossing infrastructure Buildings (toilet, CVR) Guidance constructions Drainage Portals and brackets Playsets Area furniture Road surface Road markings	Oil- and gasoline separator Traffic signs and signage Road banks Road ditches Greening Wildlife crossing infrastructure Buildings (toilet, CVR) Guidance constructions Drainage Portals and brackets Playsets Area furniture Road surface Road markings Road cuts Sheet piling Drainage outlets Retaining walls Shore vegetation Curbs	Oil- and gasoline separator Traffic signs and signage Road banks Road ditches Greening Wildlife crossing infrastructure Buildings (toilet, CVR) Guidance constructions Drainage Portals and brackets Playsets Area furniture Road surface Road markings

In short it can be concluded that the four performance contracts are all more or less the same. However, it should be noted that within the maintainable objects, the contract of WNN features some extra objects. These are objects resulting from the so called 'wet' areas. Beside the extra objects, as seen in Table 4, a wet area does have consequences for the conditions of the other objects as well. Different types of asphalt are used in the particular area and road furniture, road markings and signage are exposed to wet circumstances. This has implications on the amount of cleaning/maintenance needed. Furthermore, the versions of the contracts differ, because of some being older, though these only result in minor differences such as differences in inspections. This is discussed later on as well.

3.3. Contractual objectives

The most important objective within the performance contracts of RWS is that besides maintaining the objects technically, also the functionality of the object should be improved or optimized. This means the contract is not only a maintenance contract, but also one where improvements and optimizations are communicated and appreciated. Within the 'Project Management Plan' of Van Doorn (2016) and the 'Tender Specification' of RWS (2013) the following objectives stated by RWS are written down:

- **Objective 1 Maintaining functionalities:** Based on the performance indicators availability, reliability, safety and costs (part of RAMSSHEEP) the existing functionalities need to be maintained. This means:
    - The road infrastructure needs to be maintained in such a way that the safety for both humans and the surroundings are guaranteed.

- The road infrastructure needs to be maintained in such a way that there is as little as possible hinder for the traffic and the traffic flow.
- The road infrastructure needs to be maintained in such a way that the use of the network is experienced as comfortable by the road users by taking into account theirs wishes.
- The road infrastructure needs to be maintained in such a way that the lifespan of the different components is as long as possible and that major maintenance is needed as little as possible.
- The road infrastructure needs to be maintained in such a way that the environment isn't affected, or if inescapable, at least as possible.
- The road infrastructure needs to be maintained in such a way that the values of nature within the (road) banks, shores and other green areas and water systems are maintained and where possible improved.

- **Objective 2 Insight in current state and development:** Risk in the systems, who appear on the RAMSSHEEP aspects, need to be signaled and communicated as fast as possible to RWS. In case when the qualitative development of the area differs from the expectations, this needs to be signaled and communicated as fast as possible, possibly also providing solutions.
- **Objective 3 Optimal functioning RWS:** The maintenance and management needs to be executed in such a way that RWS can primarily focus on her core activities.

3.4. Roles of involved parties in general

Within the performance contracts, between the involved parties RWS, Van Doorn and Arcadis different roles and responsibilities exist.

3.4.1. Role of RWS

RWS is the client and is owner of the assets/highways that need to be maintained. The objectives mentioned in the previous paragraphs are those developed by RWS as the owner of the assets/highways. Furthermore, RWS sets the performance criteria the area has to comply with and delivers the area data at the start of the performance contract. RWS also does periodical checks on the area, to check whether or not their area is maintained well and does comply with their performance criteria.

3.4.2. Role of Van Doorn

Van Doorn is the contractor within the performance contracts. They are contracted by RWS to perform the maintenance and management of the assets/highways. What is seen within the performance contracts is that in reality Van Doorn mainly executes the actual maintenance. They perform more or less the 'physical' activities. Here the actual maintenance tasks are part of, but also inspections and surveillances (services). Van Doorn is partly involved in the data management process, through the registration of data from their maintenance tasks and services.

3.4.3. Role of Arcadis

Arcadis is a subcontractor of Van Doorn within the performance contracts. As previously mentioned, Arcadis is the data and information manager for the maintenance work of Van Doorn. Where Van Doorn is performing the actual 'physical' activities, Arcadis in general collects and processes data and plans and arranges maintenance activities based on this data. This is the domain of data analytics. Reason why Arcadis is doing this is because of their experience and knowledge and the ability to deliver high quality. Furthermore, Arcadis is well known for its high quality MEAT (Most Economically Advantageous Tender) reports, which attracts contractors to cooperatively step into the performance contracts, because before contractors are awarded with a performance contract, a public tendering has to be won. Van Doorn herself is not able to deliver output of the same quality as Arcadis can.

3.5. Importance of the performance contract for each party

Within this paragraph, the importance of the performance contracts for each party, thus RWS, Van Doorn and Arcadis, is discussed. This importance is retrieved from the exploratory talks at the start of the research and the expert interviews held, as well as some project documents which are cited down.

3.5.1. Importance for RWS

For RWS, the maintainable area is of great importance. RWS is in the Netherlands the executive agency of the Ministry of Infrastructure and the Environment. RWS manages and develops the infrastructural works commissioned by the Ministry. It is the tasks of RWS that these infrastructural works do comply with the social importance. Concerning the highways in the Netherlands, RWS needs to take cares of this by providing smooth and safe traffic on the road and by providing reliable and useful information. Furthermore, RWS wants to be profiled as the public and leading road manager, being able to quick-witted resolve crises (Rijkswaterstaat, 2013). Even though RWS outsources the maintenance of their highways through the performance contract, they keep grip on it by stating the contractual objectives as mentioned within paragraph 3.3. Most important of these objectives are maintaining the functionalities of the highways, including the several sub-objectives as explained before (Van Doorn, 2016; Rijkswaterstaat, 2013). For RWS, it is thus of great importance that the contractual objectives are guaranteed by the work of the contractor. Therefore, they also state in their 'Tender Specification' (Rijkswaterstaat, 2013) that they require the contractor at all times to be able to show that the work done by the contractor is in line with their contractual objectives. The work should by no means be contradictory to these.

3.5.2. Importance for Van Doorn

The four performance contracts together are for Van Doorn a guarantee of work for at least three years. As a contractor, Van Doorn is dealing with a lot of competitors, so it's almost their duty to keep RWS satisfied with the work they're doing, in order to keep the relationship with RWS on good terms. Van Doorn has established several instructional documents (principles, guidelines) and templates to ensure they execute work in a certain matter, providing certain quality. The quality the client, RWS, requires to be delivered. These are mainly their 'Project Management Plan' (Van Doorn, 2016) and the 'Integral Work Plan Surveillance, Inspection & Advice' (Via Optimum, 2016). For Van Doorn, the performance contracts are thus mainly a matter of earning money and trying to stay on good terms with RWS.

3.5.3. Importance for Arcadis

The four performance contracts together do more of less have the same importance for Arcadis as for Van Doorn. Arcadis, as the data and information manager within the performance contracts, also wants to earn money and stay ahead of competitors in the competitive world they act in. Arcadis is involved in many performance contracts, altogether providing them a lot of work. Because Arcadis is aware of the fact that their competitors are not standing still in their development of new knowledge and capabilities, Arcadis themselves also keeps seeking to new opportunities. In this way it is tried to stay in the lead.

As mentioned in paragraph 3.4.3, in the field of data and information management, Arcadis is known as an experienced player. Furthermore, they are known for their high quality MEAT reports. Arcadis has a clear vision within the performance contracts for the upcoming years. One example is the use of BIM within the performance contracts, focusing on the information exchange between the management system Atrium of Van Doorn and Arcadis and the management system Ultimo of RWS through a common data exchange format. In terms of the BIM level, this BIM application is multi-disciplinary, facilitating information and data streams between multiple parties in a common format. A more thorough explanation of this BIM information exchange is provided in Appendix I. Furthermore, Arcadis sees a lot of potential within data analytics, especially within the performance contracts where they collect and process a lot of data.

4. THE HARDWARE AND SOFTWARE

The mapping of the current information system starts with the analysis on the first component of the information system of Bourgeous (2014); the hardware and software. The chapter starts in paragraph 4.1 with an analysis of the hardware, followed by an analysis of the software in paragraph 4.2. In paragraph 4.3 a comparison between the four performance contracts is given. Then the existing problems are discussed in paragraph 4.4, followed by paragraph 4.5 were the link with the theoretical framework is discussed. At las a conclusion is given in paragraph 4.6. The information within this chapter is both retrieved from case documents (Arcadis, 2015; Via Optimum, 2016; Van Doorn, 2016) and from the expert interviews held (interview shown in Appendix III, results shown in Appendix IV).

4.1. Hardware

In the current situation, a lot of hardware is used within the information system of maintenance planning of the four performance contracts. This is shown in Table 5.

Table 5 – Hardware used within the performance contracts

Hardware type	Usage
Laptop computers	To access all the different types of software. Most of the work is processed within the laptop computer. Laptops are chosen instead of desktops computers because employees can carry laptops with them. This increases their mobility.
Tablets	Used by people outside during inspections and surveillances to report their findings.
Mobile phones	Used for communication means.
Input devices (keyboard, mice, photo camera, video camera, geodetic equipment)	Keyboard and mice are used to make working on the laptops easier. Photo cameras are used to make performed tasks and activities provable. Video cameras are used to analyze the road condition (performed at the Arcadis office in Romania). Geodetic equipment is used for land surveying and GPS mapping.
Storage devices (servers, flash drivers)	To store and back-up data.
Output devices (printers)	To transfer digital files to physical documents.

The laptop computers, tablets and mobile phones can be seen as the ‘processing devices’ of the hardware. On these software is programmed used to streamline the maintenance planning process. Linked with these processing devices are the ‘input devices’ that enable input of data and information, ‘storage devices’ that enable storing and backing-up of data and ‘output devices' that enable to get the data out of the system (Bourgeous, 2014). The configuration of the hardware can be mapped within a scheme as presented in Figure 5.

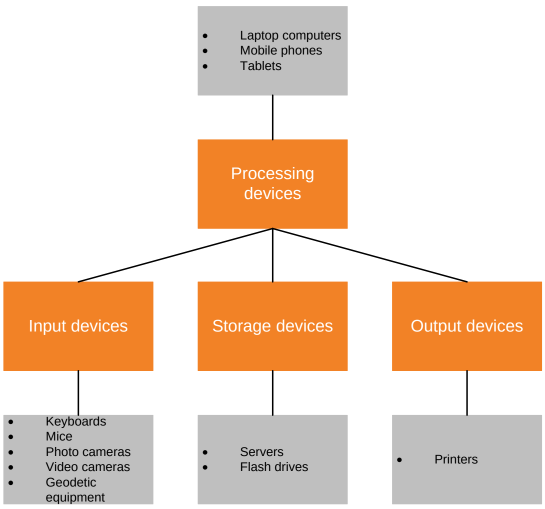

Figure 5 – Schematic overview of hardware configuration within the system

Within the four performance contracts analyzed, the hardware configuration used is the same. This means the same processing devices, input devices, storage devices and output devices are used. Because the four performance contracts are all performed within the same organizations, this conclusion is not very strange. Organizations most of the time have the same configuration throughout their whole organization or throughout individual departments (Bourgeous, 2014). As the four performance contracts all fall under the same department both within Arcadis and Van Doorn, the hardware configuration is logically the same. Furthermore, as mentioned by F. van Ruth during the interviews, the maintenance done within the performance contracts is no “rocket science”, and therefore doesn’t need very specific types of hardware. Also important to acknowledge, is that overall seen, the same activities are performed within all of the four contracts, though this is discussed in more detail in the next chapter (chapter 5). There are no specific activities that differ between the contracts and have consequences on the use of hardware.

4.2. Software

Within the four performance contracts, the operating system that is used is Microsoft’s Windows. Microsoft’s Windows is one of the most popular operating systems and almost all the software is programmed so that it can work on Windows. Furthermore, the version of Windows that is used, Windows 7 mainly, has proven that it is a very stable operating system (Bourgeous, 2014; Paul, 2015). Within this research, the application software is more interesting to analyze and above all more important. Several types of application software are used in the performance contracts. These are briefly described within the following paragraphs.

4.2.1. Ultimo – Management system

Ultimo is the management system of RWS that provides information and data about the area. This contains data about the maintenance and technical documentation. The basis of Ultimo is the decomposition of the area, based on the NEN2767, coupled to specific object information and quality scores (condition, inspection results, faults and defects, maintenance history). Based on the information within Ultimo, RWS can opt to modify their long term maintenance planning system RUPS (Rijkswaterstaat Uniforme Programmering Systeem) (Infram, 2016). Within the performance contracts, Ultimo has to be kept up-to-date of the latest developments within the area, as a result of the maintenance tasks executed by Van Doorn and Arcadis (Arcadis, 2015; Van Doorn, 2016). These can result in mutations within the following: the drawings and data, faults and defects / faults and defects register, the GIS data and the condition scores. These data types are continuously updated by Arcadis. Furthermore, RWS is kept periodically updated of the latest developments in the area by Arcadis through several reports, such as progress (every two months), inspection reports (after inspections) and weekly reports (giving an overview of last week’s activities). This will be explained in more detail within the next chapter, which elaborates the activities and processes.

4.2.2. Atrium – Management system

Atrium is the management system developed by Arcadis and used by Van Doorn and Arcadis. In Atrium, Arcadis processes the maintenance tasks, inspection reports, surveillance reports, faults and defects and the planning. Atrium is an object oriented system, based on the NEN2767 decomposition. Only two registers however within the system are not based on this decomposition, which are the faults and defects register. The reports within Atrium are shared with RWS through Ultimo, in order to keep RWS up-to-date of what is going on. Atrium is therefore the system in which Arcadis and Van Doorn process their own activities and processes. Ultimo is only updated in cases when mutations within the area have occurred, as explained within the previous paragraph. If no mutations take place, nothing in Ultimo itself will change, except that Arcadis and Van Doorn provide RWS of their latest reports. Within Atrium, for the four performance contracts separate workspaces are created (Arcadis, 2015; Van Doorn, 2016).

4.2.3. Relatics

Relatics is an object oriented cloud platform to control information within a project, which is within the analyzed cases based on the NEN2767 decomposition. Relatics makes it possible to manage the requirements, tests, risks, tasks and all other objects in a coherent network of explicitly described information (Relatics, 2016). Relatics is used by Arcadis and Van Doorn to map the object tree and functions / requirements tree. These are retrieved from the contract documents from the client, RWS. Based on the object tree and function/requirements tree, an FMECA is developed. Based on both the object and function / requirements and the FMECA, a maintenance concept that is used within the performance contracts is then formed outside Relatics. Furthermore, based on the FMECA, Arcadis and Van Doorn are able to plan the maintenance, resulting in a Technical Management (TM) planning used within Atrium. Within Relatics, just as within Atrium, four workspaces are created for each of the performance contracts. The relation between Relatics and Atrium is one-sided, which exists in the link between the FMECA within Relatics and the TM-planning based on this FMECA within Atrium. The FMECA is at least once a year updated (if necessary) based on the actual development of the area. It might turn out that the TM-planning based on the FMECA does not succeed in guaranteeing the requirements, meaning adjustments are required. Furthermore, it is continuously checked after execution of maintenance tasks within Atrium how these relate to the requirements within Relatics. This means the activities from Atrium are verified and validated to the requirements within Relatics. This verification and validation is done manually because of no direct relation from Atrium to Relatics (only the other way around, the one-sided relation as explained).

4.2.4. DTB – GIS database

DTB stands for 'Digitaal Topografisch Bestand' (Digital Topographical File). This is the topographical source of RWS and contains hundreds of assets / objects in x-, y- and z-coordinates situated at the highways and waterways of RWS. The DTB forms the topographical basis for Kerngis (Arcadis, 2015; Rijkswaterstaat, 2016). Within the performance contracts, DTB is managed by Arcadis, and adjusted in case of geographical mutations within the assets, though Van Doorn registers data after their maintenance tasks and services as well.

4.2.5. Kerngis – GIS database

Kerngis is a geographical information system (GIS) and the source of RWS in which it keeps the attribute data about the assets / objects within the area, based on the topographical information from DTB. Kerngis is used to support the maintenance and management of the assets / objects as here the attribute related information about each of the assets / objects can be found (Arcadis, 2015; Rijkswaterstaat, 2016). Within the performance contracts, Kerngis is managed by Arcadis and is adjusted in case of mutations within the attribute data, though Van Doorn registers data after their maintenance tasks and services as well.

4.2.6. DISK – Object database

DISK stands for 'Data Informatie Systeem Kunstwerken' (Data Information System Civil Structures) and is the source of RWS where it keeps its information about the civil structures in their areas. Data within DISK exist of area data (GIS), inspection results, risks and requirements for safe usage (Rijkswaterstaat, 2016). Within the performance contracts, DISK is managed by Arcadis.

4.2.7. Garantiebank – GIS database

Garantiebank (Warranty database) is based on GIS and provides RWS of information about the warranty on the objects within their area in case of faults and/or defects (Rijkswaterstaat, 2016). Within the performance contracts, Garantiebank is managed by Arcadis.

4.2.8. RUPS – Management system RWS

RUPS stands for 'Rijkswaterstaat Uniforme Programmering Systeem' (Rijkswaterstaat Uniform Programming System). RWS uses RUPS for their long term planning of the maintenance and the programming of it. RUPS retrieves its information out of inspections, and based on these inspections, it is known when what objects needs what kind of maintenance. Within the four performance contracts analyzed in this research however, this part of maintenance planning is mainly done by Arcadis through the FMECA and resulting TM-planning. Within the actual planning part of the maintenance, RUPS thus plays a minor role. However, it does provide information concerning the decomposition of the area (giving input to the object tree within Relatics), and within the whole maintenance process within the four performance contracts, advices are given by Arcadis to RWS for optimizations of the RUPS planning.

4.2.9. AutoCAD – CAD application

AutoCAD is an application that is used for 2D and 3D computer-aided design and drafting. Within the performance contracts, drawings along with their data are developed and read within AutoCAD. As-built data encompasses CAD drawings and can be seen as the most important CAD output.

4.2.10. Other: Microsoft's Word, Microsoft's Excel, PDF viewers, billing system

Besides the above listed application software, within the overall maintenance process several other programs are used. These are Microsoft's Word, Microsoft's Excel and PDF viewers. Within Word and Excel, the several reports, such as the inspections and surveillances report, are written. These are then often saved within a PDF format and send to the client, in this case, RWS. Also documents between Van Doorn and Arcadis are shared within either Word, Excel or PDF formats. At last a billing system is used to process the invoices. The billing system is not of important to the actual planning of the maintenance. It is therefore not mentioned any further within this research.

4.2.11. Overview of application software environment

The previous mentioned application software has been mapped within Figure 6 to provide an overview and show what the relations are between the multiple applications.

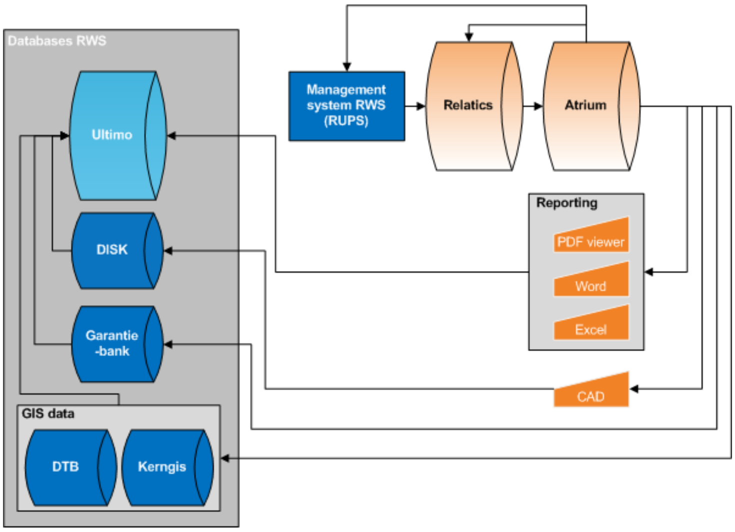

Figure 6 – Application software environment

4.3. Comparison between the performance contracts

The previous paragraphs have discussed the hardware and software used within the performance contracts. In Table 6 an overview is given of the comparison of the use of hardware and software within the four performance contracts.

Table 6 – Overview comparison component hardware and software

	Explanation	Reason and consequences
Similarity	All performance contracts make use of the same hardware involving laptop computers, tablets, mobile phones, keyboard, mice, photo camera, video camera and geodetic equipment	All the performance contracts do address in theory the same topic, not requiring specific hardware. Consequences are that equal operation and application software can be used, creating more uniformity. This is also desirable concerning both BIM and BI.
Similarity	All performance contracts make use of the same operation software being Microsoft's Windows 7.	Windows 7 has proven to be a solid operation software, being able to run all the required application software. This means throughout all the four contracts, the same foundation exists and the same application software can be used. Just as with the hardware, the use of equal operation software enables a more uniform process throughout the four contracts.
Difference	The contracts ONZ and ZNM don't make use of Relatics within their contracts. Apart from that, the same application software is used, being Ultimo, Atrium, DTB, Kerngis, DISK, Garantiebank, RUPS,	In the contracts ONZ and ZNM, Relatics isn't used, because these contracts are relatively old and at the time they stared, Relatics didn't act as a part of the system configuration. Within the contract WNN and MNZ Relatics is used, as will be done within future performance contracts. Reason is the increasing maturity of Arcadis and Van Doorn in the world of performance contracts,

	Microsoft's Word, Microsoft's Excel and a PDF viewer.	in which Relatics makes the management of data much more convenient, but also transparent and accessible, having the data stored in a single database instead over multiple spreadsheets of Excel, which could be stored everywhere.

4.4. Existing problems

During the interviews it turned out that several problems existed within the hardware and software. Within Table 7 an overview is given of these problems, as well as a brief explanation. During the interviews, additional problems came up, though those being irrelevant to the domain of BI and BIM were left out. These however are provided in Appendix VIII.

Table 7 – Overview of problems within the hardware and software

Problem	Explanation
Slow and not user-friendly Atrium, lacking a mobile reproduction and visualization capabilities	Atrium is experienced slow and not always even user-friendly, lacking also a mobile reproduction that can be used on mobile platforms. Atrium is furthermore not able to create graphs or maps showing outcomes of the data processed within the system and thus has no visualization capabilities. The increasing requirements of RWS might in the future ask for such. Also its data processing power might be questionable regarding the future increase in data.
Separate workspaces in Atrium and Relatics	Within Atrium and Relatics for each of the contracts a separate workspace is created. Between these workspaces, it is hard to share data and information, an issue concerning data analytics. A shared workspace is needed to ensure data can be made accessible and transparent between the contracts.
One-sided link between Atrium and Relatics	Between Relatics and Atrium a one-sided link exists, which is the link between the FMECA within Relatics and the TM-planning based on this FMECA within Atrium. Relatics and Atrium integrated is desirable, for on the one hand automatic verification of the requirements within Relatics and on the other hand automatic updates of the TM-planning after adjustments within the FMECA.
Lack of uniformity concerning the registration within Atrium	Within Atrium predefined fields which are mandatory to be filled in exist, but within these fields, still a lot of freedom of registration exist. This can result in differences, even though the same is meant, making analysis also more difficult. Predefined options or guidelines and principles specifically for the way of registration are needed. Uniformity in how is registered is necessary.
Manual analysis of trends, developments and optimizations within Excel	Automatic analyses by Atrium will make the analytics process more easy and faster, showing analysis on the required moments. The manual processing of the analyses now within Excel is very time-consuming and error-prone.
Processing of inspection data manually within Excel	Inspection data is now processed manually within Excel, but this could be done way more efficient in Atrium, making it also less error prone.
Integrated data management system at RWS	The same data is now often processed multiple times within the multiple data management systems (databases) of RWS (as seen in Figure 6). Besides, these systems create many data streams, sometimes contradicting ones, without having a priority in the systems, making it difficult to know what data streams should have priorities over the other. An integrated system can resolve both these issues.
No direct integration of DTB and Kerngis within Atrium	GIS data is currently not used within Atrium, although it can be used to map the problems and make the locations of objects better visible to work teams. Furthermore, such a map also can show where still maintenance activities or services need to be performed. By integration of DTB and Kerngis within Ultimo, this could be made possible.

4.5. Link with theoretical framework

Based on the analysis of the previous paragraphs, it is possible to reflect the within the theoretical framework defined BI and BIM capabilities on the hardware and software. Knowing what capabilities exist, the hardware and software can then be positioned within the integrated BI and BIM matrix.

4.5.1. BI capabilities and maturity

Within the theoretical framework, two **BI capabilities** were defined for the hardware and software. Below is elaborated how the hardware and software can be reflected against these capabilities based on the analysis within this chapter.

A scalable and extensible information foundation

- The common information foundation within all four performance contract is Atrium. Atrium is experienced slow quite often, not even dealing with the amount of data that possible will be loaded into the system through the means of future real-time data such as real-time insights in the functioning of the lightning and degradation of the asphalt. This higher volume of data complements with the higher velocity the data will obtain. It is the question whether or not Atrium will be capable of dealing with higher volumes of data with a higher velocity and is really scalable and extensible.

A proper data warehousing configuration

- The central database within the performance contracts is Atrium, although this database does not contain all information. Data from both DTB and Kerngis is not stored within Atrium, meaning Atrium lacks GIS data (also addressed in the BIM capability of integrated and coordinated infrastructure). Furthermore, reports and inspection data are developed and processed outside Atrium within Excel. Also important for data warehousing is to remove the veracity of the data, the uncertainty. Because of the freedom of registration within Atrium, this veracity remains an issue. At last, the hardware and software should support data visualization on the higher BI maturity levels, though within Atrium, no visualization techniques are supported.

Based on the reflection of the BI capabilities on the hardware and software, the BI maturity can be defined. Before this is done however, it is elaborated if there are differences between the contracts that could influence the BI maturity.

Differences between contracts: Within the contracts, no significant differences were seen that could influence the BI maturity of the hardware and software.

Concluding maturity: The performance contracts have a central data warehouse configuration in the form of Atrium, though it does lack GIS data and reports and inspection data are developed and processed outside Atrium in Excel. Furthermore, the warehouse allows veracity in the data due to the freedom it provides within the registration and lacks visualization techniques. It is above all experienced slow quite often, and the question remains if it can deal with the future amount of data and if the configuration is really scalable and extensible. Because of the above, the following is concluded:

- The BI maturity on the hardware and software can be is **descriptive analytics**.

4.5.2. BIM capabilities and level

Within the theoretical framework, one **BIM capability** was defined for the hardware and software. Below is elaborated how the hardware and software can be reflected against this capability based on the analysis within this chapter and do support a shared knowledge resource.

Integrated and coordinated infrastructure

- Within all contracts, equal hardware is used. The hardware enables the use of shared databases and servers and is capable of running the required software. Furthermore, flexibility is guaranteed by the use of both laptops and tablets. A common server is used for all four performance contracts.
- Atrium (except for the faults and defects register) and Relatics are both object oriented and make use of the same NEN2767 decomposition. This makes the exchange and communication of information between these two more straightforward and convenient, making it possible to integrate and coordinate the information about the objects.
- Access to Atrium is granted within the contracts to all parties: RWS, Van Doorn and Arcadis. Arcadis and Van Doorn both use Atrium for the storage and processing of data gathered from the maintenance activities. Arcadis on its turn can also access Ultimo, and does manage the data within Ultimo, involving collaborative working. Concerning development of the FMECA, Relatics can both be accessed by Arcadis and Van Doorn. However, Relatics is not part of the contracts ONZ and ZNM, thought it will be part of all future contracts. Interchangeability of software is possible, because of the contracts having all the same operating system. Atrium is just as Relatics, web-based and thus accessible from every location from a wide range of devices. Accessibility and transparency of the software is therefore seen.

- Atrium and Relatics do for each of the contracts have their own workspaces. The other contracts do not have access to the data stored within these workspaces. There is no common model or integrated workspace for all the contracts together limiting cross-project cooperation.
- The databases within single contracts themselves are not completely integrated with each other. Manual processing is seen between Ultimo and Arcadis. DTB and Kerngis also are not used within Atrium and act as a separate database. This shattering is also seen at the databases of RWS (see Figure 6). Relatics only has a one-sided relation with Atrium.
- Within the communication between Atrium and Ultimo, a lot of inefficiencies are seen in the form of many information flows. This should be delimited to a single information container, as now is developed with COINS and VISI (Appendix I). No single information format is used. This is seen within all performance contracts. COINS and VISI are introduced in the future performance contracts.

Based on the reflection of the BIM capabilities on the hardware and software, the BIM maturity can be defined. Before this is done however, it is elaborated if there are differences between the contracts that could influence the BIM maturity.

Differences between contracts: Within the contracts, no significant differences were seen that could influence the BIM level of the hardware and software. The lack of Relatics within the older contracts ONZ and MNZ is not seen as a significant difference, because in all future contracts, Relatics will be used.

Concluding maturity: A shared environment between all the four performance contracts is used. The same hardware and software (except Relatics in two contracts) is seen within every contract and both Atrium (except for the faults and defects register) and Relatics are based on the NEN2767 decomposition. However, within these environments, no real collaboration finds place. Atrium and Relatics even have their own workspaces, creating separate environments. Within a single contract, the involved parties RWS, Arcadis and Van Doorn share Atrium and Relatics, and Arcadis furthermore has access to the databases of RWS. The databases within single contracts are not complete integrated. However, focusing on the level where BIM is applied, a uniform environment is used throughout all four contracts, though having the focus in terms of collaboration on single contracts. Because of the separate workspaces and lack of coordination between multiple projects, but having a coordinated way of working within single contracts, despite lacking some integration, the following can be concluded:

- The BIM level on the hardware and software is **multi-disciplinary BIM**.

4.6. Conclusions

Within this chapter the BI maturity and the BIM level for the hardware and software has been determined based on a reflection of the existing capabilities on those required for the certain BI maturity and BIM level. Below in Table 8 the hardware and software are positioned within the integrated BIM and BI matrix.

Table 8 – Positioning the component hardware and software

		BI maturity			
		Level 1 Descriptive	Level 2 Diagnostic	Level 2 Predictive	Level 3 Prescriptive
BIM levels	Mono-disciplinary BIM				
	Multi-disciplinary BIM	**Hardware and software**			
	Multi-project BIM				

The table shows that especially in terms of BI maturity, a lot of improvement is possible. However, it should be acknowledged that all BI maturity levels address the same capabilities for the hardware and software. In the next chapter the BI maturity and BIM level for the second component, the activities and processes, will be determined.

5. THE ACTIVITIES AND PROCESSES

The second component of the information system according to Bourgeous (2014) is the component 'activities and processes'. Activities and processes are a series of steps that are undertaken to achieve a desired outcome or goal. To get a proper understanding of what Arcadis and Van Doorn do within the performance contracts with RWS, these activities and processes are analyzed. In this chapter the activities are discussed. This chapter starts with the specific formulated activities in paragraph 5.1. In paragraph 5.2 a comparison between the four performance contracts is given. Then the existing problems are discussed in paragraph 5.3, followed by paragraph 5.4 where the link with the theoretical framework is discussed. At last a conclusion is given in paragraph 5.5. The information about the specific activities are both retrieved from case documents (Arcadis, 2015; Via Optimum, 2016; Van Doorn, 2016) and from the expert interviews held (interview shown in Appendix III, results shown in Appendix IV).

Within this chapter, the underlying processes of the activities are not discussed. The activities themselves are explained in a great level of detail, including many of the processes already, which would make the contribution of the specific processes within this chapter minimal. However, these processes are all worked out in Appendix II. The processes are here ordered within the activities, so it becomes clear what specific processes happen within what activity.

5.1. Maintenance planning activities

Within the performance contracts, this research focuses on the maintenance planning process. The overall maintenance planning process followed within these performance contracts is seen in Figure 7. This scheme, developed by Arcadis, functions as the basis for identifying the activities, processes, and data and information streams of the maintenance planning process within this research.

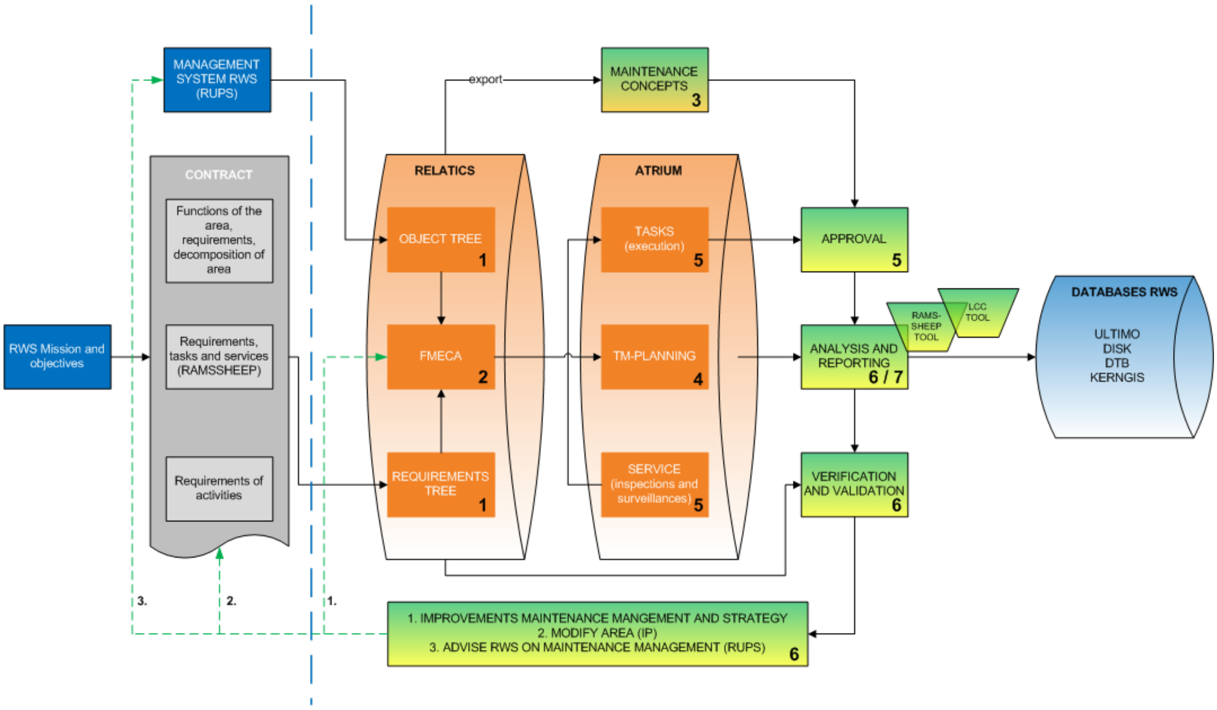

Figure 7 – Maintenance process followed within the performance contracts (Arcadis, 2016)

Within this figure, the several maintenance activities both Arcadis and Van Doorn are performing can be recognized by the numbers as specified for each activity. The whole maintenance process can be divided into seven primary activities. These activities are:

1. Contract management (development of object tree and requirements tree);
2. Risk management (development of FMECA);
3. Development of work plans and maintenance concepts;
4. Development of the TM-planning;
5. Execution of the maintenance tasks and services;
6. Analysis, verification and validation;
7. Keep up data management data within systems RWS.

In the following seven (5.1.1 till 5.1.7) paragraphs, each of these activities are discussed.

5.1.1. Contract management (development of object tree and requirements tree)

The activity contract management involves the development of an object tree and requirements tree within Relatics. As mentioned earlier on in paragraph 4.2.3, Relatics makes it possible to manage the requirements, tests, risks, tasks and all other objects in a coherent network of explicitly described information (Relatics, 2016). Relatics in other words does define what in the first place should be controlled, along with their functions, risks and failure modes.

The first step within Relatics is to get a clear definition of the object tree. Which objects need to be included? To do so, a common language is needed between the involved parties Arcadis, Van Doorn and RWS. Within all the four performance contracts, the NEN2767 is used. Although this NEN isn't considered perfect, it does guarantee consistency. Besides the NEN2767, an Object Type Library (OTL) is used, to ensure that within the project, different parties speak the same 'language'. To develop the object tree, RWS delivers area data and information. Within the OTL, definitions of relevant object types are saved, so involved parties known what is meant by these object types. Based on this information, Arcadis and Van Doorn develop the object tree. To ensure that the data retrieved from RWS is valid, inspections are done at the start of the contract to check if all objects are registered and are in the right place.

After having developed the object tree, Arcadis and Van Doorn start with the requirements tree, the second step within Relatics. First the coupling of the RAMSSHEEP and LCC aspects to the object within the object tree is done. The RAMSSHEEP analysis is a tool that enables Arcadis and Van Doorn to give a thorough and consequent judgement of the current condition of an object. Within this analyses, for each of the RAMSSHEEP aspects is determined what the risks are. This risk is on its turn determined on the possibility of occurrence and the consequences. To determine the RAMSSHEEP score, the scores of all the individual aspects are accumulated for the specific object. The scores themselves are mostly determined based on experience. The LCC aspects on their turn are a derivative of the RAMSSHEEP aspects.

Second step within the development of the requirements tree is to couple the requirements of the contract to the objects. Within the contract with RWS many requirements are prescribed, to ensure the area can perform its required functions. These functions and objectives the overall area has to fulfill with are defined earlier on within the contractual objectives of RWS, discussed in paragraph 3.3. The requirements do involve object related requirements, but also work process related requirements. However, often the requirements within the contract aren't SMART (Specific, Measurable, Achievable, Relevant and Time-bound). An important task here is to translate the contract requirements which aren't SMART to SMART requirements that can be used within the performance contract. Systems Engineering (SE) is used in this step, which is considered one of the most difficult tasks within the whole maintenance process. Furthermore, sometimes requirements contradict each other. In this case, it is checked in which document the requirement is mentioned. Here the requirements mentioned in less important documents are overruled by those mentioned in more important ones. This prioritizing may differ per performance contract. All the requirements together, after being made SMART, are collected within a requirements tree.

5.1.2. Risk management (development of FMECA)

The object tree and requirements tree do gather all of the objects along with their functions and requirements within the maintainable area. However, for successful maintenance, it should be known what risks these functions are exposed to and what the failure modes of the objects are. This results in the FMECA; the Failure Mode, Effect and Criticality Analysis. The FMECA is developed by Arcadis and Van Doorn to determine the failure modes of each of the objects functions together with their probability and effects, based on the RAMSSHEEP and LCC analysis and the requirements of the requirements tree.

This information is used to plan the maintenance activities (a different activity). Based on the failure modes, both preventive and corrective maintenance measures are developed and coupled to the failure modes of the objects. Then coupled to these measures, the surveillance and inspection frequencies/method are added. This results in a certain maintenance regime. Together with the translation of the contract requirements to SMART requirements, the development of the FMECA is also considered a very difficult tasks. The FMECA is reviewed at least once a year, to check if the failure modes correspond with what is actually happening in the area. This review is explained in more detail in paragraph 5.1.6.

In sum the FMECA does thus consists of the following for the objects within the area: failure modes, probability and effect of failure modes, maintenance measures (preventive and corrective) and the surveillance and inspection frequencies/method (Van Doorn, 2016). Together, these form the maintenance regime.

5.1.3. Development of work plans and maintenance concepts

Before the actual planning is made and the maintenance tasks and services start, the work plans and maintenance concepts are developed. The work plans are made at the start of the project, keeping in mind the requirements stated within the contract concerning the execution of activities. These work plans are developed by Arcadis and Van Doorn to try to work as uniform as possible and to meet the requirements concerning activities from the contract. Examples of these work plans are the 'Work plan data management' (Arcadis, 2015), the instructions/manual for Kerngis and DTB (Arcadis, 2016), the 'Integral Work Plan Surveillance, Inspection & Advice (Via Optimum, 2016) and the 'Project Management Plan' (Van Doorn, 2016). Furthermore, for each of the activities executed by Van Doorn within the area, it is defined within a specific work plan what the scope of the activities are, the planning, what permits/permissions/waivers are needed and what risks are present (Van Doorn, 2016).

The maintenance concepts are an output from Relatics. Together, the object tree, requirements tree and FMECA are the information that is given as input from Relatics and form the maintenance concept. These maintenance concepts are used within the maintenance process to approve the maintenance tasks on content and way of registration.

5.1.4. Development of TM-planning

Within the first two activities, the development of the object tree, requirements tree and the FMECA, in other words, the configuration of Relatics, all the information necessary to be able to develop a maintenance planning for the maintenance tasks and services within the maintenance concept is gathered. The planning of the maintenance tasks and services is included within the TM-planning. For the TM-planning it is of high importance that the FMECA with its maintenance regime is finished and approved, as based on these the planning is determined. Within the TM-planning is it mentioned what is done, where it is done, when it is done, and who it does. The TM-planning does not only involve the plan based maintenance (preventive), but also a planning for inspections and aimed surveillance. The TM-planning does of course not include corrective maintenance, as this is only done after having identified faults and defects by inspections and surveillances. Corrective maintenance is logically planned afterwards. The planning is stored within the OMS (Maintenance Management System) of the performance contracts, Atrium.

Important to acknowledge is that the TM-planning is a planning in week numbers. A daily planning is made to have clear what is done each specific day, to be able to plan the available resources in a better way. The TM-planning functions thus as a basis for the daily planning. This daily planning also incorporates corrective maintenance, as the TM-planning is merely preventive.

5.1.5. Execution of maintenance tasks and services

Having a clear planning means the execution of the maintenance tasks and services can start. The tasks can be divided within preventive/predictive maintenance tasks and corrective maintenance tasks. This is done by Van Doorn. For the maintenance tasks, permits, permissions and waivers are requested, in order to be able to execute the work. The work teams are assigned by Van Doorn. After execution, the maintenance tasks need to be approved on content and way of registration, before moving on to the analysis and reporting phase. This is explained in more detail in the next paragraph 5.1.6. If the tasks are not approved, they need to be redone or adjusted.

The services on the other hand involve the inspections and the surveillances. The services thus more focus on monitoring of the area. For the inspections, four types can be identified: the current state inspection (showing faults and defects together with their risks), the NEN2767 condition measurement (measure condition of objects), the conservation inspection (long term analysis of safe functioning of objects) and the NEN3140 inspection (electrical installations, performed by SPIE). For these inspections, inspection reports are developed and analyzed on trends and development. This is explained in more detail in the next paragraph 5.1.6. Surveillances are divided into three types which are: the general surveillance (surveillance that takes all aspects into account, not so specific), the aimed surveillance (surveillance on a specific part of the area) and juridical surveillance (checking on dangerous situations to prevent juridical claims).

The data and information retrieved from the maintenance tasks and services is all stored within Atrium. Atrium consist of several registers and storages, also mentioned in paragraph 4.2.2, such as the faults and defects register and the inspection and surveillance data. Also inspection reports are generated within Atrium, which are in a later stage not only analyzed but also communicated with RWS.

5.1.6. Analysis, verification and validation

Whereas the previous five activities focus on the development of the maintenance planning and the actual execution of the maintenance tasks and services, the analysis, verification and validation comes post completion of all these, as seen in Figure 7. The analysis, verification and validation mostly is in hands of Arcadis, although analyses are also communicated between Arcadis and Van Doorn during two weekly meetings, where Van Doorn shares their findings as well. Outcomes of the analyses are compared to the Key Performance Indicators (KPIs), which are based on the contractual requirements, gathered and processed during the development of the requirements tree. A KPI is an indicator which is used to measure whether or not a certain aspect does meet with the desired performance.

Within the maintenance process, two types of analyses are seen. One focusing on the inspections and surveillances, and one specifically focusing on the RAMSSHEEP aspects. Within the analyses of the inspections and surveillances, it is first of all checked whether or not the findings of the surveillance and inspection reports are within or outside the scope of what is defined within the contract. The findings that fall outside the scope are periodically shared with RWS. Findings that fall within the scope, and show imperfections within the current maintenance planning, are used to modify and optimize the planning process. This involves modifications and optimizations of the FMECA with its maintenance regime and thus consequently the TM-planning. This analysis is also done to check whether or not objects deviate from the (functional) requirements. At last, if objects can't be repaired anymore, an advice is given to RWS of how to solve it. This may lead to I&V proposals.

Within the risk management activity, for all objects a RAMSSHEEP score has been determined. By analyzing the object on changes in this score, trends and/or increasing risks can be identified, which may result in modifications within the maintenance regime. By comparing this score of the current condition with the score initially determined for the object, it can be seen how the condition develops over time. Together with the yearly adjustment in the FMECA (discussed below), the RAMSSHEEP is also at least once a year verified.

After the analysis of both the inspections and surveillances and the RAMSSHEEP score, verification and validation takes place. This verification checks whether or not the requirements of RWS are met. Verification is done on so called 'process' requirements and 'technical' requirements. The process requirements are verified if these are captured within certain work processes or work plans at Van Doorn. For the technical requirements the FMECA is developed, in which a certain maintenance regime is determined which is included in the TM-planning. This means, if everything from the planning is done, it is implicitly said by Arcadis and Van Doorn the technical requirements are met.

If the demands are not met, or when it is seen that optimizations can be made within the planning process, modifications may take place. These modifications can be split into three possibilities, as also seen in Figure 7. At first (1), the maintenance management and strategy within Relatics can be improved. This mostly focuses on the FMECA, where the maintenance regime is captured. It might for example be the case that certain maintenance frequencies are too low or too high, which then should be adjusted. This may thus also result in modifications within the TM-planning. The FMECA is at least updated once a year, along with the RAMSSHEEP scores. A second modification (2) is de actual modification of the area itself. In this case, in the area certain objects are constantly showing imperfections, not fulfilling their functions. This may lead to a (physical) modification on this specific object or maybe even implementing a whole new one. Such modifications do have consequences for the information stored within Relatics, mostly involving the decomposition of the area (object tree). Modifications to the area are communicated with RWS and often proposed through an I&V proposal. At last, a third modification (3) involves the advice of Arcadis towards RWS on their management system (RUPS). This management system describes, as discussed within paragraph 4.2.1, how RWS manages their long term planning of maintenance and the programming of it. Optimizations found during the maintenance process can be leveraged towards this planning.

In sum an analyses on the maintenance planning is done by analysis on the inspections and surveillances and a separate RAMSSHEEP analysis. These analyses are both reported and then verified and validated. By having this system of analysis, verification and validation, it is tried to increase the effectivity of the overall maintenance planning process and the maintenance management process.

5.1.7. Keep up data management data within systems RWS (Ultimo, DTB, Kerngis, DISK)

All of the tasks and services that are executed during the period of the performance contract, do result in bulks of data. As RWS is the client within the performance contracts, they would like to be kept updated with the latest developments within the area. Keeping RWS up to data with the latest data is done by keeping Ultimo, DTB and Kerngis up-to-date. For each of these processes, there are work plans developed by Arcadis to guarantee a uniform way of data processing (Arcadis, 2015).

For keeping Ultimo up-to-date several types of data are updated. First of all, the decomposition of the area might change as a consequence of maintenance tasks, such as the replacement of a road sign. As every object has its own code, it is necessary to update these codes after mutations within the decomposition. An example of modifications within the decomposition in Ultimo is shown within Appendix V. Secondly, the condition scores of the objects are stored within Ultimo and modified in case of degeneration or corrective/planned maintenance. Thirdly, the planning of the plan based maintenance is constantly shared with RWS, so RWS has insights in what is done every week. Fourthly, it is communicated with RWS what falls under warranty through Garantiebank (in case of replacement of elements/objects). Fifthly and last, a weekly report is stored within Ultimo which consists of multiple aspects. Within the weekly report, the inspection (including surveillance) results are included, showing what has been inspected over the last week. This also includes the faults and defects, along with their settlement. Analyses on these faults and defects are, if done, also included, so RWS gets an insight in where faults and defects for example might occur more often. Furthermore, the maintenance history of the last week is captured within these weekly reports, as well as the loss of functions of objects (caused by faults and defects or degeneration).

Besides a weekly report, also progress reports and verification reports are shared with RWS. The progress reports are developed every two months and consist of all the maintenance activities and updates in the area of the past period. This includes all the faults and defects, all the surveillance reports, the inspection reports and the maintenance history. Analyses on the inspection/surveillance results and the faults and defects are shared as well, and the analyses of the past two months are all captured within the progress reports. The progress reports thus keep RWS up-to-date of everything that has happened within the past two months, and gives RWS insights through the analyses. A fairly new phenomenon is the development of a yearly verification report. This report discusses the process and technical requirements explained in the previous paragraph 5.1.6. The report verifies if the contractual process and technical requirements of RWS are met during the last year.

Not only Ultimo should be kept up-to-date, but also the systems DTB, Kerngis and DISK. Because of the several maintenance tasks and activities, the registered GIS data within DTB and Kerngis, but also DISK in case of civil structures, might need to be modified. The databases are a very important data source for RWS, as they want to have their area mapped in high detail without mistakes. Therefore, every modification to the area, for example a replacement of road signage, should besides being registered within the decomposition, also be registered within DTB and thereafter Kerngis and in case of civil structures within DISK. Keeping these databases up-to-date is a task of Arcadis within the performance contract. They receive data from Van Doorn about the activities and process the modifications within DTB, Kerngis and DISK. By having the data matched to the real outside area, the transition to a new contract becomes easier as well, as the area within DTB, Kerngis and DISK is already up-to-date.

Concerning the speed of updating the databases of RWS, the actual data should be processed within six weeks after retrieval. However, because of inefficiencies and contradicting communication channels at RWS this deadline is often not reached. The communication about how it should be processed is very shattered at RWS, but also at Arcadis and Van Doorn. The approval to actually update the information often takes a long time because of the many channels the communication has to follow. Furthermore, at RWS it is not always clear what they actually want to have loaded in their databases and often it remains unclear who is responsible, resulting in cautious behavior.

Important to acknowledge, especially concerning BIM, is the use of an Information Document System (IDS), which is part of the contract between RWS and Arcadis and Van Doorn. IDS specifies how data should be transferred between these parties. This contract document enables a more uniform way of how data about the area is exchanged between RWS, Arcadis and Van Doorn. Such a uniformity in data exchange leverages improvement within the BIM level, although the way of how data is going to be exchanged in the future will be drastically improved, as discussed in Appendix I.

5.2. Comparison between the performance contracts

The previous paragraph discussed the maintenance activities performed within the performance contracts. In Table 9 an overview is given of the comparison of the activities and processes within the four performance contracts.

Table 9 – Overview comparison component activities and processes

	Explanation	Reason and consequences
Similarity	In general, the same seven activities and processes are identified and the contracts are almost identical	The performance contracts are quite similar in terms of the performed maintenance. All the four areas within the contracts address similar objects, and involve the same client, RWS. There is also one maintenance engineer for the four contracts taking care of the FMECA. Despite having differences in the version of the contracts, the same configuration exists (except for the use of Relatics within ONZ and ZNM). Having the same activities and configuration throughout the four contracts, stimulates collaboration and sharing of data and information.
Similarity	The same integrated resource planning by Van Doorn is used throughout all four contracts	Having similar activities and processes, also resulted in an integrated resource planning. The teams at Van Doorn execute similar maintenance tasks and services and also are used throughout all the contracts.
Difference	Development of FMECA and TM-planning differs as a consequence of project specific characteristics	The contracts are similar for around 80%. The differences exist in the fact that contracts and their areas have specific characteristics the other's don't have (such as retaining walls in WNN). This difference is inevitable, although it does have as a consequence that some data types won't be fruitful to share with other contracts. However, for future contracts also addressing these objects, it certainly is.
Difference	Despite having many principles and guidelines, it is still seen that differences exist in the way of reporting between the four performance contracts	Reason for the differences in reporting is the existing routine within the individual teams of the performance contracts. Within a specific contract, there is worked within individual teams, led by different portfolio managers. Consequence for data analytics and integrated data is that this forms an obstacle for effective comparison and analysis cross-project wise.

Difference	Differences in communication	Because of having different teams working in each project, with also different portfolio managers, communication differs as well, both between and within Arcadis and Van Doorn, but also with RWS.
Difference	In Ultimo, data is not always processed equally	Because of different project managers of RWS for each contract, different needs exist concerning the processing of data within Ultimo. WNN for example requires as the only contract urgency scores coupled to the findings. There is no explicit reason for this difference, except for preferences of the teams themselves. Consequence is that the uniformity of data is lacking, delimiting possible analytics.
Difference	Not in all four contracts the same type of inspection is used	Through the evolution of the performance contracts over time, different types of inspections are seen within the contracts. ONZ only uses condition measurements, whereas the other three all use a combination of condition measurements and current state inspections. Consequence is mainly that the findings are reported in a different way, making comparison of the findings cross-project much more difficult.

5.3. Existing problems

During the interviews it turned out that several problems existed within the activities and processes. Within Table 10 an overview is given of these problems, as well as a brief explanation. During the interviews, additional problems came up, though those being irrelevant to the domain of BI and BIM were left out. These however are provided in Appendix VIII.

Table 10 – Overview of problems within the activities and processes

Activity	Problem	Explanation
Execution of maintenance tasks and services	Lacking uniformity in reporting between the contracts	The way how data and information is reported, differs between the performance contracts, making it hard to compare the reports with each other. Uniformity is necessary and could be provided by a fixed format of reporting between all performance contracts. These differences occur in the file names or in making the reports vertically (per data category) or horizontally (per road section) concerning the decomposition.
Analysis, verification and validation	Limited sharing of trends, developments and optimizations between performance contracts	The trends and developments found within one contract are only shared during meetings, where it still remains the question if they are brought up. Other contracts in this way could miss important data and information about how to manage the maintenance planning process. A platform where this information is shared is required, coupling to the shared workspaces defined as a need within the hardware and software.
Analysis, verification and validation	Lacking analysis on and use of previous progress reports	Previous progress reports can give good insights about how and why decisions were made in the past. However, for this analysis to take place, it is important for cross-project analysis of these reports, that they are processed in the same way.
Contract management (tender phase)	Differences in working between contracts due to routines and own preferences	A standard contract for all performance contracts, not only those involving RWS, will create an even bigger database of uniform made data, making analysis more effective. It is now experienced that despite all the principles and guidelines, the four contracts still work on their own way (discussed in more detail in paragraph 5.2). This standard contract can then be used with multiple clients.
Keep up data management data within systems RWS	No integral and coordinated process of data processing and communication with the RWS databases	It often is not clear who should take responsibility for Ultimo, which leads to ineffective communication and unclear appointments, wasting time and money. The contract managers of RWS also differ for each of the performance contracts, resulting in differences in how they require the data to be loaded within Ultimo. Furthermore, RWS doesn't give an approval when data is uploaded within their systems, meaning it is often not known whether they approve the data or not.

5.4. Link with theoretical framework

Based on the analysis of the previous paragraphs, it is possible to reflect the within the theoretical framework defined BI and BIM capabilities on the activities and processes. Knowing what capabilities exist, the activities and processes can then be positioned within the integrated BI and BIM matrix.

5.4.1. BI capabilities and maturity

Within the theoretical framework, five **BI capabilities** were defined for the activities and processes. Below is elaborated how the activities and processes can be reflected against these capabilities based on the analysis within this chapter.

Uniform query and reporting

- Query and reporting is currently done within all four the performance contracts by accessing the information from Atrium and transporting it to an Excel file, where analyses take place and reports are formed. The data within Atrium is stored within the registers. Automatic analysis through Atrium (not Excel) is desirable because of the higher error proneness of manual processing.

Data mining and predictive modeling

- Within the performance contracts, data mining is basically not recognized. The analysis now done are only focusing on the (degradation) behavior of the objects within the area. These analyses are done on the surveillance and inspection data and the RAMSSHEEP scores. Based on these analysis, verified whether or not the current maintenance regime (FMECA) is sufficient and meets the KPIs. It is done to check whether or not the objects deviate from the (functional) requirements. It is not tried however to discover new insights such as past performance in terms of quality by using all the data generated within the contracts. The analyses are mainly based on descriptive analytics, thus 'what has happened?'. The data gathered within the performance contracts is all based on the past. Predictive modeling however, addressing predictive analytics, is done during the development of the FMECA, and the analyses on the inspection and surveillance data is used with the performance contracts to optimize the FMECA and its maintenance regime.
- Data of previous reports is not analyzed. This means it is difficult to understand why certain decisions were made in the past. This is in line with not analyzing past performance within the performance contracts.

Data visualization

- Data visualization is not seen within the contracts. Atrium is namely not able to perform visualization techniques, though these could be performed by other tools or dashboards that could be integrated with Atrium. For diagnostic analytics and onwards, data visualization is a very important feature, providing easy and fast insights in the data, leveraging decision-making. Only the visualization functions within Excel are used for the reports, reporting what has happened. Visualization is not used as a means to optimize analytics by providing insights in how datasets change after certain made modifications.

Optimizations and simulation

- Within the performance contracts, optimizations are specifically focused on the FMECA. There is a whole process integrated within the performance contracts that focuses on the optimization of the FMECA, and once a year, a complete update is performed. Optimizations of other processes is incrementally seen through experiences though this is seen within every industry. Simulation is not used within the performance contracts, but shows real potential. The efficiency of maintenance measures for example would be great to simulate, knowing what impact a certain maintenance measure has on the costs and quality. In this manner, the whole maintenance process can be more efficient and effective.

Analytics on semi-structured and unstructured data

- Concerning semi-structured and unstructured data, geospatial analytics is not used within the performance contracts, but shows real potential. A lot of GIS data is generated within the contracts, which could provide useful insights on the behavior of objects within a specific area. Video analytics is used within the performance contracts, in the form of video surveillances. Arcadis uses video cameras situated near the roads, to be able to monitor the roads real-time. The video images are processed by an office of Arcadis within Romania. If any worth mentioning is found, such as a fault or defect, or a sudden decrease of the condition quality, this office sends this through the office of Arcadis at Amersfoort, who then takes care of further action.

Based on the reflection of the BI capabilities on the activities and processes, the BI maturity can be defined. Before this is done however, it is elaborated if there are differences between the contracts that could influence the BI maturity.

Differences between contracts: Within the contracts, no significant differences were seen that could influence the BI maturity.

Concluding maturity: Query and reporting is done quite simple, and data mining is only performed on condition data of objects by analyzing the surveillance and inspection reports and the RAMSSHEEP scores (what has happened?). Concerning the FMECA however, preventive modeling and optimization is applied. The FMECA however is the only data source where preventive modeling is applied. Data visualization is not applied regarding analytics, also because of the lack of visualization techniques in Atrium. Furthermore, optimizations are seen in the optimization of the FMECA as said, though simulations don't take place. Unstructured and semi-structured data is only done a little through video analytics. The following can be concluded:

- The BI maturity on the development of the FMECA (and optimization) can be concluded as **predictive analytics**.
- The BI maturity on the other activities and processes can be concluded as **descriptive analytics**.

5.4.2. BIM capabilities and level

Within the theoretical framework, one **BIM capability** was defined for the activities and processes. Below is elaborated how the activities and processes can be reflected against this capability based on the analysis within this chapter.

A uniform way of working

- Throughout all the performance contracts in general the same activities and processes are identified, and the contracts themselves are also almost identical. The uniformity among the contracts concerning activities is therefore considered high.
- All of the activities are based on shared guidelines and protocols written by both Arcadis and Van Doorn. Also an Information Document System is part of the contracts, specifying how data should be transferred between Arcadis, Van Doorn, and RWS. However, despite these, it turned out that differences still exist in reporting and processing of data between the four performance contracts, caused by having different portfolio managers on the contracts for ONZ and ZNM compared to WNN and MNZ. Because of the different portfolio managers, communication with RWS concerning Ultimo also differs, because of individual preferences. At lasts, different types of inspections are used between the four performance contracts, which has its effect on the way of reporting. The content is mainly identical, though reported in a different way.
- For all the contracts, the same work teams are used by Van Doorn for the maintenance activities. This is also the result of having an integrated resource planning. Having the same teams work over all the contracts can be seen as integrated resources. This also results in a more uniform way of working by the teams of Van Doorn over all the contracts.
- Cross-project seen, activities and processes are not shared or integrated between the projects, except sometimes copying the FMECA of other contracts as a basis for a new one, and verbal exchange of new developments within a certain contract with the others through periodical meetings. This is also the result of having separate workspaces in both Atrium and Relatics. This means cross-project, only little cross-project learning is seen. There is no guided collaboration between the contracts to make use of each other's data and outcomes.

Based on the reflection of the BIM capabilities on the activities and processes, the BIM level can be defined. Before this is done however, it is elaborated if there are differences between the contracts that could influence the BIM level.

Differences between contracts: Important differences concerning integration are especially the differences in reporting and processing of data, the differences in communication with RWS and the differences in applied inspections. These all decrease the uniformity in working, limiting the transparency and accessibility of the data between the multiple contracts.

Concluding maturity: Within all four performance contracts the same activities and processes are recognized. However, because of individual preferences and different portfolio managers, it is seen that despite the existing guidelines and protocols differences exist in how data is processed and reported. Furthermore, cross-project wise no real activities or processes are shared with each other, such as analyzing trends and developments. I.e., there is very little cross-project learning. Within single projects, a uniform way of working exists. The guidelines and protocols define what roles the parties have and how they should work together. This is in reality also seen, though as said, cross-project differences exist. As this counts for all activities and processes, the following can be concluded:

- The BIM level on the activities and processes is **multi-disciplinary BIM**.

5.5. Conclusions

Within this chapter the BI maturity and the BIM level for the activities and processes has been determined based on a reflection of the existing capabilities on those required for the certain BI maturity and BIM level. Below in Table 11 the activities and processes are positioned within the integrated BIM and BI matrix.

Table 11 – Positioning the component activities and processes

		BI maturity			
		Level 1 Descriptive	Level 2 Diagnostic	Level 2 Predictive	Level 3 Prescriptive
BIM levels	Mono-disciplinary BIM				
	Multi-disciplinary BIM	**(remaining) Activities and processes**		**Development / Optimization of FMECA**	
	Multi-project BIM				

The table shows that concerning the activities and processes (except the development/optimization of the FMECA) the BI maturity is very low, addressing level 1, descriptive analytics. A lot of improvement therefore is possible. Concerning the BIM level, for cross-project purposes the activities and processes should increase their BIM level to multi-project BIM. In the next chapter the BI maturity and BIM level for the third component, data, will be determined.

6. THE DATA

The third component of the information system according to Bourgeous (2014) is 'data'. Within the process of performance contracts, a lot of data is collected, created and processed. Concerning data analytics, knowing what (kind of) data is used at the moment is of great importance. In this chapter, the use of data within the maintenance planning process is discussed. This chapter starts with the use of data within the performance contracts analyzed in paragraph 6.1. Then, in paragraph 6.2, the quality of the data is discussed. In paragraph 6.3 a comparison between the four performance contracts is given. Then the existing problems are discussed in paragraph 6.4, followed by paragraph 6.5 where the link with the theoretical framework is discussed. At last a conclusion is given in paragraph 6.6. The information about the specific data are both retrieved from case documents (Arcadis, 2015; Via Optimum, 2016; Van Doorn, 2016) and from the expert interviews held (interview shown in Appendix III, results shown in Appendix IV).

6.1. Data use within the performance contracts

Within the activities and processes discussed in the previous chapter, a lot of data is generated and used. This data is basically the most important component of the information system concerning data analytics. It is therefore very important to map the data which is now used. The data is clustered in data categories within this paragraph.

The use of data within the performance contracts is determined based on the semi-structured expert interviews Multiple contract documents also have been searched through, to check if the results of the interviews missed certain data types. These were among others the 'Work plan data management' (Arcadis, 2015), the instructions/manuals for Kerngis and DTB (Arcadis, 2016), the 'Project Management Plan' (Van Doorn, 2016) and the 'Integral Work Plan Surveillance, Inspection & Advice' (Via Optimum, 2016).

The data categories found are shown in Table 12. In this table, for each interview it is marked with an 'X' if the specific data category was mentioned in that interview. The column at the far right 'Times mentioned' shows how many times in total the data category was mentioned. Important to acknowledge however, is that many of these data categories exist of multiple types of data on themselves. So these data categories are a cluster of data too. It was however chosen to cluster these underlying data categories into one bigger category, to make things more accessible and easier to understand. An explanation of each of the data categories is provided after Table 12, in which the underlying data categories are still mentioned.

Table 12 – Data use per performance contract

No.	Data category	Christian Jurg	Henry Seigers	Rick de Boer	Floris van Ruth	Niek de Vries	Peter Bornkamp	Chris Baggerman	David Waanders	Paul Grandia	Remco Blonk	Times mentioned
1	Inspection reports		X	X	X		X			X		5
2	Faults register	X	X	X	X	X						5
3	Defects register	X	X	X	X	X						5
4	GIS data (DTB and Kerngis)		X		X				X		X	4
5	Technical condition score (inspection)	X				X				X		3
6	Condition score (surveillance)	X				X				X		3
7	I&V proposals			X	X			X				3
8	Surveillance and inspection data		X		X		X					3

9	Contract requirements	X		X								2
10	Maintenance objects	X			X							2
11	Progress reports				X			X				2
12	Work plans/ maintenance concepts			X					X			2

Inspection reports

The inspection reports are reports written after execution of the several inspections. Within these reports multiple things are included, which apply to three types of inspections (current state inspection, NEN2767 condition measurement and conservation inspection). The NEN3140 inspection is performed by SPIE, which also develops its own reports. Within the three types of inspections, it is written down what the objective quality is of the inspected object. This objective quality consists of faults, defects, a condition score (in case of the NEN2767 condition measurement) and the functioning of the object. After having determined this objective quality, Arcadis and Van Doorn are now contractually obliged to also write a chapter about the analyses done on the object, based on the outcomes of the inspections. This analyses also tells what the consequences of the outcomes are for the planning of the maintenance. The inspection reports are shared with RWS through Ultimo. The following data is captured within an inspection report (Via Optimum, 2016):

- Date of inspection;
- Current condition;
- Development of degradation compared to predicted degradation;
- Chronological process of performance and functioning;
- Influences of faults and defects on the safe functioning;
- Overview of executed maintenance activities in the period following after the previous current state inspection;
- Analyses and consequences for the planning.

Faults register

The faults register is a register within Atrium, in which all the faults are stored. With a fault is meant that an object is not functioning anymore, though not having real damage. An example is that the lightning is off. These faults can be found during the different inspections and/or surveillances. Within the faults register, for a fault multiple things are registered. These are:

- General aspects (number, date of detection, time of detection, name of detector);
- The location (road number, side, kilometer index, lane, road/bank, et cetera)
- The description (description fault, urgency score, date when happened, analysis of cause, description repair measure, resources to be used, et cetera);
- Date and time of repair (name mechanic, function, date/time start repair, data/time of finishing repair, et cetera);
- Consequent actions (action, description action);
- Financial (possibility declaration, month of billing, year of billing, accepter (yes or no), SAP number);
- Closure (detection closed (yes or no));
- Area mutation (yes or no).

Defects register

The defects register is a register within Atrium, in which all the defects are stored. With a defect is meant that an object has real damage and is thus more severe than a fault. An example is asphalt damage caused by a traffic accident. These defects can be found during the different inspections and/or surveillances. Within the defects register, for a defect multiple things are registered. These are:

- General aspects (number, date of detection, time of detection, day of detection, name of detector, financial category, et cetera);
- The location (road number, side, kilometer index, lane, rest area, status);
- The description (description defect, approach/appointments, time on spot, time fixed);
- Financial (total costs, month of billing, year of billing, SAP number);

- Closure (possible future actions, date of closure);
- Additional remarks;
- Area mutation (yes or no).

GIS data
GIS data is data that is stored both in DTB and Kerngis. The GIS data exists of the area's assets/object in x-, y- and z-coordinates (DTB), including the specific attribute data for each of these (Kerngis). In case of an area mutation, the GIS data needs to be adjusted. If such a mutation takes place, the DTB and Kerngis mutation manually needs to be processed (Arcadis, 2015; Arcadis, 2016). For every mutation and asset/object, the following is registered within DTB and Kerngis:

- General aspects (project (ID, project number and client), type of activity, and surveying data (who, date, date send to Arcadis);
- Coordinates of inside/outside bank;
- Kerngis fields (guidance construction, portals and brackets, road markets, cables et cetera);
- Mutation information (type of object (point/line/plan), object, type of mutation (DTB or Kerngis));
- Location (number, highway, lane, kilometer index, Globespotter link).

Technical condition score (inspection)
The condition score through inspections is only specifically determined within the NEN2767 condition measurement. Within this inspection, a score of 1 to 6 is given, where 1 is considered as good as new, and 6 as end of life span. The score is determined based on the extent, intensity and seriousness of the 'flaw'. The extent and intensity are determined by the inspector, the seriousness of a 'flaw' is coupled to a list according to the NEN2767. Graffiti for example is considered a small issue, whereas cracking is considered as serious. The NEN2767 is therefore a quantitative measure. Condition measurements are mainly done on objects with a higher risk.

The current state inspection is more of a qualitative kind, where is described whether or not an intervention level is exceeded and/or the object is not able to function properly anymore. The conservation inspection is qualitative, describing how should be dealt with the degeneration of an object and analyzes where the object reaches the limit of well-functioning.

Condition score (surveillance)
Conditions out of surveillance are of a qualitative kind. From both the general surveillance as the aimed surveillance, a list of flaws detected is the outcome. Findings of the surveillances are stored within the surveillance register within Atrium. An example of such a finding of a flaw is 'growth height of bank is incorrect', which means nothing more than that the grass is too tall. An urgency is then given to the findings, in terms of when to solve (for example within the next two months). Within the surveillances, no quantitative score is determined to assess the condition, as done with the NEN2767 condition measurement.

I&V proposals
The I&V proposals are the result of analyses done on the surveillance and inspection data. Based on these analyses, it can be decided to propose qualitative improvements in the area (for example, within certain corners many accidents are seen) or increase the efficiency within the maintenance planning process (for example, change of light bulbs after showing defects too often). These I&V proposals are communicated with the client, RWS, and if accepted, are executed.

Surveillance and inspection data
The surveillance and inspection data is stored within the surveillance and inspection register within Atrium. Every surveillance and inspection executed is here registered. Within these registers, the following is captured:

- General aspects (date of detection, detection by whom, type of detection (surveillance or inspection));
- The location (road number, side, kilometer index, lane, road/bank, rest areas et cetera);
- The description (object, element, flaw, description detection, urgency, in scope, damage road users, remarks for repair, time span repair);

- Date and time of repair (date/time start repair, data/time of finishing repair, maintenance crew, time needed, approval of repair (name, result, remarks), deadline of repair);
- Area mutation (yes or no).

Contract requirements
Within the contract, the functions of the area, the decomposition of the area, the requirements of the area (object/assets), the requirements of tasks and services and the requirements of the activities are mentioned. These requirements are translated to SMART requirements by Arcadis and Van Doorn.

Progress reports
Every two months a progress report is developed and shared with RWS. Within a progress report, all the activities and findings of the past two months are registered. Specifically, this means the following data is captured within the progress reports:

- Overview of all executed maintenance tasks and services;
- Overview of all faults, defects and other detections;
- Analyses done on the data retrieved within this period.

Work plans/maintenance concepts
For the maintenance planning process, many work plans/maintenance concepts are used, both by Van Doorn and by Arcadis. Van Doorn, as responsible for the maintenance tasks, has its own work instruction for its employees. Van Doorn also has its own 'Project Management Plan', in which all the processes they execute are determined (Van Doorn, 2016). Furthermore, Arcadis and Van Doorn together developed the 'Integral Work Plan Surveillance, Inspection & Advice' (Via Optimum, 2016). Arcadis on the other hand has also many work instructions, captured within their 'Work plan data management' (Arcadis, 2015). This plan contains how to work with DTB and Kerngis, how to report to the client (RWS), how to verify and validate processed data, how communication between Van Doorn and Arcadis is streamlined and what the responsibilities of the involved parties are. These reports also function as a verification to show RWS that the activities and processes are executed according predefined plan, meeting the contractual process requirements.

6.2. Data quality of the performance contracts

The quality of the data is determined by the information retrieved from the interviews held (interview results are shown in Appendix IV). Based on this information, the overall data quality and the data quality per category is determined and analyzed. However, first of all it is explained how data quality is tried to be guaranteed within the performance contracts.

6.2.1. How is data quality guaranteed?

Within the performance contracts, data quality is perceived as important. For the different categories of data, this is done in several ways.

From the interviews, it turned out that a high focus lies on getting the area data of RWS at the start of high quality. Several interviews mentioned the term 'ABC' ('Actueel' (Topical), 'Betrouwbaar' (Reliable), 'Compleet' (Complete) for the area data. To try to get it as topical, reliable and complete, at the start of ever performance contract now (and in the future), an extensive check on the area is done through inspections. The concept of 'a lack of quality at the start, gives problems at the end' counts. For the processing of the area data within DTB and Kerngis, a manual is written (Arcadis, 2015; Arcadis, 2016) as mentioned earlier on, to ensure the data is registered in the correct way. In this way, it is tried to have the GIS data and maintenance objects of the required quality. For the FMECA and TM-planning templates are developed, guaranteeing that the required information is also included within both. Furthermore, these templates provide a uniform way of working throughout all the performance contracts, making it almost a routine job, diminishing the changes of errors.

For the maintenance tasks and services (inspections and surveillances) work plans and maintenance concepts have been developed, providing both instructions about how to execute these task and services and how to process the data (Arcadis, 2015). For the maintenance tasks, an approval needs to be given before closure. This to ensure the right tasks are executed and the required results are achieved. The data generated within these tasks and services, such as the faults, defects, condition scores, inspection and surveillance data are all saved within Atrium, and predefined fields are programmed within this system, so the same type of information is registered. However, as mentioned earlier on, despite having these predefined fields, freedom of registration remains an issue within Atrium. Concerning the output of Atrium, the multiple reports, differences are seen. The inspection reports are generated by Arcadis themselves, following their own report layout. The progress reports on the other hand, are a contractual demand by RWS. Within these reports, certain predefined chapters need to be included, such as an analyses on the results of the past two months. However, even if having a proper layout and written pieces of high quality, the reports also are dependent on the quality of the data that counts as the input for them. This also applies to the I&V reports, which are purely based on the outcomes of analyses of data.

6.2.2. Data quality: an overview

The data quality has been determined based on five data quality dimensions, which are accuracy, completeness, timeliness and reliability. These data quality dimensions have been chosen based on a throughout literature review. In Table 13 the definitions used within this research for each of the data quality dimensions are provided.

Table 13 – Data quality dimensions used within research

Data quality dimension	Definition
Accuracy	The extent to which the data is capable of defining the actual value.
Completeness	The extent to which all data is retrieved, with sufficient breadth and depth for the task at hand.
Timeliness	The extent to which the data is sufficiently up-to-date for the tasks at hand.
Accessibility	The extent to which data can be retrieved fast, simple and without required actions.
Reliability	The extent to which the data is reproducible within the same context.

For each of the dimensions, the importance as well as the score on quality are defined. The data quality is determined based on the outcomes of the interviews. For each interview, the data quality was assessed for the data categories mentioned within that particular interview. Within the interviews, for each of the data categories first of all was determined what the importance of the data quality dimensions for the specific data category were by applying a ranking. This ranking is translated to the numbers 1 to 5, where the number 5 stands for high importance and the number 1 for minor importance. After the ranking of the data quality dimensions per data category, the interviewee determined the score of each data category on every quality dimension, by giving a value between 1 and 5. Here the number 1 stands for a bad and the number 5 for a good quality judgment. This means in the first place it is investigated how important the quality dimensions are for the specific data category, and in the second place how this certain data category scores on this quality dimension. The complete data quality method and data quality results are provided in Appendix VI and VII. The data quality has been determined overall seen and for each of the data categories. Within this paragraph, the results of the analysis are provided. In Figure 8 the overall quality of the area is showed.

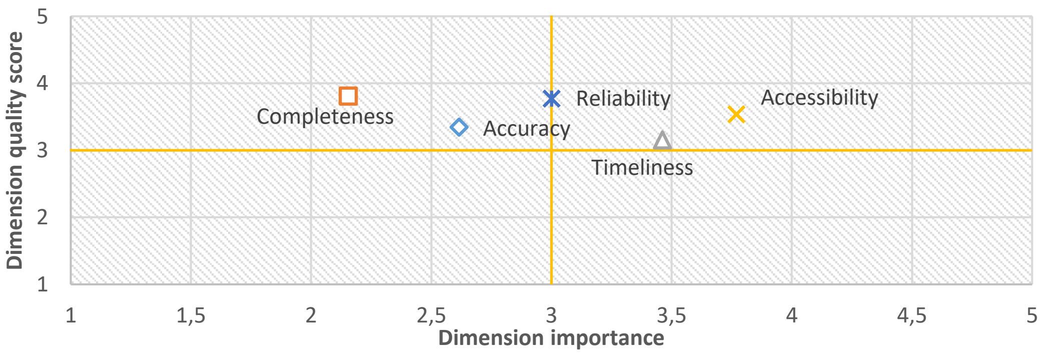

Figure 8 – Overall data quality performance contracts n = 26

The analysis showed that the overall data quality score on the data dimensions is perceived as good and that the quality dimensions completeness and accuracy are considered as most important ones. For the multiple data categories, the following data quality was found:

Inspection reports: The inspection reports score good on the dimensions reliability and completeness, while accuracy is just above the threshold of low quality. The accuracy could be higher if the reports weren't processed manually within Excel. These dimensions are also considered the most important ones. Only dimension scoring low on quality is the dimension timeliness, because of the fact that no deadlines are used for finishing of the reports.

Faults register: The faults register scores just above the threshold of a low quality score on the dimensions completeness and timeliness, which are considered most important. For data analytics, especially completeness is important, but the quality of this dimension varies with how the fields within Atrium are filled in. The freedom of registration within Atrium stays a problem. Also the accuracy and reliability depend on this registration, seen in a similar quality score. The quality scores however all score above the threshold of low quality.

Defects register: The defects register scores slightly better than the faults register having the same distribution of the data dimensions. However, also here the quality of completeness, accuracy and reliability strongly depends on how the data is registered within Atrium. The freedom of registration within Atrium stays a problem.

GIS data: The GIS data is stored within DTB and Kerngis. Most important for the GIS data is to be complete and accurate, and both score relatively well. For data analytics however, improvements can still be made. The completeness and accuracy are often lacking within the GIS data delivered by RWS and within the GIS data registered by Van Doorn. However, an extensive check before the start of the contract and the changing mindset of Van Doorn in willing to have the GIS data correct, is already increasing the quality. Because of the sometimes lacking mindset at Van Doorn, the GIS data is often not timely handed over, simply because it is forgotten or not found necessary to measure the coordinates of those objects worked on, so the team has to come back to do the measurement later on. This decreases the timeliness of the data.

Condition scores: During the interviews, quality of the condition scores (inspection and surveillance) was considered equal and the interviewees therefore gave only one score to the condition scores together. The data is considered of good quality, except the accuracy, because of the freedom of registration within Atrium.

I&V proposals: For the I&V proposals, especially the number of proposals and the type of proposal are of importance for data analytics. Therefore, the description of what kind of proposal is done, should be complete, accurate and reliable. The quality on all dimensions is good, but could be improved, since often the proposals are only mentioned on a simple memo.

Surveillance and inspection data: The surveillance and inspection data scores well on all dimensions except timeliness. The accuracy of the data also can be increased, being just above the threshold of low quality, as it is now processed manually within Excel and thereafter processed within Atrium. This should be done automatically and directly within Atrium, without using Excel. The freedom of registration in Atrium is here less of a problem because of many fixed fields which leave no room for own interpretation.

Contract requirements: The quality on all dimensions is above good, although the accuracy sits on the threshold of low quality. This connects to the fact that the quality of the requirements depends on how well the translation to the SMART requirement is done. Furthermore, often the requirements provided by RWS remain vague and abstract.

Progress reports: The progress reports have a good quality on all dimensions, where completeness, timeliness and accuracy are most important. Timeliness scores the highest quality score, because of the contractual requirement of delivering a report every two months. Completeness and accuracy score good as well, through the fixed format the reports are based on ensuring uniformity as well.

Work plans/maintenance concepts: The plans and concepts are considered having a good quality, except for the dimension timeliness. Reason for this is that the plans and concepts are not frequently updated. Regarded most important are accessibility and reliability, which both score good, though just above the threshold of low quality.

6.2.3. Data quality remarks

The first remark involves the maintenance management system that is used, Atrium. Atrium has some quality guarantees through mandatory fields that need to be filled in. However, a big problem within Atrium at the moment is the freedom of registration. Even though the fields are mandatory to fill in, not all have predefined options. Some concern open text boxes, which leaves room for own interpretations of data and consequently registration. This means the quality of the data heavily relies on the person filling the data in. This is applicable to all the registers that are saved within Atrium, though the register saving the surveillance and inspection data seems to suffer the least, as here only little fields leave room for interpretation. A more uniform way of registering the data would help greatly, especially concerning data analytics, where it is a must to compare the data with each other. Such a change however, also asks for change in the working processes at Van Doorn, who is providing most of the data.

Second remark involves the GIS data within DTB and Kerngis. It turned out that the overall quality is quite good, except for the dimension timeliness. However, this is different at the start of the project. Often stated within the interviews was, that the area data delivered by RWS at the start of the project is of a very low quality. This can involve missing objects, objects in the wrong place, missing location data of objects and missing attribute data. Even though RWS says the GIS data is one of their most important datasets, they themselves don't give the attention it should require to be of a good quality. Therefore, Arcadis is now always doing an area check before the project is started, to ensure all the GIS data is topical, reliable and complete.

6.3. Comparison between the performance contracts

The previous paragraphs have discussed the data used within the performance contracts to plan and execute the maintenance. In Table 14 an overview is given of the comparison of the data within the four performance contracts.

Table 14 – Overview comparison component data

	Explanation	Reason and consequences
Similarity	The same data categories are used	Within all contracts the same configuration of Atrium is used, where the same data registers are used. Furthermore, work plans and maintenance concepts are shared, and each of the contracts delivers the same kind of output. Having similar contractual objectives, the required data also is equal. Such a uniformity provides chances for cross-project data analytics.
Similarity	Data is registered within all projects in Atrium	Work plans and maintenance concepts are shared, resulting in equal data registration within Atrium, also keeping in mind the shared work teams as explained within the activities and processes. The same registration in Atrium makes it possible to cross-project analyze, but also stimulates to develop an integral data analytics framework.
Similarity	The quality of the data is perceived as equal	Because of the same data categories and the equal way of registration within Atrium, the quality of the data was perceived equal for all four contracts. None of the contracts is therefore lacking behind in terms of data quality on the others.
Difference	The maintenance objects from WNN differ from the other contracts	Within the contract WNN extra 'wet' maintenance objects are included, resulting in a slightly different object tree. Consequence is that cross-project analyses on these objects are not possible between the four contracts. However, future contracts also involving such objects might benefit from analyses done on these objects within WNN.

6.4. Existing problems

During the interviews it turned out that several problems existed within the data. Within Table 15 an overview is given of these problems, as well as a brief explanation.

Table 15 – Overview of problems within the data

Data category	Problem	Explanation
GIS data, maintenance objects	Poor registration of the area data involving both spatial and attribute data	Data that is received from RWS at the start of a contract, is often inaccurate and incomplete. An extensive area check by Arcadis is therefore done to guarantee that the area data is topical, reliable and complete. Attribute data is furthermore often lacking or poorly registered (consequence of lacking mindset of data management at Van Doorn), resulting in the inability of analyzing the specific attribute data. The extensive check therefore remains highly necessary.
Condition score (inspection), condition score (surveillance), faults register, defects register, surveillance and inspection data	Lacking uniformity concerning the registration within Atrium	Within Atrium predefined fields which are mandatory to be filled in exist, but within these fields, still a lot of freedom of registration exist. This can result in differences, even though the same is meant, making analysis also more difficult. Predefined options or guidelines and principles specifically for the way of registering are needed. Uniformity in how is registered is necessary.
GIS data, maintenance objects, condition score (inspection), condition score (surveillance), faults register, defects register, surveillance and inspection data	Poor registration of GIS data during and after maintenance tasks and services by Van Doorn, especially concerning attribute data	The mindset of Van Doorn is not focused on data management, but on doing the work outside as good as possible. This results often in having not the right data registered and gathered, making the tasks of data management very difficult and time consuming. For an efficient maintenance process, proper registration is necessary. Now often objects are missing, objects are not measured correctly or attribute data is not registered correctly and complete. Training or workshops might be beneficial.
Faults register, defects register	Faults and defects not based on Ultimo decomposition (NEN2767)	The faults and defects register are not based on the Ultimo (NEN2767) decomposition. This means verification of objects to the requirements within Relatics and analysis on faults and defects coupled to objects is difficult.
Surveillance and inspection data	Limited use of real-time data	Only video cameras are used now, but real-time data could and should be used much more to fasten the monitoring process and decrease the number of surveillances and inspections needed. Sensors could be applied more often, in for example measuring whether or not the lights are still working. Real-time data makes the date furthermore more topical.

6.5. Link with theoretical framework

Based on the analysis of the previous paragraphs, it is possible to reflect the within the theoretical framework defined BI and BIM capabilities on the data. Knowing what capabilities exist, the data can then be positioned within the integrated BI and BIM matrix. What should be acknowledged is that data is intertwined with the hardware and software and activities and processes. This means that for the component data both the BI and BIM capability strongly depend on how BI and BIM capable the other two components are.

6.5.1. BI capabilities and maturity

Within the theoretical framework, one **BI capability** was defined for the data. Below is elaborated how the data can be reflected against this capability based on the analysis within this chapter.

Strict and uniform registration of data, facilitating topical, reliable and complete data

- Atrium creates veracity in the data. Because of the freedom of registration within the system, data is not always registered in a uniform way, making analysis on this data difficult. The data that is stored within Atrium are the faults register, defects register, condition scores and the surveillance and inspection data. Therefore, the completeness, reliability and topicality is lacking on these categories for proper data analytics. However, reflecting against the actual scores, only the accuracy on the condition scores and the timeliness on the surveillance and inspection data scores below the threshold of good quality. Concerning data analytics, the quality might not prove sufficient though.

- The manual processing of the inspection and progress reports within Excel makes the processing more error prone. Furthermore, the extra processing step of the surveillance and inspection data between Excel and Atrium also increases its error proneness. The reports are both considered complete though, and progress reports are even written according to a fixed format.
- GIS data within DTB and Kerngis is considered relatively complete and accurate, though GIS data delivered by RWS and by Van Doorn is still often lacking quality. Within DTB often the spatial data of objects is missing or incorrect and attribute data is often missing within Kerngis. By an extensive check at the start of the contracts, the quality of the GIS data is already improved. The lacking data management mindset at Van Doorn often means GIS data is not provided in time, meaning the timeliness of the data is not sufficient. Furthermore, this lacking mindset decreases the completeness, reliability and accuracy of the data due to improper registration.
- The data categories I&V proposals, contract requirements and work plans/maintenance concepts all have a sufficient data quality, expect the timeliness of the work plans/maintenance concepts, though this is not considered relevant for data analytics.

Differences between contracts: Within the contracts, the differences on the reporting and registration of data are most trivial concerning cross-project analytics. These however do not directly influence the single project analytics.

Concluding maturity: Data in general is perceived as good, though a lot of room is left for improvement. The data registered within Atrium is all lacking the completeness, reliability and topicality required for the higher levels of data analytics. Furthermore, attribute data is often not complete, spatial data is often not correct or missing and GIS data in general often is not timely provided. Concerning the reports, it can be said that these even though they are still manually processed, score a solid data quality. All the above means data is not always strict and uniform registered, though this differs for the different data categories. Therefore, different BI maturities are seen within the data. The following can be concluded:

- The BI maturity of the data registered within Atrium (faults register, defects register, condition scores, surveillance and inspection data) is **descriptive analytics**.
- The BI maturity of the GIS attribute data within Kerngis is **descriptive analytics**.
- The BI maturity of the GIS spatial data within DTB is **descriptive analytics**.
- The BI maturity of the data categories inspection reports, I&V proposals, contract requirements, progress reports and work plans/maintenance concepts is **diagnostic analytics**.

6.5.2. BIM capabilities and level

Within the theoretical framework, one **BIM capability** was defined for the data. Below is elaborated how the data can be reflected against this capability based on the analysis within this chapter.

Transparent and accessible data for all involved parties

- All performance contracts make use of the same data categories because of the use of the same databases in all four contracts. Data quality is furthermore perceived as equal throughout the four contracts. Data however is not integrated and all contracts make use of their own databases, which connects to the lack of integration of activities and processes. Often only major events such as important developments are shared, through the mentioned verbal periodical meetings.
- Data is transparent and accessible for the parties, though being in their own projects. Atrium as the main database is accessible by all parties, and Arcadis can furthermore access Ultimo. However, not all data of the maintenance activities is stored and processed within Atrium. This is also done within many other databases, which are DTB, Kerngis, DISK and Garantiebank. The analysis and reports are even processed within Excel, after extraction of data from Atrium. There is no common database or shared workspace in which all information is stored. Data is shattered over many, both at Arcadis and Van Doorn and at RWS.

- Concerning the integration of data cross-project, no integration at all is seen, except for sometimes using old FMECA's in new performance contracts and sharing of analyses through personal communication. This is mainly because of having separate workspaces in both Relatics and Atrium.

Differences between contracts: Within the contracts, no significant differences were seen that could influence the BIM level. Only difference are some other maintenance objects within the contract WNN.

Concluding maturity: The data is only very limited shared among multiple performance contracts. No real integration of data is cross-project seen. Within single contracts, data is shared and made transparent and accessible by the use of the shared database Atrium, however the shattering of databases decreased this transparency and accessibility. Through, because of the projects build around Atrium, the following can be concluded:

- The BIM level on the data is **multi-disciplinary BIM**.

6.6. Conclusions

Within this chapter the BI maturity and the BIM level for the data has been determined based on a reflection of the existing capabilities on those required for the certain BI maturity and BIM level. Below in Table 16 the data is positioned within the integrated BIM and BI matrix.

Table 16 – Positioning the component data

<table>
<tr><td></td><td></td><td colspan="4">BI maturity</td></tr>
<tr><td></td><td></td><td>Level 1
Descriptive</td><td>Level 2
Diagnostic</td><td>Level 2
Predictive</td><td>Level 3
Prescriptive</td></tr>
<tr><td rowspan="5">BIM levels</td><td>Mono-disciplinary BIM</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Multi-disciplinary BIM</td><td>Data within Atrium</td><td rowspan="3">(remaining) Data</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Attribute data</td></tr>
<tr><td>GIS spatial data</td></tr>
<tr><td>Multi-project BIM</td><td></td><td></td><td></td><td></td></tr>
</table>

The table shows that there is a difference in BI maturity between the types of data. Especially the data within Atrium, the attribute data and the GIS spatial data can improve greatly, being on the level of descriptive analytics. However, the other data involving the data categories inspection reports, I&V proposals, contract requirements, progress reports and work plans/maintenance concepts are also only on the level of diagnostic analytics. Concerning the BIM level, it is seen that within single contracts, data is made transparent and accessible through the common system Atrium, although cross-project very little data is exchanged. Contracts only make use of each other's data very little, limiting cross-project learning.

In the next chapter, also the next section, the future opportunities of the performance contracts concerning BVP and data analytics in specific are elaborated and also mapped within the theoretical framework.

SECTION III

CASE STUDY
(FUTURE OPPORTUNITIES)

ARCADIS UNIVERSITY OF TWENTE.

7. THE POTENTIAL: FUTURE OPPORTUNITIES

Within the previous section, it was analyzed what current BI maturity and BIM level is seen on the components hardware and software, activities and processes and data. This was done based on an extensive analysis on the existing information system including the existing problems. Within this chapter, it is specifically analyzed what future opportunities in terms of analytics the performance contracts have, related to the requirements BVP and BIM might ask for. This chapter stars in paragraph 7.1 with describing the future opportunities, as well as their required BI maturity and BIM level for each of the information system's components. This makes it possible to analyze the gap between the existing BI maturity and BIM level with the ones required for the future opportunities, though this is discussed in the next section and chapter. In paragraph 7.2 the opportunities are prioritized in terms of added value, based on a workshop held at Arcadis. At last a conclusion is given in paragraph 7.3.

7.1. Future opportunities

The adoption of BVP by many agencies and governments formed the starting point of this research. This type of procurement asks for many other factors besides price, which can be, as mentioned earlier on, past performance, technical and managerial merit and financial health. Together with BVP, BIM will also be required more and more often in future performance contracts. Concerning the future opportunities, this research aims to provide new insights in the data that can be of great help in these future BVP and BIM contracts. The opportunities are based on analysis of the existing information system and the outcomes of the interviews. For each of these opportunities it is discussed below what the goal is, what the benefits are, and what the required BI maturity and BIM level is for each of the information system's components to be realized.

7.1.1. Measuring future quality of area based on RAMSSHEEP scores

It remains unclear within the performance contracts what the exact relation is between the quality of the area and the RAMSSHEEP score. Quality of the area is here defined as the ability of the area to maintain its functionalities. These functionalities were determined in paragraph 3.3. Maintaining its functionalities goes hand in hand with the number of faults and defects within the area. A high number of faults and defects indicates that many objects fail in their functionality, resulting in a lower area quality. The number of faults and defects on its turn is directly influenced by the RAMSSHEEP scores of the objects. An increasing RAMSSHEEP score means the condition of the object decreases, making it more prone to failure, and thus faults and defects. It thus can be concluded, that the overall quality of the area has an indirect, but very interesting relationship with the RAMSSHEEP scores. Within the performance contracts at Arcadis, there is a desire to know how the RAMSSHEEP scores influence the number of faults and defects and therewithal the overall quality of the area.

The goal of this first opportunity is therefore:

Being able to determine the overall future quality of the area, based on the RAMSSHEEP scores.

By achieving this goal, the following benefits can be achieved:

- Predicting the quality of the area based on the RAMSSHEEP scores, provides insights in how the area is developing. By knowing what quality of the area is expected, maintenance can be planned more effectively.
- In general, the involved parties are able to better monitor the quality of the area, resulting in less faults and defects, letting the area maintains its functionalities.

For this opportunity to be realized, the following BI maturity and BIM level is required for each of the information system's components. These have been reflected against the capabilities, just as was done at the analysis of the components themselves.

The following BI maturity and BI level is required for this opportunity:

Hardware and software

BI maturity: The hardware should facilitate readily available and accessible data, as well as supporting the actual data mining. Data visualization, optimization and more complex data mining should be supported. The required maturity is therefore **predictive analytics**.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Activities and processes

BI maturity: Analyzing the future area quality based on the RAMSSHEEP scores addresses predictive modeling and more complex data mining. Data visualization might also prove useful in showing how certain RAMSSHEEP scores in the past influenced the area's quality and how this can be reflected on the current situation. The maturity required is therefore **predictive analytics**.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Data

BI maturity: The opportunity addresses the faults and defects register and the condition scores (on which the RAMSSHEEP is based). These should be complete, reliable and topical, addressing all requirements for being at least at the **predictive analytics** maturity.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

7.1.2. Measuring costs of maintenance regime

For all involved parties, costs are an important aspect within the performance contracts. Oddly however, costs are in not involved within the whole maintenance planning process. It is not analyzed what the impact is of a certain developed maintenance regime on the costs. In other words, it is not known how costs change if other maintenance measures within the maintenance regime are chosen. Costs are completely left out. The only way in which costs are now incorporated within the performance contracts, is by checking afterwards how expensive the maintenance tasks and services were. There is no tight control on the costs, and maintenance activities are not planned and executed with having these in mind.

By knowing the impact of a certain maintenance regime on the costs, it will become clear where the money goes within the performance contracts. Furthermore, it is then possible to compare different maintenance measures and analyze how they influence the costs. Eventually, by knowing the costs of a maintenance regime, and how different maintenance measures influence these costs, beforehand can already be said what approximately the costs will be if that particular maintenance regime is opt for. Knowing costs beforehand also helps within the tender phase, by showing new clients already what the costs are of different maintenance regimes that could be applied. The other way around, the maintenance regime can be developed in such a way that it stays within the budget of the client.

The goal of this second opportunity is therefore:

Implement the costs of the maintenance measures, so the costs of the maintenance regime in total can be assessed beforehand.

By achieving this goal, the following benefits can be achieved:

- Knowing beforehand what the costs of the chosen maintenance measures within the maintenance regime are, which can be used in convincing new clients in the tender phase.
- Being able to compare the costs of multiple and different maintenance measures and their impact on the overall costs of the maintenance regime.

The following BI maturity and BI level is required for this opportunity:

Hardware and software

BI maturity: The hardware should facilitate readily available and accessible data, as well as supporting the actual data mining. Data visualization, optimization, simulation, and more complex data mining should be supported. Advanced statistical models need to be supported. The required maturity is therefore **prescriptive analytics**.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Activities and processes

BI maturity: Measuring the costs of the maintenance measures involves analyzing what the costs of the chosen maintenance regime likely will be. Having such an analysis can show and prescribe the most efficient maintenance regime, optimizing the decision-making process. It becomes clear what should be done to require the certain outcome. This addresses **prescriptive analytics**. Simulation and data visualization here can help greatly.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Data

BI maturity: The costs are not implemented within the performance contracts yet. This means that for every maintenance measure, this still should be done. To be able to analyze the costs, this required a strict and uniform way of registration. It should be clear how the costs are registered (are the costs for example per month, or per year, or per single activity?). This requires complete and reliable data. Topicality is important as well, as prices could change over time. Therefore at least the maturity of **predictive analytics** should be met.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

7.1.3. Measuring effectivity of maintenance regime

The effectivity of the maintenance regime is a very interesting and important opportunity to investigate and analyze. At the moment, the maintenance regime is based on the FMECA only, which is the result of an analysis of the RAMSSHEEP scores and the contractual requirements. Basically, the whole maintenance regime is now thus only based on the pure condition of objects, and when they can fail. However, by focusing only on the conditions of objects, the maintenance regime lacks the optimizations of the maintenance measures themselves. It is not known how effective the actual maintenance measures are, and if there are better options available.

This effectivity of the maintenance measures, and therewithal the overall maintenance regime, provides very useful information for the development of the maintenance regime. Knowing that one certain maintenance measure delivers a higher effectivity can make the difference in fulfilling to the requirements or not, and will above all save costs. By the effectivity of maintenance measures here is meant, how they succeed in guaranteeing the quality in the area. Furthermore, by knowing the effectivity of the maintenance measures, new clients can be convinced more easily, as beforehand it already can be said what maintenance measures will deliver what kind of performance. This thus, as said, also goes hand in hand with the quality of the area, as a higher effectivity of the maintenance measures will make it possible to deliver a higher quality as well.

Very interesting here is to couple the effectivity of the maintenance measures with the costs, the opportunity discussed before. By not only knowing how much a certain maintenance measure will cost, it then also is known what the effectivity of the measure is. This provides a lot of information to be able to optimize the cost-quality balance of the maintenance measures.

The goal of this third opportunity is therefore:

Determining the effectivity of the maintenance regime by analyzing how the maintenance measures succeed in delivering the required quality of the area.

By achieving this goal, the following benefits can be achieved.

- Comparing the effectivity of multiple maintenance measures to each other, which makes it possible to find the optimal measure in terms of effectivity and costs.
- Predicting beforehand what impact on the area's quality the maintenance measures have, which can be used in convincing new clients in the tender phase.
- Knowing both the costs and the effectivity of the maintenance regime, provides information for the optimization of the cost-quality balance.

The following BI maturity and BI level is required for this opportunity:

Hardware and software

BI maturity: The hardware should facilitate readily available and accessible data, as well as supporting the actual data mining. Data visualization, optimization, simulation, and more complex data mining should be supported. Advanced statistical models need to be supported. The required maturity is therefore **prescriptive analytics**.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Activities and processes

BI maturity: Analyzing the effectivity of the maintenance measures can show and prescribe the most effective maintenance regime, optimizing the decision-making process. It becomes clear what should be done to require the certain outcome. This addresses **prescriptive analytics**. Such an analysis requires strong data mining capabilities, requiring to analyze how maintenance measures effect the quality of the area. Simulation is very useful here to analyze how effective measures are. Visualization techniques can complement this.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Data

BI maturity: From the data it is required that the quality of the area can be determined. Therefore, the faults and defects and condition scores need to be registered complete, reliable and topical, just as with the first potential (assessing future quality of the area based on the RAMSSHEEP scores). This means at least the **predictive analytics** maturity is required.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

7.1.4. Measuring durability of maintenance regime

An increasingly important aspect in many future BVP contracts is durability. Also in the contracts from RWS seen at Arcadis, this factor becomes more often used. Therefore, the performance contracts need to be modified in such a way that they meet the durability requirements of future contracts. Important aspect of durability during tendering phases is the so called ‘CO_2-Prestatieladder’ which is a tooling consisting of five steps that describe how durable a tender is. This addresses mainly energy reduction, efficient use of materials and the use of durable energy. The five levels should be seen as a ladder, and the better a tender scores on durability, the higher it will be on the ladder, resulting in an advantage concerning the contract awarding.

It therefore becomes important to be able to show that the chosen maintenance measures and regime address the durability criteria. In order to do so, the measures should possess the right data describing how durable they are in the first place. For example, within a regime it can be tried to minimize the materials used, or to minimize the amount of energy, by for example reducing the number of kilometers ridden during maintenance tasks or services by combining these within a single ride. By having this data known beforehand, a strong position can be acquired in terms of durability.

The goal of this fourth opportunity is therefore:

Implement the durability of the maintenance measures, so the durability of the maintenance regime in total can be assessed beforehand

By achieving this goal, the following benefits can be achieved.

- Predicting beforehand how durable the maintenance regime is, enabling room for optimizations, eventually can be used in convincing new clients in the tender phase.

The following BI maturity and BI level is required for this opportunity:

Hardware and software

BI maturity: The hardware should facilitate readily available and accessible data, as well as supporting the actual data mining. Data visualization, optimization, simulation, and more complex data mining should be supported. Advanced statistical models need to be supported. The required maturity is therefore **prescriptive analytics**.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Activities and processes

BI maturity: Analyzing the durability of the maintenance measures can show and prescribe the most durable maintenance regime, optimizing the decision-making process. It becomes clear what should be done to require the certain outcome. This addresses **prescriptive analytics**. Such an analysis requires strong data mining capabilities, requiring to analyze how maintenance measures effect the durability of the area. Simulation is very useful here to analyze how durable measures are. Visualization techniques can complement this.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Data

BI maturity: From the data it is required that the durability of the area can be determined. Therefore, additional data that now is not registered and processes is required, such as materials used, CO_2 emissions and energy consumption. The data should be at least complete and reliable. Topicality is not that important, as analysis is basically done over past data. This means at least the **diagnostic analytics** maturity is required.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

7.1.5. Determination of error prone objects and sections

Within the performance contracts, it is seen that within certain sections of the area more faults and defects are registered. A higher number of faults and defects can indicate a more error prone section within the area. However, question remains what kind of objects are then more error prone, and how frequent the faults and defects are occurring within these particular sections. At the moment, for the faults and defects only the location and a description is registered. The faults and defects are not based on the Ultimo decomposition (NEN2767), meaning the analysis on which objects are most prone to faults and defects stays a difficult task. Furthermore, the location is not based on GIS data as well, but only on the kilometer set.

Knowing more specific what kind of objects are more prone to faults and defects from happening, as well as what areas, provides very useful information for the development of the FMECA and the maintenance regime, the basis for the whole maintenance process. It can be determined what areas are more prone, as well as the objects, allowing maintenance to be focused more onwards preventing these faults and defects from happening. Eventually, less faults and defects do result in a higher quality of the area in general.

The goal of this fifth opportunity is therefore:

Determine the error prone sections and error prone objects within the area based on the faults and defects register.

By achieving this goal, the following benefits can be achieved.

- Steering the FMECA and maintenance regime more specifically on preventing faults and defects within error prone sections.
- Steering the FMECA and maintenance regime more specifically on preventing faults and defects on error prone objects.
- An overall increase of the area's quality by a decrease of the number of faults and defects.

The following BI maturity and BI level is required for this opportunity:

Hardware and software

BI maturity: The hardware should facilitate readily available and accessible data, as well as supporting the relatively simple data mining. The required maturity is therefore **descriptive analytics**.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Activities and processes

BI maturity: The analysis focuses on determining the error prone objects and sections, based on the past faults and defects. This means it is analyzed what has happened and why. It is tried to get insight in why certain objects or sections are more prone to errors than others, in order to adjust the maintenance regime to prevent these errors from happening. The BI maturity required is therefore **diagnostic analytics**.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

Data

BI maturity: The faults and defects need to be linked to the decomposition (NEN2767). Furthermore, it is necessary to registered the faults and defects as well as the GIS and attribute complete and reliable. Topicality is considered less important, though if wanting to analyze on the error prone objects and sections of the last period (month for example), data should have been registered. However, this doesn't mean data should be immediately registered, though agreements could be made to at least do this every week for example. The BI maturity required is therefore concerned **diagnostic analytics**.

BIM level: The analysis is performed within a single project, but requires Van Doorn and Arcadis to cooperatively process and manage the data. The BIM level required is therefore **multi-disciplinary BIM**.

7.1.6. Cross-project combining datasets for analysis

Within the performance contracts, in general the same hardware and software, activities and processes and data are recognized. All performance contracts address similar types of maintenance task and services, as the areas to be maintained all involve highways of RWS. By having more or less equal contracts, datasets can be combined in order to extent the dataset and increase the reliability of the outcomes. Having more data available means the analyses have a better foundation to be executed on. The datasets that could be combined for analysis are the following:

- Faults register;
- Defects register;
- Degradation behavior of objects (condition scores).

More pragmatically, combining the datasets of the faults and defects register will provide a more reliable insight in what objects are more prone to faults and defects. Together with having a more reliable insight in how objects behave in terms of degradation through combining condition scores cross-project and analyze them, it will be known more precisely how objects develop. This will lead to optimizations within the maintenance planning of the projects and within their risk management. Having a better insight in the faults and defects as well as the conditions scores eventually provides very useful input for the opportunity discussed in paragraph 7.1.1, where the quality of the area is determined based on the RAMSSHEEP scores.

However, it should be kept in mind that not always all data just can be combined. Contracts may have different maintenance regimes through different requirements by the client. This can lead for example to a lower quality in an area compared to others leading to more faults and defects on a certain object, influencing the overall analysis on that particular object. It is therefore very important that when combining the datasets, a uniform way of working is established. Then it can provide a proper advantage.

The goal of this fifth opportunity is therefore:

Being able to combine the datasets of similar performance contracts to increase the reliability of the outcomes of the analyses on the data.

By achieving this goal, the following benefits can be achieved.

- Having a more reliable say about what objects are more prone to faults and defects, leading cross-project to a better understanding on these objects and how to optimize the maintenance regime;
- Having a more reliable say about how objects within the area degrade, leading cross-project to a better understanding of the risks on these objects and how to optimize the maintenance regime.

The following BI maturity and BI level is required for this opportunity:

Hardware and software

BI maturity: The hardware should facilitate readily available and accessible data, as well as supporting the actual data mining. Data visualization, optimization and more complex data mining should be supported. The hardware and software furthermore should support the larger datasets. The required maturity is therefore **predictive analytics**.

BIM level: The analysis is done on the combined datasets of multiple projects. This requires an integrated and coordinated infrastructure where the data of the multiple contracts can be exchanged and analyzed. The BIM level required is therefore **multi-project BIM**.

Activities and processes

BI maturity: The combined analyses will mostly be beneficial to increase the reliability of the degradation behavior of objects and their error proneness. The analyses therefore mostly focus on having a better grip on the risk management within the contracts in order to optimize the maintenance regime. Concerning risk management, it is also especially interesting to be able to predict the future behavior of the objects, involving predictive modeling. Data visualization is here very useful, to show the predicted behavior of objects over time. The BI maturity that here is applicable is therefore **predictive analytics**.

BIM level: The analysis is done on the combined datasets of multiple projects. This requires a uniform way of working between the projects, ensuring that the same is meant with the data throughout the multiple projects. The BIM level required is therefore **multi-project BIM**.

Data

BI maturity: Combining datasets requires very strict and uniform registered data, which all should be complete and reliable. Data furthermore should be up-to-date to have a proper say about the latest developments within the area. This thus requires a BI maturity of at least **predictive analytics**.

BIM level: The analysis is done on the combined datasets of multiple projects. This requires the data within all the contracts to be transparent and accessible for the other contracts. The BIM level required is therefore **multi-project BIM**.

7.1.7. Cross-project benchmarking

Data analytics provides a lot of opportunities by using data cross-project. In other words, by sharing and integration of data throughout the multiple performance contracts. Such a sharing and integration of data also stimulates the BIM level. Being able to compare the outcomes of each performance contract with each other, thus cross-project benchmarking, does provide useful insights in why for example one contracts scores a higher effectivity on the maintenance regime than the other ones. Furthermore, such benchmarks can be used at the start of future contracts providing necessary background information, but also during tenders to show how was performed in the past. Below is shown what could be benchmarked cross-project:

- The quality of area (in relation to RAMSSHEEP, number of faults and defects, number of inspections and surveillances);
- The effectivity of the maintenance regime;
- The costs of the maintenance regime;
- The error prone objects and sections;
- The follow-up time of faults and defects (the time between detection and repair);

- Progress reports provide information about the past period, such as the maintenance history, which can be compared and analyzed.

The opportunities of cross-project benchmarking are eventually all steering towards a similar goal. The goal of this seventh opportunity is namely:

Being able to learn from the other performance contracts by sharing and comparing of multiple types of data.

By achieving this goal, the following benefits can be achieved.

- The learning curve is stimulated as the different contracts not learn but also 'compete' with each other, resulting in an environment where the contracts keep stimulating each other to optimize;
- Past benchmarks provide great material to be used during tenders, to show past performances.

The following BI maturity and BI level is required for this opportunity:

Hardware and software

BI maturity: The hardware should facilitate readily available and accessible data, as well as supporting the data mining on analyses where differences are seen. Visualization techniques should be supported as well. The required maturity is therefore **diagnostic analytics**.

BIM level: The analysis is comparing the outcomes of multiple projects, requiring an integrated and coordinated infrastructure where data can be exchanged and analyzed. The BIM level required is therefore **multi-project BIM**.

Activities and processes

BI maturity: Benchmarking involves the comparison of multiple datasets, in this case of performance contracts. Concerning benchmarking it is not only interesting to see what the differences are between the contracts, but also why. Data visualization here is a great help in making clear what the differences between contracts are. Knowing why these differences occur furthermore can lead to optimizations. The BI maturity that here therefore is required is **diagnostic analytics**.

BIM level: The analysis focuses on comparing the outcomes of multiple projects, requiring a uniform way of working between the contracts to be able to analyze the same types of data. The BIM level required is therefore **multi-project BIM**.

Data

BI maturity: Comparing multiple datasets requires that these datasets are uniform. It is therefore very important that contracts register their data strict and uniform. Data should be at least complete and reliable to be compared. Topicality may be of less importance, although if there is a desire to benchmark the last period for example, all contracts should have registered the data from that period. Therefore, also topical data is required here. The BI maturity should thus be at least **predictive analytics**.

BIM level: The analysis is comparing the outcomes of multiple projects, requiring the data to be transparent and accessible between the projects. The BIM level required is therefore **multi-project BIM**.

7.2. Prioritization of opportunities

The in the previous paragraph explained opportunities, were discussed during the workshop held among three employees of Arcadis and one of Van Doorn. A brief overview of this workshop is provided in Appendix IX. The reason why the opportunities are prioritized, is that it is important to know which opportunity is perceived as most crucial to implement, so the framework can be arranged in the desired order. The prioritization was mainly based on added value for Arcadis and Van Doorn. The opportunities that during the workshop were perceived as most crucial to implement first to outcompete competitors in future (BVP) contracts were given a higher priority. Feasibility and the costs of implementation of the opportunities were taken into account during the prioritization, though these were perceived in very general terms, as these were not analyzed during this research. Therefore, the crucial factor in the prioritization was determined to be the added value.

The prioritization during this workshop resulted in a prioritization in which several opportunities were perceived equally important. Two opportunities were placed second, four opportunities were placed third. The prioritization of the opportunities resulted in the following:

1. Measuring cost of maintenance regime;
2. Cross-project combining datasets for analysis;
2. Cross-project benchmarking:
3. Determination of error prone objects and sections;
3. Measuring future quality of area based on RAMSSHEEP scores;
3. Measuring effectivity of maintenance regime;
3. Measuring durability of maintenance regime.

Measuring the costs of the maintenance regime was concerned as the most important opportunity to realize. During the workshop it was mentioned that eventually, the costs are always leading in every performance contract. Winning a tender still puts a lot of strain on the costs, even in BVP contracts (around 25% often), and by knowing these beforehand, future clients can be convinced more easily, together with the fact that the maintenance regime can be steered towards lower costs and the given budget of the client.

Cross-project combining datasets for analysis came in second place together with cross-project benchmarking. Having a better grip on the risk management will optimize the maintenance regime. Furthermore, the ability to learn from projects, both ongoing but also previous ones, does not only optimize current projects, but also future ones. By showing future clients at tenders how success was guaranteed in the past could make the difference in winning a tender or not, especially in BVP contracts, where past performance is often included as an award criterion.

Within the other opportunities, no real preferences were made. These opportunities were perceived equal in terms of importance and are therefore all numbered as ‘3’.

7.3. Conclusions

For all of these opportunities, the BI maturity and BI level was determined. A recap of all the BI maturities and BIM levels is provided in Table 17. Within this table, the opportunities are numbered in the same order as their paragraph number.

Table 17 – Recap of BI maturity and BIM levels for all opportunities

	BI maturity			**BIM level**		
Opportunity	Hardware and software	Activities and processes	Data	Hardware and software	Activities and processes	Data
1	Predictive	Predictive	Predictive	Multi-disciplinary	Multi-disciplinary	Multi-disciplinary
2	Prescriptive	Prescriptive	Predictive	Multi-disciplinary	Multi-disciplinary	Multi-disciplinary
3	Prescriptive	Prescriptive	Predictive	Multi-disciplinary	Multi-disciplinary	Multi-disciplinary
4	Prescriptive	Prescriptive	Diagnostic	Multi-disciplinary	Multi-disciplinary	Multi-disciplinary
5	Descriptive	Diagnostic	Diagnostic	Multi-disciplinary	Multi-disciplinary	Multi-disciplinary
6	Predictive	Predictive	Predictive	Multi-project	Multi-project	Multi-project
7	Diagnostic	Diagnostic	Predictive	Multi-project	Multi-project	Multi-project

Below in Table 18 the opportunities are positioned in the integrated BIM and BI matrix.

Table 18 – Positioning the opportunities

<table>
<tr><td></td><td></td><td colspan="4">BI maturity</td></tr>
<tr><td></td><td></td><td>Level 1
Descriptive</td><td>Level 2
Diagnostic</td><td>Level 2
Predictive</td><td>Level 3
Prescriptive</td></tr>
<tr><td rowspan="5">BIM levels</td><td>Mono-disciplinary BIM</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Multi-disciplinary BIM</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Multi-project BIM</td><td rowspan="3"></td><td rowspan="3"></td><td colspan="2">Data</td></tr>
<tr><td rowspan="2"></td><td>Hardware and software</td></tr>
<tr><td>Activities and processes</td></tr>
</table>

This table shows that the activities and processes both require the highest BI maturity and the highest BIM level. The data requires the highest BIM level, but not the highest BI maturity. However, as for the data predictive analytics and prescriptive analytics address the same capabilities, data is positioned at both these levels. The same counts for the hardware and software, where all BI maturity levels address the same capabilities for the hardware and software, though they should be capable of supporting the activities and processes. This means hardware and software is positioned on prescriptive analytics as well (supporting the activities and processes). The hardware and software also required the highest BIM level.

Concerning the future BVP contracts, the opportunities do address many factors. Technical and managerial merit is showed by measuring the future quality based on the RAMSSHEEP scores, determination of the error prone objects and sections, and measuring the effectivity of the maintenance regime. This shows the capability of having the maintenance regime in control. Measuring the costs of the maintenance regime shows technical and managerial merit as well, though it also provides a better insight in the costs factor. Durability is furthermore addressed by being able to measure the durability of the maintenance regime. Cross-project learning is facilitated by cross-project combined datasets for analysis and cross-project benchmarking. This also enables past performance to be measured, by having a lot of benchmarks and past analyses from multiple projects. All these together eventually will result in an optimization of the maintenance regime and the performance contract in general, increasing the effectivity and efficiency and therefore lowering the costs, still an important factor within BVP. The opportunities thus address the BVP factors costs, quality, past performance, technical and managerial merit and durability. Financial health is not addressed by these opportunities, though this factor is more related to the organization/department itself, instead of the performance contracts.

For measuring the costs and durability of the maintenance regime, the required data is not yet implemented within the performance contracts. The costs and durability aspects should be implemented in order to actually measure these. Analysis on these is therefore not possible at the moment though should be realized in the nearby future.

The in this chapter discussed opportunities and their maturity will in the next chapter be compared to the already determined BI maturity and BIM level of the information system's components. This will show the existing gaps in the maturity that need to be addressed before implementation of those opportunities can take place. Based on the prioritization, the next chapter provides the concrete steps to be taken by Arcadis and Van Doorn to increase their BI maturity and BIM level to be able to implement the data analytics opportunities.

SECTION IV

OUTCOMES

8. THE STEP-WISE FRAMEWORK

This chapter involves the final step of the research, providing the step-wise framework. This framework is based on the existing gaps in the BI maturity and BIM level. This chapter starts in paragraph 8.1 with a comparison of the existing BI maturity and BIM level of the information system with those required by the opportunities. Thereafter, in paragraph 8.2 the concrete steps are provided for Arcadis and Van Doorn, that will help them in increasing both their BI maturity and their BIM level. In paragraph 8.3 these concrete steps are translated to the step-wise framework Arcadis and Van Doorn need to follow, incorporating the prioritization of the opportunities.

8.1. Existing versus required BI maturity and BIM level

The BI maturity and the BIM level of the information system's components and the opportunities were determined in the previous two sections. These are put together into one matrix, as presented in Table 19. The in red text positioned components address the existing BI maturity and BIM level of the hardware and software. The in blue text positioned components address the existing BI maturity and BIM level of the activities and processes. The in green text positioned components address the existing BI maturity and BIM level of the data. The in orange text positioned components at last address the BI maturity and BIM level the components require for the opportunities to be realized. In the next paragraph, it is assessed what is needed to fill the gap between the existing BI maturity and BIM level, and the required ones.

Table 19 – Overview of the information system's maturity and required maturity of the opportunities

<table>
<tr><th></th><th></th><th colspan="4">BI maturity</th></tr>
<tr><th></th><th></th><th>Level 1
Descriptive</th><th>Level 2
Diagnostic</th><th>Level 2
Predictive</th><th>Level 3
Prescriptive</th></tr>
<tr><td rowspan="9">BIM levels</td><td>Mono-disciplinary BIM</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Multi-disciplinary BIM</td><td>Hardware and software</td><td rowspan="5">(remaining) Data</td><td rowspan="5">Development / Optimization of FMECA</td><td rowspan="5"></td></tr>
<tr><td>(remaining) Activities and processes</td></tr>
<tr><td>Data within Atrium</td></tr>
<tr><td>Attribute data</td></tr>
<tr><td>GIS spatial data</td></tr>
<tr><td rowspan="3">Multi-project BIM</td><td rowspan="3"></td><td rowspan="3"></td><td colspan="2">Data</td></tr>
<tr><td rowspan="2"></td><td>Hardware and software</td></tr>
<tr><td>Activities and processes</td></tr>
</table>

8.2. The concrete steps

Within this paragraph, for both the BI maturity and the BIM level, it is discussed what capabilities need to improve. This is done in a step-wise manner, by analyzing for each next BI maturity or BIM level what is necessary.

8.2.1. Increase BI maturity

The BI maturity as defined consists of three maturity levels, involving four analytical levels, which are descriptive analytics, diagnostic analytics, predictive analytics and prescriptive analytics (Williams & Thomann, 2003; Puget, 2015). In Figure 9 the BI maturity process is schematized, showing the four analytics levels, as well as the processes A, B, C and D, which consist of the necessary steps to be followed in order to reach the specific following maturity level. The levels can only be assessed in a sequential manner, meaning no maturity level can be skipped. Below, for each of these processes, it is discussed what needs to be done for each of the analyzed components of the information system.

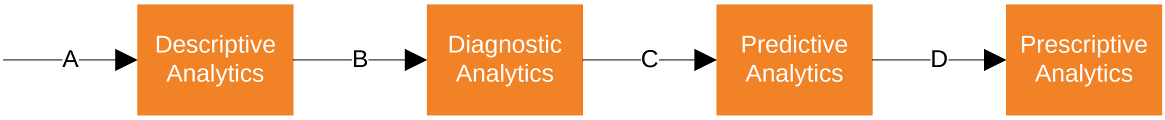

Figure 9 – BI maturity process

Process A – Towards descriptive analytics

Descriptive analytics involves analytics on 'what has happened?'. Out of the mapping of the BI maturity it turned out that all of the components possess this first BI maturity level. This means no steps are necessary to be taken, as the maturity level is already present. However, to be able to extent the range of analytics possibilities, being able to perform analytics on semi-structured and unstructured data is very promising. This step is therefore seen as an optimization that is beneficial within all analytics levels:

- **Analytics on semi-structured and unstructured data:** Within the performance contracts, only little analysis is done on semi-structured and unstructured data. Video analytics is applied, but should be used much more. Furthermore, geospatial analytics on GIS data provides useful input for the opportunity to determine the error prone sections but is lacking at the moment.

Process B – Towards diagnostic analytics

Diagnostic analytics involves analytics on 'why did it happen?'. Out of the mapping of the BI maturity it turned out that the hardware and software, the (remaining) activities and processes, the data in Atrium, the attribute data and the GIS spatial data do not possess this second BI maturity level. Therefore, below it is discussed what is required to reach this maturity. For the component hardware and software, the following concrete steps are required:

- **A scalable and extensible information foundation:** Diagnostic analytics requires more processing capacity of the information foundation to analyze why events happened. The increase of data for this type of analytics, means the information foundation should support the growing volume, variety and veracity of the data. The future will turn out whether or not Atrium is sufficient for this.
- **A proper data warehousing configuration:** Atrium acts as the central database, though GIS data and Relatics are not integrated. For proper analytics integral data is required which facilitates easier analyses on the data. The configuration furthermore needs to have data visualization techniques.

For the component activities and processes (besides development/optimization of FMECA), the following concrete steps are required:

- **Uniform query and reporting:** Reporting is not in all contracts the same, making it difficult to analyze the reports of the multiple performance contracts. A uniform way of reporting is required. Furthermore, the manual processing of data within Excel should be automatically done in Atrium, to decrease the data's error proneness.
- **Data mining:** This phase requires relatively simple data mining, though the current analysis only focuses on the (degradation) behavior of the objects within the area, on what happened. A shift should be made towards analyzing also why certain objects behave in a certain matter for example. This requires the broadening of the mindset from only object focused to the broader maintenance aspect within he performance contracts. This requires (statistical) models, as well as the know-how of the users to operate these. This modeling however is not elaborated within this research.

- **Data visualization:** For diagnostic analytics data visualization might prove useful to make the outcomes of analysis easily interpretable. This requires the following:
  - *A separate tool or dashboard:* A separate tool or dashboard is required as Atrium is not capable of this visualization. This tool or dashboard can then be integrated within Atrium.
- **Optimizations and simulations:** Optimizations should be part of this analytics level, leveraging optimizations based on the analysis on why certain events happened. This now only happens with the FMECA. Optimizations should be supported by the activities and processes.
- **Analytics on semi-structured and unstructured data:** This capability has already been assessed at descriptive analytics.

For the component data, involving the attribute data within Kerngis, the GIS spatial data within DTB and the data within Atrium (faults register, defects register, condition scores, surveillance and inspection data), the following concrete steps are required:

- **Strict and uniform registration of data, facilitating reliable and complete data:** Analyses on why events happened requires historical data, which should be reliable and complete in order to receive proper outcomes. Now often the data is incomplete as well as unreliable. This involves the following:
  - *Better registration of data during and after maintenance tasks and services by Van Doorn, especially concerning attribute data:* The lacking data management mindset of Van Doorn results in poor registration of the maintenance data. For analysis on this historical data, Van Doorn should collect and process the data properly. However, it remains unclear often at Van Doorn what data they should collect and process. Training and more detailed principles and guidelines are necessary.
  - *Uniformity concerning the registration within Atrium:* Data to be analyzed needs to be uniformly registered. Veracity in data is undesirable. The freedom of registration within Atrium still creates this veracity. Data registration should be stricter and guided. A guideline might be fruitful for the registration within the not predefined fields.
  - *Better registration the GIS attribute and spatial data:* Area data should be reliable and complete, which often not is the case now. This both involves the attribute data within Kerngis and the spatial data within DTB. Arcadis should keep doing the extensive area checks before the contracts start, as RWS has the area data often not correctly mapped. This also connects to the poor registration of data by Van Doorn during and after maintenance tasks, as they also register the attribute and spatial data gathered at these maintenance tasks.

Process C – Towards predictive analytics

Predictive analytics involves analytics on 'what will happen?'. Out of the mapping of the BI maturity it turned out that only the development/optimization of the FMECA possesses this BI maturity level. Therefore, below it is discussed what is required for each of the components to reach this level. For the component hardware and software, the following concrete steps are required:

- **A scalable and extensible information foundation:** Predictive analytics requires more processing capacity of the information foundation. The increase of data for this type of analytics, means the information foundation should support the growing volume, variety and veracity of the data. The future will turn out whether or not Atrium is sufficient for this.
- **A proper data warehousing configuration:** This capability has already been assessed at diagnostic analytics.

For the component activities and processes (besides development/optimization of FMECA), the following concrete steps are required:

- **Uniform query and reporting:** This capability has already been assessed at diagnostic analytics.
- **Data mining:** The contracts are not focusing on data mining and predictive modeling at the moment, as analytics is mostly done on the past. The statistical models to actually perform the data analytics are not included in this research, though they are crucial for predictive modeling. Increasing the analytical

capabilities might also require training of the data employees, as they are currently not involved with such kind of analytics and use of (statistical) models to perform data analytics.

- **Data visualization:** This capability has already been assessed at diagnostic analytics.
- **Optimizations and simulations:** Besides optimizations, at this analytics level simulations are a great help in predicting future data. Excel is able of doing simulations, though this again requires manual processing which is not desired. Simulations should therefore be running within Atrium, though it is not sure whether or not Atrium is capable of this. If Atrium is not capable, this requires an integrated tool that does this.
- **Analytics on semi-structured and unstructured data:** This capability has already been assessed at descriptive analytics.

Now all data is on the maturity level of diagnostic analytics, the following concrete steps are:

- **Strict and uniform registration of data, facilitating topical, reliable and complete data:** Whereas descriptive and diagnostic analytics mostly rely on reliable and complete data, at predictive analytics, topical data becomes important as well. To improve the topicality of the data, the following is of importance:
  - *Real-time data:* The inspections and surveillances requires human resources, which are not always available. Real-time data increases the amount of data available, making the dataset to analyze bigger. Furthermore, data becomes readily available, making it more topical. Analysis then can be done on the latest data, including the latest developments within the area and the performance contract. Examples of real-time data that could prove useful are insights in the functioning of the lightning (light output) and the degradation of the asphalt through sensors.

Process D – Towards prescriptive analytics

Prescriptive analytics involves analytics on 'what should I do?'. Out of the mapping of the BI maturity it turned out that none of the components possess this fourth and last BI maturity level. Therefore, below it is discussed what is required for each of the components to reach this level. For the component hardware and software, the following concrete steps are required:

- **A scalable and extensible information foundation:** Prescriptive analytics requires even more processing capacity of the information foundation. The increase of data for this type of analytics, means the information foundation should support the growing volume, variety and veracity of the data. Especially for prescriptive analytics, it is the question if Atrium is sufficient.
- **A proper data warehousing configuration:** This capability has already been assessed at diagnostic analytics.

Now all activities and processes are on the maturity level of predictive analytics, the following concrete steps are required:

- **Uniform query and reporting:** This capability has already been assessed at diagnostic analytics.
- **Data mining:** For prescriptive analytics, even higher analytics capabilities are required. The (statistical) models are not included in this research, though they are crucial for prescriptive modeling. Increasing the analytical capabilities might also require training of the data employees, as they are currently not involved with such kind of analytics and (statistical) models.
- **Data visualization:** This capability has already been assessed at diagnostic analytics.
- **Optimizations and simulations:** Both optimizations and simulations are required within this section to leverage the potential of prescriptive analytics. This capability has already been assessed at predictive analytics.
- **Analytics on semi-structured and unstructured data:** This capability has already been assessed at descriptive analytics.

For the component data, the following concrete steps are required:

- **Strict and uniform registration of data, facilitating topical, reliable and complete data:** Data requires to be topical, reliable and complete. This capability has already been assessed at diagnostic and predictive analytics.

8.2.2. Increase BIM level

The BIM level as defined consists of three levels, which are mono-disciplinary BIM, multi-disciplinary BIM and multi-project BIM (Adriaanse, 2014). In Figure 10 the BIM level process is schematized, showing the three levels, as well as the processes A, B and C, which involve the necessary steps to be followed in order to reach the specific level. The levels can only be assessed in a sequential manner, meaning no level can be skipped. Below, for each of these processes, it is discussed what needs to be done for each of the analyzed components of the information system.

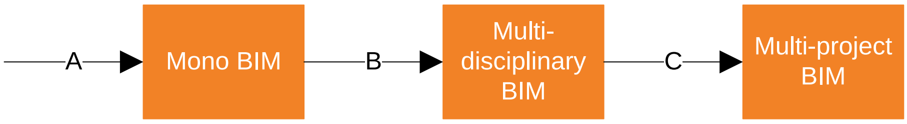

Figure 10 – BIM level process

Process A – Towards mono-disciplinary BIM

Mono-disciplinary BIM involves the use of BIM within a single discipline. Out of the mapping of the BIM level it turned out that all of the components possess this first BIM level. This means no steps are necessary to be taken. However, for mono-disciplinary BIM, three optimizations are still possible; two concerning the integrated and coordinated infrastructure and one concerning the data. For the component hardware and software, the following concrete steps are required:

- **Integrated and coordinated infrastructure:** BIM requires an integrated and coordinated infrastructure, which is the foundation for transparent and accessible data for all involved parties, or within mono-disciplinary BIM, for all involved people within the single discipline. An integrated and coordinated infrastructure facilitates a common place where data is processed.
    - *Integrated Relatics and Atrium:* Atrium and Relatics are now separate databases, only connected through a one-sided link from Relatics to Atrium in the form of the FMECA, where in Atrium the TM-planning is based on. Because they are both object oriented and based on the same decomposition, the NEN2767, information about the objects can be integrated. Integration of these two creates a common model in which the data of the objects is stored, but also facilitates automatic adjustments in the FMECA and automatic verification to the requirements.
    - *Integration of GIS data through DTB and Kerngis within Atrium:* Integration of GIS data through DTB and Kerngis within Atrium is a huge optimization which enables direct processing of mutations of the objects, instead of having separate databases requiring extra manual processing.

For the component data, the following concrete steps are required:

- **Transparent and accessible data for all involved parties:** To be able to share and exchange data between the involved ones within a single discipline, the data itself should be transparent and accessible. For the performance contracts, this involves the following:
    - *Faults and defects register based on NEN2767:* Within Atrium, the only two registers not based on the Ultimo NEN2767 decomposition are the faults and defects register. For having a uniform framework in which all the objects and their attributes can be listed, based on the NEN2767 decomposition, it is required to have the faults and defects mapped as well registered based on this decomposition. Faults and defects can then be stored within the depository of the object.

Process B – Towards multi-disciplinary BIM
Multi-disciplinary BIM involves the use of BIM between multiple disciplines. Out of the mapping of the BIM level it turned out that all of the components possess this second BIM level. This means no steps are necessary to be taken.

Process C – Towards multi-project BIM
Multi-project BIM involves the use of BIM cross-project, enabling multiple projects to use each of their others data and information. Out of the mapping of the BIM level it turned out that none of the components possess this third and last BIM level. Therefore, below it is discussed what is required for each of the components to reach this level. For the component hardware and software, the following concrete steps are required:

- **Integrated and coordinated infrastructure:** Multi-BIM requires integrated and coordinated infrastructure, facilitating a common used infrastructure between the multiple projects. For the performance contracts, this capability involves the following:
    - *Shared workspace within Atrium and Relatics:* A shared workspace/database is required to share data between projects, thus being necessary to make data transparent and accessible for the involved parties, being RWS, Arcadis and Van Doorn.
    - *Integrated data management system at RWS:* Many databases exist within the management system, being Ultimo, DISK, Garantiebank, DTB and Kerngis. Though they store different types of data, for effective communication between Atrium (Arcadis and Van Doorn) and RWS it is important to have a common database or a common data exchange format. Within the contracts, the latter is under development in the form of COINS and VISI (discussed in Appendix I). Communication with RWS differs between the multiple contracts.

For the component activities and processes, the following concrete steps are required:

- **A uniform way of working:** To be able to share and exchange data between multiple projects, a uniform way of working is required between these. For the performance contracts, this involves the following:
    - *Uniformity in reporting between the contracts*: Concerning the uniformity of data, it is extremely important within the activities and process that the data is uniformly processed and reported within single contracts, but especially between multiple projects. A common data processing and reporting format enables exchange of data between multiple projects, but also making the data transparent and accessible of one project for another. However, despite having many principles and protocols, differences exist between the contracts, because of different portfolio managers and existing routines. Training and workshops could be held to make the importance of the uniformity clear.
    - *Integral and coordinated process of data processing and communication with the RWS databases:* Connecting to the need of having an integrated data management system at RWS, an integrated process of data processing and communication with the RWS databases is necessary. No differences should be seen between the contracts in this processing and communication. This also connects to the uniformity in data processing and reporting, which is the basis for the data processing and communication with the RWS database.
    - *Sharing of trends, developments and optimizations between performance contracts:* Sharing the trends, developments and optimizations cross-project is important to be facilitated, even though there is a shared workspace/database. The activities and processes should be steered into a culture where this is done.
    - *Standard contract:* Having a standard contract facilitates a more uniform way of working over all the contracts. Multi-project wise, this stimulates the integration and coordination of the four performance contracts. Such a standard contract could even be transferred towards the other performance contracts at Arcadis, increasing the overall uniformity of these.

For the component data, the following concrete steps are required:

- **Transparent and accessible data for all involved parties:** To be able to share and exchange data between multiple projects, the data itself should be transparent and accessible. For the performance contracts, this involves the following:
    - *Uniformity concerning the registration within Atrium:* Whereas the activities and process focus on how data should be processed and reported, this data aspect focuses on the actual uniformity in terms of the data itself. Between the multiple projects it should be made clear what data is wanted to be processed and reported. This means in this case that it should be clear within all contracts for Van Doorn what data they need to collect outside and register within Atrium, DTB and Kerngis. Guidelines and fixed protocols are necessary as this often remains unclear.

8.3. The step-wise framework for the performance contracts at Arcadis

Within the previous paragraph for each of the maturity levels it has been determined what capabilities need to improve, connecting to specific capabilities of the components hardware and software, activities and processes and data as defined within the theoretical framework. Within this paragraph, the prioritization of the opportunities is incorporated (discussed in paragraph 7.2).

With this prioritization in mind, a framework is developed that Arcadis can implement in order to achieve the desirable opportunities. This framework is a step-wise framework providing the steps for Arcadis that need to be followed in order to increase the BI maturity and BIM level of their performance contracts with RWS and leverage the potential of the discussed opportunities. Below the required steps and framework are provided.

1. Increase BI maturity on the component data from descriptive analytics to diagnostic analytics
    a. Create a scalable and extensible information foundation sufficient for diagnostic analytics
    b. Create a proper data warehousing configuration
    c. Create uniform query and reporting
    d. Increase data mining towards focusing on why it happened
    e. Implement data visualization through a separate tool or dashboard linked with Atrium
    f. Analysis on semi-structured and unstructured data
    g. Create strict and uniform registration of data, facilitating reliable and complete data
        i. Better registration of data during and after maintenance tasks and services by Van Doorn, especially concerning attribute data
        ii. Uniformity concerning the registration of the data within Atrium
        iii. Better registration of GIS attribute and spatial area data
2. Increase BI maturity from diagnostic analytics to predictive analytics
    a. Create a scalable and extensible information foundation sufficient for predictive analytics
    b. Increase data mining and implement predictive modeling, focusing on what can happen
    c. Implemented simulations techniques to simulate what can happen within Atrium or with a separate tool
    d. Create strict and uniform data, facilitating topical, reliable and complete data
        i. Increase the use of real-time data, increasing the topicality of the data
3. Increase BI maturity from predictive to prescriptive analytics
    a. Create a scalable and extensible information foundation sufficient for prescriptive analytics
    b. Increase data mining towards focusing on what should happen
4. Leverage the opportunity of **measuring costs of maintenance regime**
    a. Integrate Relatics and Atrium, to see how changes within the maintenance regime (Relatics) do influence the costs of the actual performed maintenance (Atrium) and vice versa
    b. Determine costs of the maintenance measures, which should be incorporated at the development of the FMECA and maintenance regime within Relatics
    c. Determine statistical models (not part of this research)
5. Increase BIM level from multi-disciplinary to multi-project
    a. Create integrated and coordinated infrastructure

i. Shared workspace within Atrium and Relatics
ii. Integrated data management system at RWS
iii. Integration of GIS data through DTB and Kerngis within Atrium

b. Create a uniform way of working
    i. Uniformity in reporting between the contracts
    ii. Integral and coordinated process of data processing and communication with the RWS databases
    iii. Sharing of trends, developments and optimizations between the performance contracts
    iv. Standard contract
c. Create transparent and accessible data for all involved parties
    i. Uniformity concerning the registration within Atrium

6. A) Leverage the opportunity of **cross-project combining datasets for analysis**
    a. Determine statistical models (not part of this research
6. B) Leverage the opportunity of **cross-project benchmarking**
7. A) Leverage the opportunity of **determination of the error prone objects and sections**
    a. Base faults and defects on Ultimo decomposition (NEN2767)
    b. Use GIS data in Atrium to position objects and map sections
    c. Implement an object information list within Atrium
    d. Implement a 3D environment in Atrium which maps the faults and defects
    e. Increase data quality of GIS data in terms of reliability, accuracy and completeness through the extensive check at the start of the project. Increase data quality of faults and defects register in Atrium through uniform way of registration.
7. B) Leverage the opportunity of **measuring overall quality of area based on RAMSSHEEP scores**
    a. Implement correction factor on number of inspections and surveillances in relation to the number of faults and defects
    b. Implement ranking system defining the area's quality
    c. Make more use of real-time data
    d. Determine statistical models (not part of this research)
7. C) Leverage the opportunity of **measuring effectivity of maintenance regime**
    a. Make use of the integration of Relatics and Atrium, to see how changes within the maintenance regime (Relatics) do influence the effectivity of the actual performed maintenance (Atrium) and vice versa
    b. Be able to determine the quality of the area (opportunity measuring overall quality of area based on RAMSSHEEP scores)
    c. Determine statistical models (not part of this research)
7. D) Leverage the opportunity of **measuring durability of the maintenance regime**
    a. Make us of the integration of Relatics and Atrium, to see how changes within the maintenance regime (Relatics) do influence the durability of the actual performed maintenance (Atrium) and vice versa
    b. Determine durability aspects involving energy consumption, CO_2 emissions et cetera
    c. Determine statistical models (not part of this research)

The above presented step-wise framework is visualized in a scheme which is presented below in Figure 11. Within this figure, the numbers of the steps are included. These steps correspond with the steps explained above. The starting point within the figure shows the starting point of Arcadis. Concerning the BIM level, the information system's components are already on the level of multi-disciplinary BIM. Concerning the BI maturity levels, the hardware and software, the (remaining) activities and processes, the data within Atrium, the attribute data and the GIS spatial data start at the BI maturity level of descriptive analytics. The (remaining) data starts at the BI maturity level of diagnostic analytics. The activity 'development / optimization of FMECA' starts at the BI maturity level of predictive analytics.

Important to mention is that after realization of step 5, the highest BIM level and BI maturity level have been realized, meaning that concerning these BIM levels and BI maturity levels, all opportunities can be implemented.

Within the prioritization, based on the added value of the opportunities, the opportunities at step 6 involving cross-project combined datasets for analysis and cross-project benchmarking were considered equally important and have no strict order of which one to implement first. This is to be decided by Arcadis. The same counts for the opportunities at step 7, involving the opportunities determination of error prone objects and sections, measuring the overall quality of the area based on the RAMSSHEEP scores, measuring the effectivity of the maintenance regime and measuring the durability of the maintenance regime.

The model without prioritization was evaluated and validated during the workshop held at Arcadis. The model was evaluated on completeness, practical applicability and the developed opportunities were prioritized within this workshop, as said, on added value. Last concretizations were made based on this workshop, resulting in the final framework including prioritization of the opportunities as presented in Figure 11.

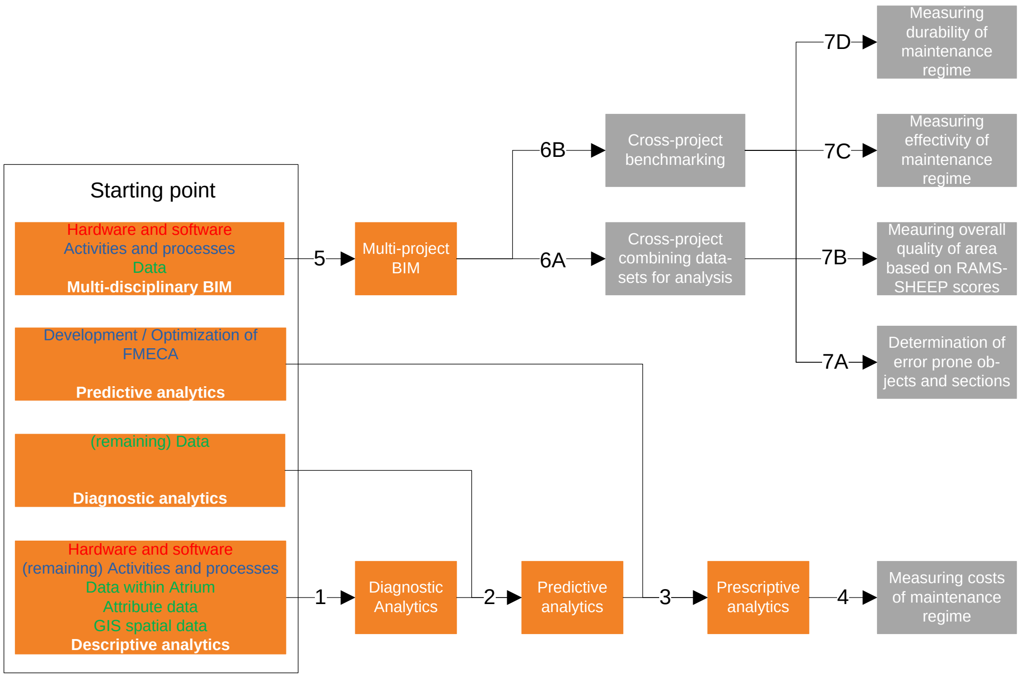

Figure 11 – Step-wise framework for optimization of the performance contracts

SECTION V

CONCLUSIONS, DISCUSSION AND RECOMMENDATIONS

ARCADIS UNIVERSITY OF TWENTE.

9. CONCLUSIONS

In this chapter the results per sub question are provided and the research question will be answered.

9.1. Sub questions

1. *How can the BI and BIM capabilities within the performance contracts be analyzed and measured?*

In order to measure the BI maturity a theoretical framework has been established based on the BI maturity levels defined by Williams et al. (2003) and Puget (2015), being descriptive analytics, diagnostic analytics, predictive analytics and prescriptive analytics. Because it is interesting to analyze the cross-project opportunities of performance contracts as well, stimulating cross-project learning, and the adaptation of BIM in future contracts, the BIM level as well was analyzed. Three BIM levels are defined by Adriaanse (2014) being mono-disciplinary BIM, multi-disciplinary BIM and multi-project BIM. BIM is furthermore a proper driver for BI, facilitating an integrated and coordinated infrastructure with a uniform way of working and transparent and accessible data (Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012), but also by enabling cross-project analytics through multi-project BIM. BIM within this research is used to create a shared knowledge resource, following the definition of BIM by the ISO Standard 29481 (ISO Standard, 2010). To map the performance contracts within the BI maturity and BIM level, the performance contracts were analyzed on the perspective from an information system. In this research, three components of the information system were analyzed, being the hardware and software, activities and processes and the data (Bourgeous, 2014).

Out of the literature, the most important capabilities for BI for the hardware and software to have, are a scalable and extensible information foundation as well as a proper data warehousing configuration. Concerning the activities and processes uniform query and reporting, data mining, optimizations and simulation, data visualization techniques and analytics on semi-structured and unstructured data are important to consider. For the data, it is highly important that these are strict and uniform registered, facilitating topical, reliable and complete data. Concerning BIM, for the hardware and software it is important to have an integrated and coordinated infrastructure. The activities and processes should be performed in a uniform way, and the data should be transparent and accessible for all involved parties.

In concluding, the theoretical model is able to map the BI maturities and BIM levels in such a way that it provides a clear basis organizations can build on. By defining for each information system component what capabilities exists on both the BI maturity and the BIM level, organizations can more easily map their existing BI maturity not only within single projects, but also cross-project. This was also demonstrated in the workshop, where the theoretical model was found applicable for the research topic. Furthermore, BIM is, especially for cross-project learning, a driver for BI, facilitating a shared knowledge resource. For organizations it is therefore wise to invest in both BIM and BI simultaneously after is known what the BI maturity and BIM level are.

2. *What bottlenecks and problems are found within the performance contracts in regard to the improvement of the BI and BIM capabilities?*

All of the three components of the information system analyzed within this research were analyzed on problems and bottlenecks hindering a proper BI maturity and BIM level. The four cases showed that concerning the hardware and software, the most important problems concerning BI were the lacking visualization capabilities and the lacking processing power of the main data management system (Atrium). Furthermore, there was a shattering of databases, which also relies to BIM. Within the main management system, no GIS information was stored, and reports are written in a separate Excel file. Within the main management system, a big problem was the lack of a shared workspace for the contracts, limiting cross-project integrated and coordinated data and the opportunities of cross-project learning, an important problem concerning BIM.

Most important problems for the activities and processes turned out to be the lack of uniformity in reporting and processing of data, and the lack of sharing of trends, developments and optimizations between contracts concerning BIM, and the focus of data mining on that was has happened concerning BI. Having uniformity between the contracts is crucial for comparing the data and applying data analytics. This connects to the need of BIM to have integrated and coordinated data which is transparent and accessible. The lack of uniformity in working was facilitated by individual preferences and different portfolio managers, despite having uniform guidelines and principles.

Concerning the data, the four cases showed that the most important problems concerning the BIM level are the lack of collaboration between the several databases and the poor data exchange (at the moment) between data management systems, being Ultimo and Atrium within the analyzed contracts. Furthermore, data is very limited shared between the performance contracts through the use of separate workspaces in the main data management system (Atrium). Most crucial problems concerning the BI maturity remain the poor registration of data, resulting in a lack of uniformity and topicality, reliability and completeness decreasing the quality of the data. Area data is often not complete, Van Doorn has a lacking data management mindset and the veracity in Atrium decreases the quality of the data.

In concluding, the cases showed that there are important problems to resolve before adaptation of BI can find place. Most concrete is seen that the hardware and software is lacking the processing capabilities and the integrality between the multiple databases, as well as the data visualization techniques. The activities and processes address a very important issue. A uniform way of working is difficult, even though there are many guidelines and protocols. Having proper registered data however, is the key to successful data analytics. This problem is also the main problem within the data, where it is seen that despite many guidelines and principles, the data still lacks topicality, reliability and completeness.

3. *What BI and BIM capabilities are seen within the performance contracts?*

All four performance contracts were mapped within the integrated BI maturity and BIM level matrix. The cases showed equal BI maturities and BIM levels because of the similarities between the contracts. The hardware and software possess descriptive analytics as a BI maturity together with a multi-disciplinary BIM level. A common framework was seen, though with a shattered configuration of multiple databases around it. Also separate workspaces were found, limiting collaboration and integration cross-project. Furthermore, the hardware and software enabled veracity in the data, and lacked visualization techniques. Within single projects, data was relatively transparent and accessible.

All activities and processes except the development / optimization of FMECA possess descriptive analytics as a BI maturity together with a multi-disciplinary BIM level. The development / optimization of the FMECA possesses predictive analytics as a BI maturity together with a multi-disciplinary BIM level. The analyses mainly focus on that what has happened. Only in case of FMECA's, the performance contracts showed predictive capabilities. Within the FMECA, optimizations were seen as well, though simulations and visualization techniques were lacking, as well as the analysis on unstructured and semi-structured data. Furthermore, activities were not shared cross-project, and despite the fact that the same activities and processes were performed in the multiple projects, differences did exist due to individual preferences and different portfolio managers.

All data except the data within the main data management system (Atrium), the attribute data and the GIS spatial data possess diagnostic analytics as a BI maturity level together with a multi-disciplinary BIM level. The data within Atrium, the attribute data and the GIS spatial data all have descriptive analytics as a BI maturity together with a multi-disciplinary BIM level. The data in general is perceived good within the analyzed performance contracts, though there is a lot of room for improvement. Data within Atrium lacks completeness, reliability and topicality due to the freedom within its registration, attribute and spatial area data is often incomplete or missing and GIS data in general is not topical. Data lacks the strictness and uniformness it needs for proper data analytics. Also concerning cross-project collaboration, no data exchange is seen, limiting cross-project learning.

In concluding, the cases showed that especially the BI maturity remained relatively low. The cases showed that for BI it is most important to have a very structured and uniform way of how data is registered. The freedom in registration needs to be limited as much as possible. The capability of having a uniform way of working together with strict and uniform registered data gave the most problems. Furthermore, contracts should be approached from a multi-project BIM perspective, to leverage cross-project learning. The cases showed that even though the contracts were very similar, very little collaboration took place.

4. *What BI and BIM capabilities do the future opportunities require?*

Within the research, several future opportunities were defined based on the outcomes of the interviews and the case study in general. In total, seven opportunities were defined. Within the cases, the first five opportunities addressed are applicable to single contracts. First one involves the measuring of the overall quality of the area within the performance contracts, by analyzing the number of faults and defects and the RAMSSHEEP scores. Second, there is a great opportunity in adding the costs within the performance contracts, to measure what the costs are of the chosen maintenance measures and maintenance regime. A third opportunity involves measuring the effectivity of the maintenance regime based on how the chosen maintenance regime does succeed in maintaining the functionalities within the area. Fourth opportunity is the determination of error prone objects and sections within the area, through analysis of the faults and defects coupled to GIS locations and a uniform decomposition (NEN2767). Fifth opportunity is to measure the durability of the maintenance regime. Together with the effectivity and costs, this enables the maintenance regime to be controlled on these three aspects already before the start of a contract.

The sixth and seventh one involve cross-project opportunities. Sixth opportunity is cross-project combining datasets for analysis, combining the datasets of multiple contracts enlarging the dataset of the multiple contracts to increase the dataset on which analysis are done, increasing the reliability of the outcomes. Most important datasets that have the potential to be combined are the faults register, the defects register and the degradation behavior of objects. Seventh opportunity is cross-project benchmarking, showing most potential in comparing the area's quality, effectivity, costs and durability, the error prone sections and the effectivity of optimizations made. Such a cross-project approach does also leverage advantages for future contracts, where the findings from previous ones can be used.

Concerning the BVP factors, the opportunities address many factors. Technical and managerial merit is shown by great maintenance control (measuring future quality based on RAMSSHEEP, determination of error prone objects and sections, measuring effectivity). Measuring the costs also shows great technical and managerial control, though it also addresses the factor costs itself, in which it gives great insights. The factor durability gets addressed within the opportunity to measure the durability of the maintenance regime. Furthermore, cross-project combining datasets for analysis increases the reliability of the outcomes, and cross-project benchmarking will make it more easy to show past performances, also cross-project wise. These opportunities will increase the quality of the performance contracts, being a BVP factor as well.

For the adaptation of the opportunities, different BI maturities and BIM levels were found to be required. However, in order to be able to leverage the advantages of all opportunities, it is required of the hardware and software, the activities and processes and the data to be on the prescriptive analytics BI maturity and the multi-project BIM level. A nuance should be made that the first five opportunities though can also be performed within a single contract, involving multi-disciplinary BIM. Multi-project BIM is a main prerequisite for the sixth and seventh opportunity.

In concluding, seven opportunities were defined within the research, being applicable to the four performance contracts. These opportunities are of great importance to organizations involved within performance contracts, as these address multiple factors of the future BVP contracts. The BVP factors costs, quality, past performance, technical and managerial merit and durability are all addressed. Only financial health is lacking, though being more related to the organization/department itself than to the performance contracts. The importance of incorporating the opportunities is thereby stressed even more.

5. *How can the steps organizations should take to increase their BI and BIM capabilities be modeled in order to implement the future opportunities?*

The seven defined opportunities require a higher BI maturity and BIM level (concerning cross-project analysis and benchmarking) than is seen on the information system's components within the analyzed performance contracts. Though these contracts do have the future need of BVP and BIM as seen within the overall industry, the case study is too little to have a representative say about the whole industry. However, the findings from this research may provide other organizations of useful input for their performance contracts. Therefore, several important lessons found within this research are brought to the overall industry.

Crucial for organizations is to have transparent and accessible data, by strict and uniform registration. This leverages topical, reliable and complete data. An overall more uniform way of working over the contracts is necessary as well. This uniformity is often lacking at the moment. Concerning the hardware and software configuration, it is highly important that there is attention for a common workspace/database or platform where the multiple contracts can share their trends, developments and optimizations. All these requirements are an important part of increasing the BIM level to multi-project BIM and increasing the BI maturity towards diagnostic analytics, and eventually predictive and prescriptive analytics. The earlier addressed problems are key to be resolved in order to increase the BIM level and BI maturity.

Within the seven opportunities, a prioritization has been made within the workshop held at the end of the research. Within these workshop it turned out that within performance contracts, even though they will be BVP focused, costs remain the most important factor. This is in line with the requirements found by literature and the fact that RWS in their BVP contracts still puts 25% of the total score on the costs. Thereafter, cross-project combining datasets for analysis and cross-project benchmarking were place as second. It was argued that collaboration between multiple performance contracts can leverage great advantages, especially in terms of past performance regarding BVP. The other opportunities were all perceived equally important.

In concluding, for organizations involved within performance contracts, it is of high importance to have strict and uniform way of registration, together with a uniform way of working. Furthermore, the hardware and software should facilitate a common workspace/environment where multiple contracts can share their data. This stimulates cross-project learning and collaboration. Having such enables organization to increase their BI maturity and BIM level, where it is the ultimate goal to have prescriptive analytics as a BI maturity and multi-project BIM as a BIM level. In terms of BVP, organizations should focus first on mapping the costs properly within their contracts. There is still a big emphasis on costs within BVP, and by knowing how to optimize the costs of the maintenance regime, organizations will leverage great advantages during tender phases. This requires prescriptive analytics and a multi-disciplinary BIM. Thereafter, organizations would do wise to invest in their multi-project BIM environment, to enable cross-project combined datasets for analysis and cross-project benchmarking, which immediately also address the BVP factor past performance. Having the highest BI maturity and BIM level at this point, organizations can choose by themselves in which following opportunity to invest in. All these have their own benefits and address different BVP factors, though these were perceived equally important.

9.2. Answering research question

This research has been executed to analyze the lacking BI maturity and understanding within performance contracts and cross-project, addressing the BIM level, in regard to the future requirements of BVP and BIM contracts and the advantages big data can leverage. The research has provided a detailed framework for Arcadis to increase their BI maturity and BIM level. The following research question has been answered by doing so.

How should organizations fill in the gaps within their Business Intelligence capabilities to increase their provability concerning future BVP contracts and leverage the potential of the data generated within and between performance contracts?

Within the research, an integrated BI maturity and BIM level matrix was established in which the components of the information system of the performance contracts, being hardware and software, activities and processes and data could be mapped based on capabilities defined within literate. To do so, the current gaps within the BI maturity and BIM level were analyzed based on the existing BI and BIM capabilities. Most crucial gaps to be addressed were the lacking processing capacities of the hardware and software, the lack of a uniform way of working (despite guidelines and principles) and the lack of strict and uniform data, which are furthermore often not topical, reliable and complete.

Key is to resolve these issues. Data analytics requires hardware and software to be capable of handling the higher volume, velocity and variety of data, while decreasing the veracity in the data. Furthermore, data visualization is especially at the higher BI maturities of high importance, though at none of the analyzed contracts this was seen. Individual preferences and different managers on the contracts turned out to be a key issue of decreasing the uniformity within the activities and processes. It is of crucial importance, especially in terms of cross-project learning, to make sure the uniformity is guaranteed. Big issue related to the lack of topical, reliable and complete data is the lacking data management mindset at the contractor within the analyzed performance contracts. The contractor provides a lot of input for analysis, but their data now lacks the topicality, reliability and completeness data analytics requires. This problem is also increased by the veracity in the data the hardware and software now allows. These problems have their effect on the BI maturity and BIM level seen within performance contracts. Within the contracts, the BI maturity on the component hardware and software remained on the lowest descriptive analytics level. The activities and processes were mainly descriptive as well, besides development/optimization of the FMECA being predictive analytics. Concerning the data, the maturity was spread over the descriptive and diagnostic maturity. The BIM level seen on all components was multi-disciplinary. The cases therefore illustrate lacking BI maturities and BIM levels within performance contracts.

Concerning the future BVP and BIM contracts, seven opportunities were defined that will increase the chance of organizations to be awarded of the contract during tender phases. These seven opportunities address the several factors BVP and BIM address, being costs, quality, technical and managerial merit, financial health, past performance and durability. From the seven opportunities, concerned most important for organizations to start with is the measuring of the cost of the maintenance regime. In none of the contracts, costs were registered, leaving no insights in how costs actually are spread over the contract. Where is the money going? In order to do so, the costs of the maintenance measures should be put in the data management systems. Knowing beforehand what the costs of a chosen maintenance regime are, requires prescriptive analytics, though it can be established in a multi-disciplinary BIM environment. This is different for the cross-project opportunities, addressing cross-project combined datasets for analysis and cross-project benchmarking. Here a multi-project BIM level is required, not seen in any of the contracts. These opportunities are concerned as second important. The remaining four opportunities were considered equally important. These opportunities help greatly in improving the provability of organizations concerning several BVP factors, addressing the factors costs, quality, technical and managerial merit, past performance and durability. Only financial health was not addressed within the opportunities, though this factor also applies more to the organization/department itself than to performance contracts.

Comparing the existing BI maturities and BIM levels to the required ones by the opportunities leaves a lot of room for improvements. First focus need to be to increase the BI maturity to prescriptive analytics, and thereafter to increase the BIM level to multi-project BIM. This will make it possible to leverage all opportunities, having acquired the highest BI maturity and BIM level. The opportunity of measuring the costs of the maintenance regime adds the most value, and should therefore be leveraged first. Thereafter, it is aim to leverage the cross-project opportunities, being cross-project combined datasets for analysis and cross-project benchmarking. These are perceived equally important in terms of added value and therefore it is up to personal preferences which to implement first. The remaining opportunities, involving the determination of the error prone objects and sections, measuring the overall quality of the area based on RAMSSHEEP scores, measuring the effectivity of the maintenance regime and measuring the durability of the maintenance regime, were all perceived equally important. Thus also here, it is up to personal preferences which ones to start with.

The performance contracts therefore have shown that there is a lot to gain concerning the BI maturity, but also concerning the BIM level. Many opportunities were found to be implemented, addressing many of the factors BVP contracts might ask for. It is thus highly recommendable to improve the BI maturity and the BIM level, so these opportunities can be implemented. This makes organizations better prepared for the future BVP contracts and keeps them ahead of the competition.

10. DISCUSSION

The outcomes of this research do lead to several points of discussion. This chapter addresses the limitations and critical footnotes in paragraph 10.1, the reflection on the literature in paragraph 10.2 and the reflection on the chosen research methodology in paragraph 10.3.

10.1. Limitations and critical footnote

Within the research, a detailed framework was developed for Arcadis, making a generalization to the broader industry not possible. The findings and conclusions do not prove scientifically what the BI maturities, BIM levels and opportunities are for the whole industry, though they may provide assumptions. Being by far the biggest consultancy in the Netherlands, as well as being characterized as innovative, it is assumable that other consultancies in the Netherlands have BI maturities and BIM levels comparable to those of Arcadis, though likely to be even lower. The recommendations and steps within this research therefore might prove beneficial to other consultancies as well. However, as should be stressed once more, this research cannot be generalized to the whole industry. Having showed the many opportunities at Arcadis however, this research does illustrate the impact BI and BIM can have on performance contracts, especially regarding future BVP contracts.

An important driver for this research was the increasing adoption of BVP in future performance contracts by governments and agencies, which asks for more than only costs to be focused on within the tender phase. Organizations needs to increase their provability also on factors such as quality, technical and managerial merit, past performance, financial health and durability. Within the research it has been tried to find opportunities that do address the requirement of these type of contracts. However, as BVP might include variations of factors within each of the contracts, it cannot be said scientifically which factors organizations should keep in mind. The weighting on these factors furthermore can differ, though it is very likely that costs remain relatively seen most important to focus on, as also mentioned within the research and during the held workshop. The research however has addressed many common factors of BVP, giving a relative complete overview.

The actual analytics on the data was no part of this research. The research only provides a framework that acts as the starting point towards an increased BI maturity and BIM level. This was also specifically mentioned within the research scope, though choosing such a scope, limits the (direct) practical applicability of the outcomes. Continuing with the scope, the research focuses on only three of the four components of the information system of Bourgeous (2014). The components 'hardware and software', 'data' and 'activities and processes' were included. The component 'people' was left out. This was also defined within the scope, but should be acknowledged once again. The component was left out because it would consider a complete other type or research, involving analysis on behavior and attitudes of the involved people, whereas the other components focus on the system of the maintenance planning itself. However, such behavior and attitudes can greatly influence the adoption of the step-wise framework as provided within this research.

Questions remain on the costs and benefits of implementing data analytics through the given opportunities in terms of real quantitative numbers. As within every other innovative research, a risk remains that the innovation in the end won't be able to deliver the expectations. Although it should be assumed that implementing the opportunities as discussed will deliver benefits in terms of costs but also in terms of granting of future contracts, it is hard to say how much this will be. Multiple problems need to be resolved before data analytics can be applied, which is not only likely to be time consuming, but also costly. However, in the competitive market of performance contracts, every percent that you can be better and cheaper that your competitors counts, as these small differences eventually result in winning a tender or not.

10.2. Reflection on literature

The outcomes of the research showed that both the BI maturities and the BIM levels require a lot of room for improvement. Furthermore, many opportunities were found that do address the future factors BVP requires.

These opportunities though require a higher BI maturity and BIM level than seen within the performance contracts. Within literature, only little information was found about the successful appliance of data analytics within performance contracts, possibly as a result of performance contracting, big data and data analytics being all fairly new phenomenon. No literature was specifically found concerning the improvement of data analytics within performance contracts, making it hard to reflect the actual developed framework on the literature.

Several findings within the research however can be reflected on the literature. The outcomes did show the importance of investing into data analytics, stressed by Rajteric (2010). Having correct and in-time decisions are of crucial importance for organizations to survive, in order to gain competitive advantage, especially concerning the future BVP contracts. The lacking BI capabilities of organizations were furthermore addressed by Gandomi and Haider (2015). They mention the fact that organizations are often not able to leverage the advantages the data has to offer due to not having the right analytics capabilities and knowledge, which also was shown within the analyzed performance contracts, where none of the components did possess the prescriptive analytics maturity, and only one activity (of the component activities and processes) did possess the predictive analytics maturity. The imaging of Adriaanse (2014) that the construction industry can be characterized as an archipelago, in which project form individual separated islands with no integration between them was also recognized. The existing BIM levels within the analyzed performance contracts did not go higher than multi-disciplinary BIM.

The reflection on the literature therefore can't be done on the framework, though several findings the framework is built on were supported by literature.

10.3. Reflecting on chosen research methodology

The research was done within the established theoretical framework. This framework involves the BI maturity levels of Williams et al. (2003) and Puget (2015) and the BIM levels of Adriaanse (2014). These models proved to be the correct models within this research to determine the BI maturity and BIM level. Both do not focus entirely on technological capabilities, which is seen in many other models, such as the BIM model of Bew et al. (2008) focusing on the software tools to be implemented. The framework used perfectly matched with the organizational and data related problems found in this research. The capabilities defined for each of the BI maturities and BIM levels were found to be suitable for the models. The framework in the form of the integrated BI maturity and BIM level matrix does provide a way for organizations to map their information system's BI maturity and BIM level.

The opportunities, BI maturities and BIM levels are all retrieved from an analysis on the contracts' information system and ten interviews held. The information from the case documents provided the necessary information to get a thorough understanding of the multiple components of the information system. However, the documents provided little information about the actual problems and quality of the data within the current information system, which was expected. To fill the gaps of the analysis on the information system, ten expert interviews were held. Even though mostly being based on the interviews, the problems and opportunities are considered valid, because of the expertise of the people interviewed and the reasonable number of interviews held. Furthermore, the interviews themselves are not focusing on a single aspect, but try to include multiple aspects, connecting to the structure of the information system, and the data retrieved proved to be solid. It was not experienced that the interviewees did colorize their answers in favor of their own position or organization, but all where honest about what went well, but also about what could be improved, even regarding each other (as in the collaboration between Arcadis and Van Doorn). Though, while a part of the interviews was semi-structured, therefore making exact reproducibility not possible, they proved to be a proper measurement technique.

A workshop at last was held at the end of the research, to validate and evaluate the outcomes. Here also the prioritization of the opportunities was done. During this workshop it was showed that the opportunities were in line with what they expected from the research. The practical applicability of the research also was perceived as good. At the workshop, both Arcadis and Van Doorn participated, getting a view from both organizations. The involved experts also had different roles within the performance contracts, ensuring a multiple perspective debate. This workshop has increased the validity and reliability of the outcomes.

11. RECOMMENDATIONS

Based on the conclusions and discussion, several recommendations are made, both involving theoretical and practical ones.

11.1. Theoretical recommendations

Several theoretical recommendations can be made based on the outcomes of this research.

- There is more research required on the existing BI maturities and BIM levels within the industry of performance contracting. An extensive case study on multiple performance contracts from multiple organizations can provide a more solid insight in the current standings of the industry.
- There is more research required on the actual requirements future BVP and BIM contracts have. It should be analyzed at different governments and agencies how they form their BVP and BIM contracts, instead of the analysis on the single agency within this research. An extensive case study on multiple BVP contracts from multiple governments and agencies can provide a more solid insight in the requirements, analyzing what factors are most important to be taken into account at performance contracts.
- There is more research required on the future opportunities concerning the BVP and BIM contracts and the advantages they can grant to performance contracts. An extensive case study on multiple performance contracts from multiple organizations can provide a more solid insight in the future opportunities.
- Research is required on the quantitative benefits the future opportunities can grant the performance contracts. A positive Return On Investment (ROI) can prove organizations to make the next step required to bring their BI maturity and BIM level to a next level.
- Research is required on (statistical) models necessary for the higher BI maturity levels. This research has not investigated what models are required for the actual data mining and analytics.
- Research is required on the component ‘people’ of the information system of Bourgeous (2014) to take human behavior into account.

11.2. Practical recommendations

For the organizations analyzed within this research, a detailed step-wise framework has been developed, providing the steps required to increase the BI maturity and BIM level and leverage the advantages of the opportunities. Besides this framework to follow, several recommendations specifically for these organizations should be added.

- The organizations could perform a more extensive analysis on the quality of the data. Where in this research the data quality analysis is done on the expertise of the interviewees being qualitative, a quantitative analysis could provide more insight in especially the completeness of the data.
- The organizations should be aware of the fact that the step-wise framework asks for a lot of contribution of their employees. The process is time consuming and shouldn’t be rushed.
- To facilitate the next step in data analytics, it is important to have a team within the organization that focuses on this aspect. At the moment, a small team has been formed at Arcadis, and it is highly recommended to keep such a team, to streamline the overall data analytics process within the performance contracts.

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