Application of Business Intelligence as Decision Support Systems in Asset Management of Water Connections

A case study in the Netherlands, in collaboration with water company "Evides"

by

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Graduation committee

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Abstract

When evaluating and applying asset management concepts, water companies can face challenges in enabling targeted recommendation-making due to difficulties in accessing and processing of large volumes of data. These factors can lead to entrance barriers in utilization of breakdown data when assessing network reliability and scope of attainable improvements in asset strategy and maintenance concepts. Proven solutions and contextualized research are not readily available for water companies which, as asset-intensive enterprise relying on physical assets to deliver water to its customers, have a big stake in optimizing its use of data. This project has set out to research whether aspects of recommendation making for asset management at water companies can be aided with application of commonly available and deployable business intelligence tools.

To this end, a water company which faces similar challenges has been selected. Evides – a water provider in the region of Rijnmond seeks more data-driven approaches in asset management of water connections. This asset group can be characterized by high volume, high technological heterogeneity and high absolute number of breakdowns as compared to distribution pipes. Together with a vast volume of data, this combination of factors leads to challenges in maintaining a continuous oversight and transparent conversion of performance data into strategic goals and clear service level agreements. The case of Evides inspired a research approach in which application of a custom-made decision support system is evaluated for the process of recommendation making in asset management of water connections.

Methodology for this research encompassed for semi-structured interviews with network specialists and managers to obtain information on current asset management goals and the corresponding recommendation-making process for water connections. Thereafter, a thematic analysis was conducted to distill the main themes depicting aspects of interests to network-specialists in charge of producing recommendations and to managers – the decision makers. The type and moments at which performance data is processed and consulted were described and positioned in a managerial decision-making model, together with aspects assessed at each stage. Simple performance indicators were selected to aid the assessments and to connect performance readings with company goals. Findings were thereafter embedded into a purpose-made prototype of a decision support system, utilizing capacity of business intelligence software in creating curated datasets and user-friendly front end. In the last phase of the research, network specialists participated in appraisal of the created tool by completing a series of tasks designed to assess performance of water connections. Surveys were then conducted among participants to evaluate the added value of the created tool in the context of recommendation-making for asset management of water connections at Evides.

Results show that, for the case study company, the created tool allows for improvements in accessibility and connectivity of company performance data and can contribute towards greater transparency in goal setting and enabling data-driven recommendation making for asset management of water connections. Performance outliers and policy non-compliers can be localized easier and help company in localizing areas in need of attention. Display of simple performance indicators for connections as per user-selected criteria can in the long run enable more nuances in describing network performance, shifting away from binary descriptions of asset's performance.

In case of Evides, the performance management framework for water connections was discovered as insufficiently defined to allow for assessments of direct benefits as result of application of the designed decision support-system. It is therefore recommended for future research to apply similar methodology for asset groups with well defined performance management standards and to focus on experimental design with higher external validity.

Acknowledgements

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My gratitude to all groups involved surpasses the strictly professional realms. The duration of this project was marked with a series of planned and unplanned occurrences, for which all of you acted on with a remarkable understanding. The planned events included my wedding, the unplanned encompassed for a painful 3-month episode with a kidney stone which concluded in a number of surgeries. In that same time window we found out that we will have to move from our current house due to reasons irrespective of our doing.

All these events ended happily, where I have made a full recovery and we found a new house. This kaleidoscope of events was however equally traumatizing as it was life- changing and educational. I will forever run short on words to recognize the merits shown and enacted by my wife – Sandra. Your lively candor and boundless perseverance have been the driving force behind the many things I treasure, above all - our love itself.

Contents

Glossary:

AM: Asset Management

BI: Business Information

DAX: Data Analysis Expression (programming language)

DSS: Decision Support System

EAM: Enterprise Asset Management

LTAP: Long-Term Asset Plan

PI(s): Performance Indicator(s)

MTTF: Mean time to failure

MTBF: Mean time between failure

PTPT: Pretest Posttest experimental design

SDM: Strategic Decision Making

SLA: Service Level Agreement

WO: Work order (instance of breakdown)

1. Introduction

1.1. Problem overview and setting the stage

Establishment of reliable access to drinking water is a key component in assuring robust sanitation potential (Connor, 2015). In piped water supply systems, the process of water delivery happens through transport and distribution networks, concluding in a water connection. This connection joins the distribution network onto the receiver's parcel which can range from a single dwelling to a multistory apartment building (Evides, 2016).

A standard water connection is depicted below (Figure 1) and consists of a series of valves and pipes. The point at which the maintenance responsibility is transferred from the network operator to parcel owner differs between countries (CIWEM, 2018). In the Netherlands, water companies are responsible for the water connections up to the end valve (Evides, 2016). A single water connection can consist of numerous subcomponents, rendering the total of all connections the most element intensive group in a in the distribution network (EAM, 2019), a volume which further translates into the number and relative frequency of failures.

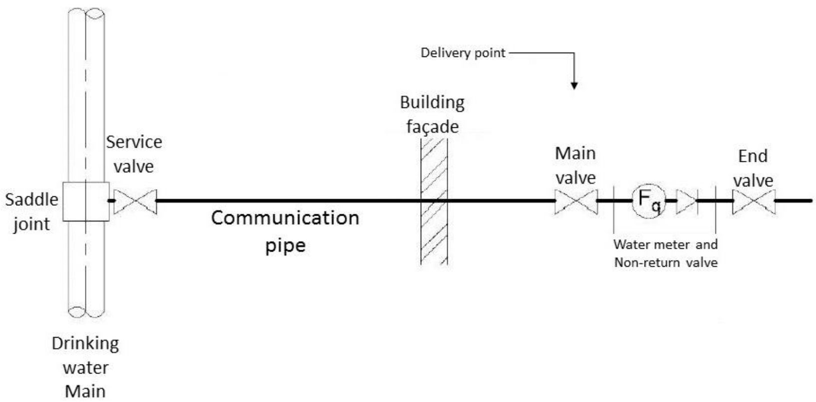

Figure 1: Standard water connection (adapted from Evides WTS, 2016)

Asset management of water connections combines thus challenges resulting from high technological and component diversity, high asset volume and no uniform failure mechanisms (Evides, 2016). Maintenance strategy of water companies for connections is predominantly reactive in contrast to pressure mains where failure mechanisms and company risk-attitude are well-defined and allow for mix of proactive and reactive maintenance (Thomas van Manen, personal communication, 25.01.2019). Reactive strategy for connections is often attributed to factors such as: low individual repair costs, (perceivably) random distribution of breakdowns and no uniform failure mechanism (Jan Vreeburg, personal communication, 14.06.2019). However, breakdowns of water connections produce cumulatively significant issues such as property damage, customer-minutes lost, labor costs and damage to company image (personal communication, Bas Dilven).

To define risk-attitude and localize where policy modifications are needed, water companies traditionally apply risk-matrices (RMs) which display their classification and urgency of resolving issues in respect to risks quantified in terms of e.g. financial and image losses (MacGillivray, 2006). This also applies to asset reliability, here defined as "The ability of a functional unit to perform a required function under given conditions for a given time interval" (ISO-55000, 2014). 'Risk' in turn, is generally defined as probability of the event occurring, multiplied with consequence of said event (Burn, 2010). Such matrices are however oftentimes tailored to large individual events, leaving ambiguity in interpretation of smaller but frequent incidents, e.g. failures of water connections. This can lead to under-utilizing of preventive maintenance potential, lower reliability, increased customer nuisance and soaring maintenance costs in the long run.

Water companies possess large volumes of technical and breakdown data, which could give more structured insights into performance and breakdown frequencies in respect to technical components, placement, and age. For this information to support policy-changes, such analyses are needed for a sizeable part of the network to produce meaningful contrasts and prioritize maintenance interventions. However, the source data is often hard to work with due to volume, has quality issues and divergent formats (Thomas van Manen, personal communication, 25.01.2019). Therefore, a limited number of employees have access to it, reducing its potential for the organization. These types of obstacles diminish with evolution of Business Intelligence (BI) tools which can meet more of these requirements in a more time-and cost-effective manner (Fink, 2016). BI tools are defined as software solutions which allow to retrieve, combine and prepare data to produce organizational insight for the company (Ibid.) In this research, it will be studied whether Business Intelligence solutions can support network specialists in producing asset management recommendations. To that end, a prototype of a BI tool will be designed based on the insights from network specialists. This will be done in order to evaluate its applicability in the context of the current practice for producing asset management recommendations for water connections. In this research, the terms 'BI tool' and 'decision-support system' are used interchangeably due to fulfilling the same purpose.

1.2. Knowledge gap

Water connections are not widely researched, particularly not in the contexts of performance management and the necessary asset management framework to support it. In fact, no academic articles on the topics could be found and there exists no research on suitable methods allowing to alter this impasse. In turn, the application of business intelligence as means to support decision-making has been researched in the context of performance management for manufacturing industries (Lasi, 2012) but not for water companies, which can be comparably asset intensive and possess large networks with limited inspection possibility.

Therefore, this research will examine the applicability of business intelligence tools in the context of decision-support for performance and asset management of water connections. Secondly, as a byproduct of this research, implications for the asset management framework needed will be considered, with the aim to enable water companies in developing more integrated approach for water connections – a numerous asset group with considerable societal impact.

1.3. Research contextualization

In the course of this graduation project, a number of domains will contribute, among others: asset management of water networks, decision support systems and managerial decision making. To display the current state of the research within these domains and to familiarize the reader with the themes present in this project, the key take-aways from the literature review are summarized below.

Asset management of water networks

Among the key asset management practices needed for water networks, replacement strategy and performance management are turning to be most influential and financially intensive for the organization (Kleiner, 2001). Performance management encompasses for activities with the explicit goal of improving the reliability and availability of physical assets (Galar, 2014) whereas replacement strategy, in short, defines the time, mode and the assets which are to be rehabilitated (ISO 55000, 2014). These tasks are fulfilled to ensure continuity in meeting water demand and to structurally allocate available budgets. Monitoring of the network performance substantiates the strategy and promotes prioritization of maintenance efforts using performance indicators or indices (aggregated set of indicators) (Haider, 2015). Asset management planning, maintenance included, is applied for varying time-horizons and scopes and needs to balance selected risk profile with available resources (Alegre, 2013).

The commonly distinguished degrees of AM are Strategic Asset Management, Tactical Asset Management and Operations and Maintenance (Burn, Marlow & Tran, 2010). These degrees vary in the time-horizons and scope, ranging between day-to-day, problem targeted activities (Operational Level), mid-long decisions on assets rehabilitation roadmap (Tactical Level) to long-term (Strategic asset management) where generally applicable asset management frameworks are defined (Alegre, 2013). In the figure below, an integrated approach to infrastructure asset management is displayed (ibid.), demonstrating necessity for synchronous actions between different company levels involved, in order to reach company asset management goals.

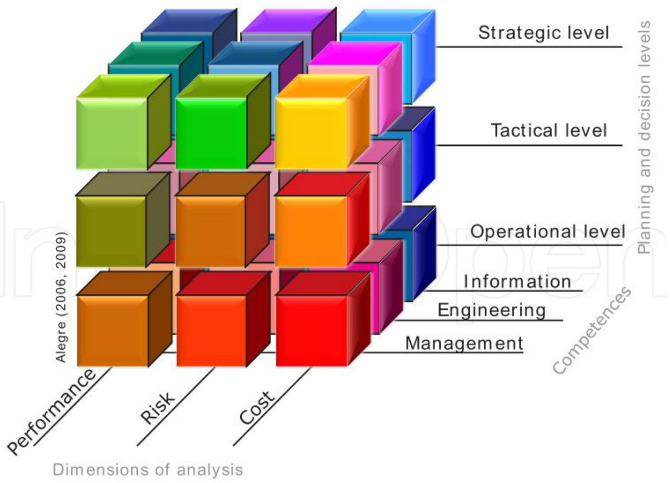

Figure 2 Dimensions of asset management strategies (reprinted from Alegre and Coelho, 2013)

Within water industries, asset management deals with continuous replacement and extension of water delivery infrastructure. Economic optimization is one of the main drivers in creating and optimizing policies, aiming to minimize life cycle costs of assets (Makar, 2010). These costs include, but are not limited to, cost of installation, maintenance, reparation and auxiliary costs in case of breakdown. A company will establish an asset strategy encompassing for risk-acceptance and desired system reliability within allocated budget (ISO 55000, 2014). Asset management strategy can also be seen through the way maintenance is decided on and deployed. Decisions with respect to asset maintenance, according to ISO, have two key components – mode of maintenance and the timing thereof (ibid.). Mode of maintenance depicts choice between reparation and replacement of an asset and the timing defines whether maintenance is performed after breakdown (corrective maintenance) or before breakdown occurs (preventive/proactive maintenance) (Birolini 2013). Corrective maintenance is conventionally applied to assets for which costs of reparation and extend of damage caused are low. Preventive maintenance is applied to assets of which both individual value and possible rehabilitation costs are high enough for the cost of rehabilitations to outweigh the costs of maintenance (ibid.). This dichotomy can be applied to water connections but no existing research on the maintenance practices has been found.

For pressure mains, water companies apply a mix of both approaches, aiming to identify and repair or replace the most vulnerable assets before breakdown (Kleiner, 2001). This approach displays the shift from strictly reactive maintenance to reliability centered maintenance (RCM) which, as an analysis tool, encompasses for both corrective and preventive practices (Selvik, 2010). In RCM potential failure modes and their impact on system performance are assessed and used in maintenance planning (ibid.). This approach is conventionally used in regimes where the primary objective is to preserve system function and requires from a company to recognize applicable failure modes. In the context of water networks, companies are unlikely to fully utilize RCM due to costs structure, extent of networks and the, theoretically, infinite life span of a network (Fynn, 2007). However, companies use it to aid in deploying maintenance-standards per asset group, benchmarking and policy updates. This approach requires from the company the ability to describe risks per asset group or individual asset and to structure the maintenance planning based on performance readings or forecasts (Kleiner, 2001).

Application of performance indicators

Performance indicators can be defined as "[…] a quantitative measure of a particular aspect of the performance of the entity or its level of service." (Vilanova, 2015). In that, they are supposed to equally define the quality of interest, together with the unit (Ibid.). A further distinction can be done, between performance indicators (PIs) and result indicators (RIs) depending on the company needs for monitoring, however in the case of this research, only PIs will be considered. The selection of PIs utilizable for the company should be done based on their relevance, analytical conditions, measurability, data quality and comparability (Vilanova, 2015).

Reliability measurements in the context of water networks are well researched in academia and pertain primarily to disturbances in water delivery on the account of breakdowns of transport or distribution pipes or pump systems (Alegre, 2013). Generic performance indicators pertinent to network reliability have been gathered from literature are displayed below.

Table 1 Performance indicators retrieved from literature

Performance indicator	Definition	Unit	Source
Customer minutes lost	Time for which customer(s) had no access to water	[t]	Kanakoudis, 2012
Non-revenue water	Water which has left the system without being accounted for	[L^3]	Alegre, 2016
Availability	Share of time in which asset is capable of fulfilling its task	%	Hastings, 2015
Breakdown rate	Share of breakdowns in the given cohort	%	Kanakoudis, 2011
Mean time to failure	Averaged age of the asset when first breakdown occurred	[t]	Muchiri 2010
Mean time between failure	Averaged time between consecutive breakdowns on the same asset	[t]	Muchiri 2010
Mean time to repair	Averaged time needed to schedule and perform reparation	[t]	Muchiri 2010
Mortality failure rate	Share of assets which needed replacement after breakdown	%	Smith, 2008
Efficiency repair cost	Remaining asset lifetime after reparation	[t]	Smith, 2008

Lastly, data-quality is said to be definitory for the quality of overall applicability of the selected PIs (Masayna, 2007). Certain decisions with respect to data selection for PIs are arbitrary cut-off points and have lasting impact on the overall accuracy. Therefore, the company goals should be embraced in the selected PIs to address special issues (Kanakoudis, 2011).

Decision Support Systems

Decision support systems (DSS) can be defined as "Interactive computer-based systems which help decision makers utilize data and models to solve (un)structured problems" (Sprague, 1980). These systems are designed to reduce specialized programming and training requirements while benefiting from metrics describing large data sets (Labadie, 1986). Two most commonly utilized models of DSS are data-driven and knowledge-driven systems where modes of data input and processing differ (Power, 2002). In knowledge-driven systems, the conditions for specific results are implemented in design stage and are based on the existing knowledge (Ibid.). These systems are common in healthcare where, e.g. blood morphology anomalies can be evaluated objectively (Kwok, 2009). Data-driven systems produce insights based on relative comparison and acceptability of extreme values. These systems are taking lead in managerial and engineering contexts ever since the computational power and internet bandwidth allowed for sufficient processing capacity (Power, 2002).

Research on DSS is divided with respect to evaluation of effectiveness and applicability of said systems. Newmann et al. (1999) discovered that in some cases, end-users of DSS become familiar with logic applied by support-system and render the system not advantageous. DSS's were discovered by Bell et al. (2001) to, in general, not compensate for lacks in data-quality or structure and produce errors in line with data shortcomings. DSS's applicability was evaluated on different company levels, where front-line employees and middle management were discovered to be the most frequent users of the DSS's (Carlsson, 2002). In that same research, senior-management was found less interested in support systems due to a belief that business-intricacies cannot be modelled (ibid.). Research on DSS in medical studies presents a considerably different set of conclusions. In his paper on clinical decision support systems, Sutton (2020) discovered that choosing of method of rehabilitation, including for drug selection, is improved by application of DSS where more variables can be taken under consideration if the patient's medical history has been digitalized (Sutton, 2020). Further, studies have shown that clinical DSS can increase adherence to clinical guidance (Kwok, 2009). The research on DSS in the context of asset management is limited.

Application of business intelligence systems

Business intelligence (BI) can be seen as a data driven DSS which combines data collection, wrangling and monitoring to produce input in decision process (Negash, 2008). BI systems process and display descriptive analytics with regard to firm and its operations, with the end-goal of simplifying the process of translating data into actionable insights and supplementing company strategy (Ibid.). To that end, BI combines techniques and resources such as data mining, GIS, DSS, and CRM to produce integrated oversight (Fink, 2016). BI leverages application of data warehouses where available information is aggregated and can be queried into the processing software. This can happen either on dedicated database management system (apart from the regular database entity) or internally in the BI environment (Negash, 2008). This distinction is displayed below and indicates which of the tasks no longer have to completed by the non-IT specialists.

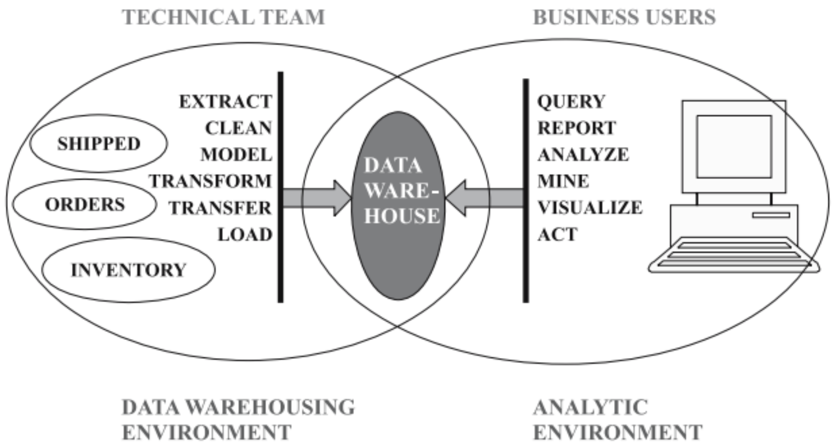

Figure 3 Functional division in application of BI, (reprinted from Negash, 2008)

This separation can offer an improvement in data-utilization, rendering new user groups capable of processing data at high cognition without necessarily mastering data-management tools and practices in the first place (Ibid.). Within BI tools, diverse data sources can be wrangled or merged, allowing for displaying data-relationships much earlier in the data analysis process, effectively removing the obligation of data (re)arrangement from the user.

Managerial decision-making models

Overview of managerial decision-making studies distinguishes 3 dominant models: classical, administrative and political (Simon, 1945). A classical model is defined as applicable to processes where both the problem specification and goals are completely known and the decision makers are fully rational and use logic (Ibid.). This is a normative approach which prescribes how decisions would be made under ideal circumstances, therefore it is outside of the scope of this research. The administrative model encompasses for two sub-groups: bounded rationality model and satisficing model. The former denounces the completeness of information on the decision-maker's side and proposes that both, people and problems, have limits on how rational and structured they are (Simon, 1945). This means that the goals to a decision can often be vague and conflicting and that rational procedures are not always used (Ibid.). Under the satisficing model, it is assumed that decision-makers will choose the first solution that satisfies minimal decision criteria (Simon, 1956). After discussion with the network specialists, it is assumed in this research that decisions at Evides relating to asset management are made under bounded-reality model.

The model employed in this research is a version of Mintzberg strategic decision-making model and can be retrieved under section 2.2. In this model, a decision is split between three stages: identification, development and selection. The identification section is composed of recognition and diagnosis, considering that problems are sometime not presented to the domain specialists and need to be located (Mintzberg, 1976). In the development stage, 2 sub-groups exist labeled 'search' and 'design'. Choice options are sought and designed here. Lastly, the selection stage begins with screening of the solutions before making a recommendation for the authorized decision-makers (Ibid.). This model was found suitable for the needs of this project because of the extended Identification stage, interconnectivity of different stages in the process and the clear distinction between where alternatives are generated and where actual decision is made.

1.4. Research approach and outline

In order to complete this research, a case study company is chosen to contextualize the findings and make resources such as data, information systems and expert knowledge available. Description of the case study company can be found in the following section. In the methodology section, a complete 'research design map' can be found.

This research will consist roughly of 3 stages. 1) Gathering and recognizing information from network specialists on asset management recommendation making for water connections, company goals and performance management practices; 2) Design and deployment of the prototype decision support system as a BI tool; 3) Evaluation of the tool's applicability to water company by network specialists in the context of requirements gathered under 1).

In the course of the project, the following research question is to be answered:

§1

How does a purpose-designed BI interface, based on selection of performance indicators derived from company data, facilitate advice-forming by water network specialists in respect to water connections?

Answering the above stated research question is to be substantiated and facilitated by answering the sub-questions below:

1 How are recommendations regarding asset-strategy currently made at Evides and how is performance-related information collected, used, and evaluated in the asset management process?
   a) What are the company's current priorities [goals] with respect to asset management and strategy for water connections? Which aspects are the network specialists and management most concerned with and are these aspects well depicted in the company's risk matrix? Who are the users of the to be developed tool for water connections?
   b) How do the recommendation-giving strategies and performance data link to the water company's attitude towards risk, threats and opportunities?

2 Based on the findings named in 1), how can the monitoring, analysis and communication of performance information be improved by means of business analytics tools?
   a) Which PIs should be used and monitored, given the available information and priorities in assessing the current performance?

3 How does the created BI tool affect the usability and consideration of available utility data in asset management choices about water connections [and is that desirable / an improvement]?

   a) How applicable and adaptable is BI portal to process and share the relevant database content for implementing/quantifying the PIs?

1.5. Business case study: Evides Waterbedrijf

Data and processes analyzed in this research will originate from Evides Waterbedrijf (*Evides Water company,* further referred to as *Evides*) – one of the 10 drinking water suppliers in continental Netherlands. The company was brought to life in 2004 as result of a fusion between former water suppliers in a number of regions, amongst which the biggest ones being: Waterbedrijf Europoort (region of Rijnmond) and Delta Waterbedrijf (Region of Zeeland), catering in total to about 2.5 million customers. Together with the fusion, asset data was merged between two companies but not all systems were harmonized and not the same enterprise asset management software is used (personal communication, Bas Dilven). Therefore, the scope of this research is limited to the region of Rijnmond for which data and quality issues are relatively known. Only active, drinking water connections will come under evaluation.

At the time of conducting this research, Evides possessed over 435 449 active water connections in the region of Rijnmond, a number growing at an annual rate of 0.8 % over the last 4 years (EAM, 2019). These connections cater to *circa* 900 000 addresses and consequently 1.4 million customers.

Evides' assets are managed by a dedicated asset-management department (Asset Management Infra, *AMI*) consisting further of two sub-teams: *Gebiedsbeheer* (Terrain management) and *Assetbeheer* (Asset management) with different task-sets. The primary responsibilities of AMI as a whole, are creating long-term asset planning framework, performance analysis for water networks, compliance management, making of recommendations for the company management and selection of the applied network elements.

Previous research on breakdown frequency and mode of Evides water connections, established that each year, roughly 3000 incidents of connection failures occur (EAM, 2019) which is approximately factor ten higher than the amount of conduit breakdowns (Ibid.). No external benchmarks exist to compare these values with other water companies. This number excludes failures of water meters and end valves and translates into an annual failure frequency of about 0,71 % per year, relatively constant over the years 2016, 2017 and 2018 (EAM, 2019). However, due to factors such as aging infrastructure, ground subsidence and construction related damage, new measures are sought to keep the failure rate from growing.

All data used in this project was retrieved from Evides' own database systems. Each existing water connection can be described using technical and geographical characteristics. This information is retrievable from databases available to the company workers known as Enterprise Asset Management (EAM) environment. Breakdown data is stored in a separate database, accessible from the same EAM environment. The two databases are only linked within the online environment and contain no performance metrics. The available characteristics for technical, geographical and breakdown history can be retrieved from the appendix.

Within Evides a risk matrix is used to delineate some of the company's attitude towards risk. This matrix is referred to throughout the project but is not presented due to the confidentiality of the information included therein.

2. Methodology

In this section, methods which will be applied in this research are described. A portion of the research design will require an iterative approach, where intermediary results will be needed before applying some of the methods. To provide the reader with a clear overview of the steps needed, their interconnectedness and the order of deployment, the graph below is presented.

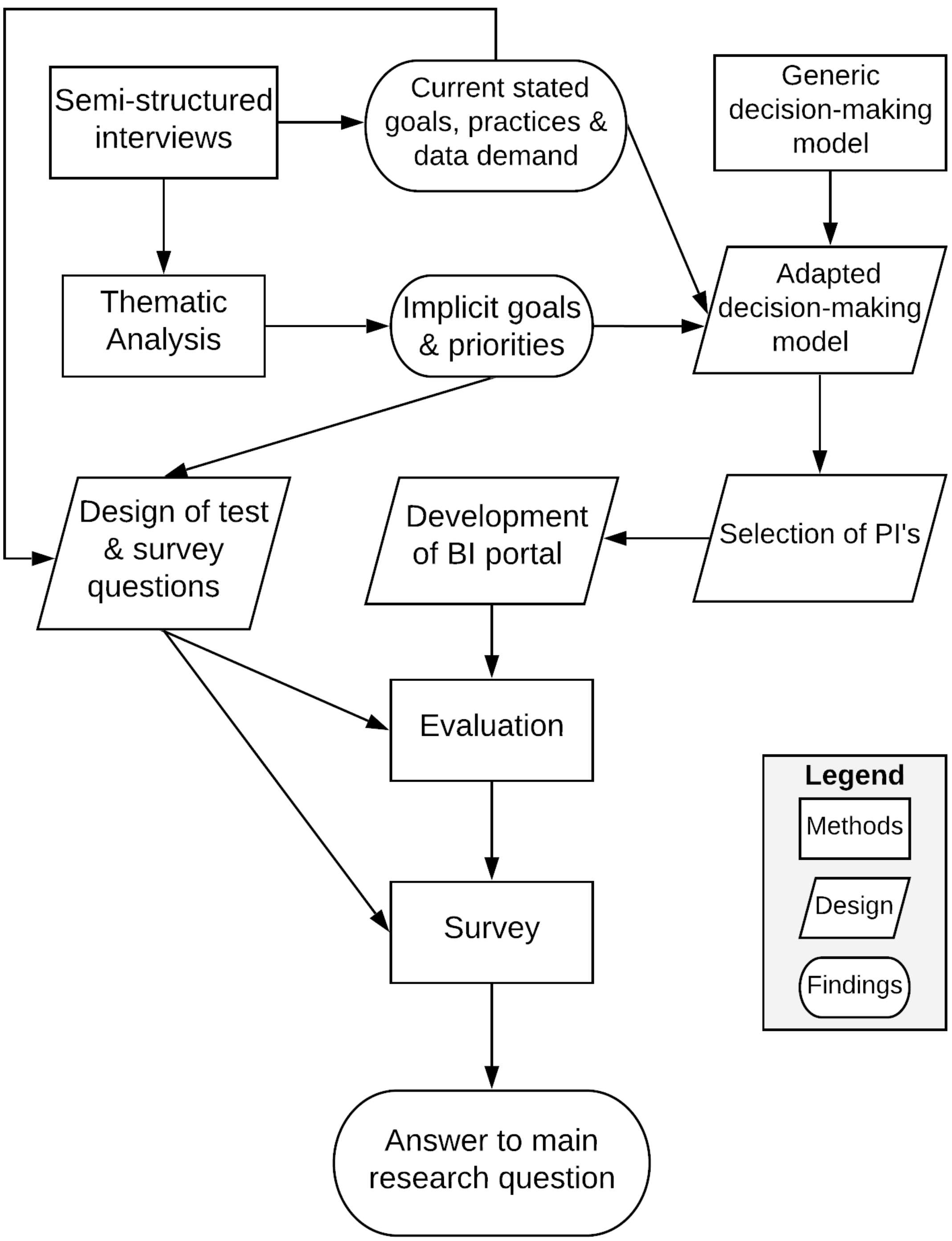

Figure 4 Research design map

2.1. Semi-structured interviews

Semi-structured interviews were chosen as primary method to attain information on current practices, recommendation making and company goals with respect to asset management of water connections at Evides. Structured interviews were considered due to the good control over the topics and the format of the interview (Kajornboon, 2005). However, adhering to a strict guide, as required by structured interviews, may prevent probing for relevant information that may not be stated (Ibid.). It is assumed that during interviews, information may sometimes be stated implicitly and therefore some flexibility in conduct will be needed to retrieve it. Unstructured interviews (also known as narrative interviews) were found unsuitable for the purpose of this research because coding and analyzing of obtained data would be difficult to do if the questions were not the same for all participants (Stuckey, 2013). Semi-structured interviews in turn allow for a defined question list with possibility to probe for views and opinions of the interviewee (Kajornboon, 2005). This is considered relevant because aspects of the decision-making framework may not yet formally exist at the case study company. However, it is assumed that network specialist will at times apply own views and opinions while making recommendations. A semi-structured interview can therefore best allow to follow up on individual decision-drivers.

Participants will be selected from within the company, based on their proximity to the topic. This entails division between asset engineers (reliability engineers and technical specialists) and terrain managers, of which both produce recommendations but with different task-list, as seen in Table 4. Members of company management will also participate in the interviews to provide insight on pertinent but more global company goals, such as asset and maintenance strategy. Every interview will last about 1 hour and will be held in a conference room. During the interviews, notes will be taken for creation of summaries. These summaries will be later shared with the interviewees for approval. The participants will be asked whether they want their names anonymized and whether they have any concerns regarding the interview process.

Question list will be available to the interviewee and attached to the invitation to participate in the interview. This is done to allow the interviewee to feel at ease rather than assessed during the talk (Raworth, 2012). At the same time, knowledge of the questions could lead specialists to over-preparing their answers to seem more advantageous or suitable. The interviewer will have an additional question sheet with extra sub-questions to ask if the topic does not come up naturally. In the course of interviews, network specialists will be familiarized with a known, case – a request from the maintenance department to look into repeating breakdowns with similar failure mode of connections at a given location. This added contextualization should serve as enabler for interviewees to talk about a known case and link it to own experiences and rationale (Barriball, 1994). This same case is later used in validating the decision-making model used in this research.

Interview content

The question list from the interviews can be found in (Interview questions) and encompasses for 4 categories, as displayed below:

Table 2 Subsections of the interview and the information to be retrieved

Recognition	Interviewee's role at the company, approach and steps in recommendation making process for asset management of water connections
Activity	Types of the recommendations made in respect to water connections
Descriptive	Parametrization of network performance, current practices, possible improvements
Oversight	Company goals and linking company's risk matrix and recommendations made

The *recognition* questions will inquire as to the occasions at which a network specialist is tasked with assessment of performance issues of water connection and how they approach the assessment. This subpart of the interview is rich with diverse questions to benefit from the interviewee's freshness. The steps taken in process of evaluating an issue relating to water connection will be asked, together with the employee's perception on the company goals, priorities and policy towards AM of water connections.

In the *activity* part, employees will be asked about the type of recommendations they produce. Here, the means of analysis leading to a recommendation will also be assessed. Variables used to study the scope (extent) of the issue will be assessed. This should allow to observe how the recommendation-making process may be affected by the characteristics of an issue. Consequently, it will be studied where in the decision-making process the extent is assessed and using which indices. Further, questions on the interconnectedness of the affected connections will be asked, with consideration for technical and geographical aspects. These questions are meant to help understanding how network specialists create cohorts and assess and filter relevance of connections' and maintenance characteristics.

In the *Descriptive* part of the interview, network specialists will be asked about the current data available to them from the company's information system and their utilization thereof. One of the goals of this part is to find out whether network specialists seek or would wish for specific performance metrics based on the available data. Findings will define the 'data demand' – total of information that specialists consult (or would like to) at different stages in recommendation making, considering for data type and origin. Here, the network specialists will also have a chance to discuss information that they wish to have but know that it is not being registered. During the interviews, the present monitoring practices will also be discussed.

Lastly, in the part *Oversight* the network specialists will be asked about the current company goals with respect to asset management of water connections. Specialists will be asked about their utilization of the company's risk matrix and the extent to which it influences their recommendation making or recognition of urgency of specific cases. Lastly, risks and threats will be discussed in the context of Evides network, performance evaluation and possible opportunities to alleviate these threats.

Participants

In discussion with company members, it was stated that a 3-tier asset management model is used at the case-study company. This model distinguishes between asset owners, asset managers and service providers and is described in the results section. In consultation with supervisors for this research, interview participants will be chosen to represent all layers in the model.

Non-managerial participants were chosen among network specialists whose daily tasks deal with performing reliability analysis or terrain management and who have a good understanding of the company data and goals with respect to network reliability, specifically for water connections.

Below, the list of interviewees can be found:

Table 3 Participants of the semi-structured interviews

Participant Number	Function within the company	AM Role
1	Reliability Engineer	Asset Manager
2	Technical Specialist	Asset Manager
3	Terrain Manager	Asset Manager
4	Terrain Manager/ Team leader Maintenance team	Asset Manager
5	Manager of Maintenance department	Service Provider
6	Manager of Asset Management Infra dept.	Asset Owner
7	Head of Strategy	Asset Owner

Asset managers can belong to one of the two subdivisions: Terrain management and Asset management. The primary responsibilities of AMI as a whole, are creating long-term asset planning framework, performance analysis and management and compliance management. The scope of information-demand and recommendation may differ between subdivisions and their tasks-division can be seen in table 4 (Evides, 2020).

Table 4 Task division of employees of the Asset Management Infrastructure department at Evides.

Terrain Management	Asset Management
Tasks: Wholistic overview of a specific terrain.	Tasks: Global overview and management of the water network.
Main activities	
• Coordinating with stakeholders on projects in the given area • Liaising with the Maintenance and Asset Management departments on the needs of given area • Evaluating replacement and cooperation projects in the area • Familiarity with the area's most persistent issues – prioritizing • Approval for network expansion	• Proposals for internal policies and frameworks • Performance management • Addressing structural problems within the network • Performance monitoring • Risk management – updating and adhering to company risk matrix

In this project, not all instances referred to as "decision" are singular executive decisions. It is assumed that each instance of "choice", thus also recommendations which can then be taken under consideration and steps leading to it, are also decisions. This adjustment allows for this research to observe employees' attitude and decision-making needs, without excluding those employees who do not bear high decision-making power within the company but whose expertise is used frequently as base for decisions (e.g. reliability engineers). This also leads to interchangeable usage of the terms "decision making" and "recommendation making".

2.1.1. Thematic analysis

Information gathered during the interviews needs to be qualitatively analyzed and interpreted to be used in adapting the decision-making model. Data which specialists consult in order to produce a recommendation will also be considered. The combination of the answers to these questions will contribute toward defining 'decision moments' and the performance indicators which can facilitate the alignment between company (use of) data and company goals by providing the necessary insight.

Thematic analysis is a qualitative analysis method in which common patterns across the data set are sought (Boyatzis, 1998). In this approach, the interview parts are first labeled (coded) as belonging to different categories. Parts belonging to matching categories are then aggregated and form a theme. Themes are the overarching descriptions of frequently occurring answers/notions and can be then utilized in further analysis.

Thematic analysis is used in this project to distill the parameters and information important to network specialists and managers, even without them stating that explicitly. The goal of such analysis is to obtain insight into the decision-drivers for network specialists and their perception on company goals and policy. The results of the analysis will display the company goals and aspects needed for improvement in AM of water connections at Evides which may not be stated explicitly as goals by the company workers during interviews. The results from the analysis will be used in adapting the decision-making model and will later serve to evaluate influence of a BI tool on the recommendation making.

There exist other methods of qualitative interview analysis, among others – narrative analysis and deductive approach (Liamputtong, 2009). The former utilizes interviewer's impressions of meanings and insights from the data in order to compose a new narrative describing the findings (ibid.). This process was deemed unsuited for this research due to relatively well definable and technical context. A deductive approach focuses in turn on evaluating pre-existing hypothesis which was not the case for this research (Fereday, 2006). In the next section, the applied model for thematic analysis is presented.

Steps in the analysis

This model, originating from work of Boyatzis and Crabtree (Boyatzis and Crabtree, 1998), defines the order of steps after conducting a (semi-structured) interview (Figure 5). Suitability of this model for this project resulted from cyclical "narrowing" of the findings, allowing for compressing large amount of information into concise themes (Feredey, 2006). Additionally, clear overview of steps allows to keep details found during 'middle-steps', giving more complete description to final themes.

This model was initially designed for broadly-scoped research with multiple researchers involved (Burnard, 1991). Due to that, the gradation of steps appears to be too fine for the scope of this research where only a few participants are involved. For that reason, this model is adapted to better suit the context of the semi-structured interview conducted.

Phases 1&2 follow the described model closely: in phase 1, the transcripts and recordings from the interviews, will be analyzed and summarized (summaries can be retrieved from Summaries of interviews). Answers to each question will be broken into a number of key-statements per each respondent (Summaries of the interview answers). Next, summaries will be used to generate open codes, where each key-statement will be converted into an open code (phase 2). Due to the relatively small size of the interview material, phases 3 and 4 have been merged, so that the codes will be aggregated and merged to create sub-themes. In the fifth phase the final themes will be defined. In this phase, more than 3 themes will likely be selected due to the variety of topics discussed. Phase 6 will be done in the context of the decision-making model where the themes will be used

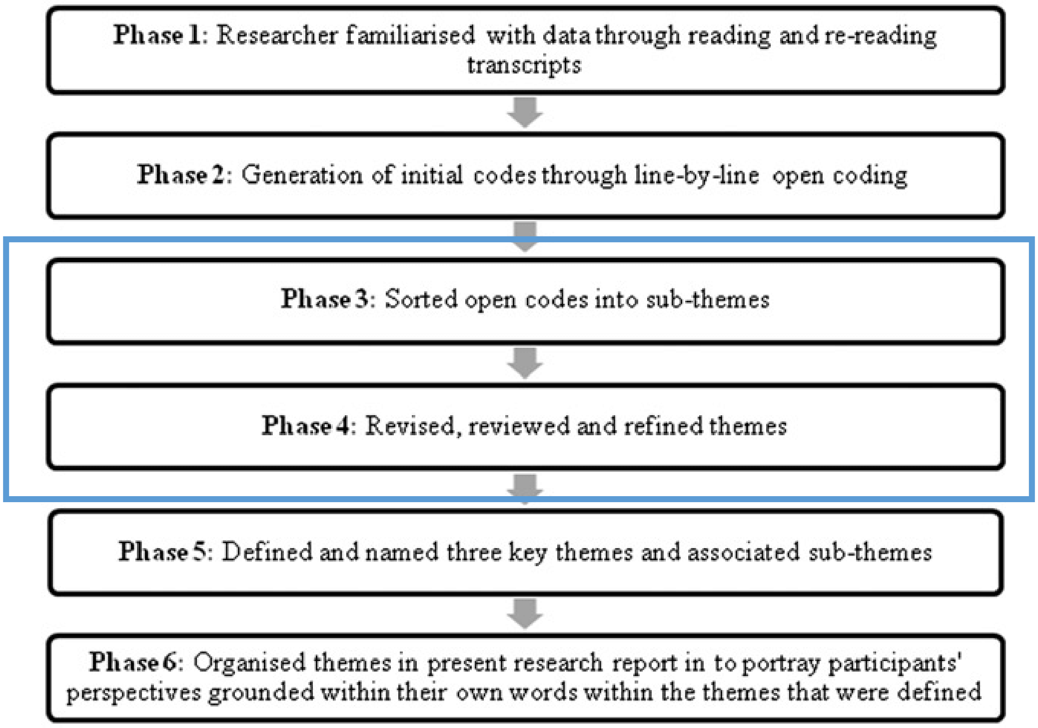

Figure 5 Phases in thematic analysis (adapted from Fereday, 2006)

2.2. Decision making model (un-adapted)

For this project, a part of literature review was dedicated to retrieving a decision-making model which could be representative for asset management department at a water company. An applicable model will allow placing and contextualizing of data-demand for network specialists together with the questions they need to answer at different stages in the process. Secondly, the themes defined during thematic analysis will be added to the model to describe which company goals/concerns are being addressed at a given stage. Thirdly, the selection process for performance indicators will be based on and reflect the data-demand moments and company goals. Lastly, the combination of the two will be used to evaluate which parts of the decision-making process benefit from addition of a BI-tool.

To select a model which can approximate the current processes at Evides, a number of models was evaluated. Among the administrative models, the original Simon's model (Simon, 1960) was first considered. It is a minimalistic model which displays interaction between Intelligence – problem identification and data collection, Design – generation of alternating solutions and Choice – selection of the solution (Campitielli, 2010). This model suggests that search for information ends at the Intelligence stage, whereas it was known prior to starting this research that domain specialist's consult data at multiple stages. Moreover, such a model assumes that decisions are made with complete information regarding the issue at hand, which rarely reflects reality at a utility company (Simon, 1945)

Secondly, a version of the satisficing model was assessed. As described in the research contextualization, in this model it is assumed that the decision maker will opt for the first solution that satisfies the key goals (Simon, 1956). However, asset management goals regarding water connections at Evides will not be known ahead of time; therefore defining a 'satisfactory' conclusion can prove ambiguous. Furthermore, this model does not encompass for evaluation moments, where performance as a result of decisions can be re-assessed and corrective action taken.

Given the limitations of the two models described above, and taking into account the afore-mentioned assumption of bounded rationality, Henry Mintzberg's decision-making model (Mintzberg, 1986) was selected as a starting framework for this research. This model, in its original form, can be seen below.

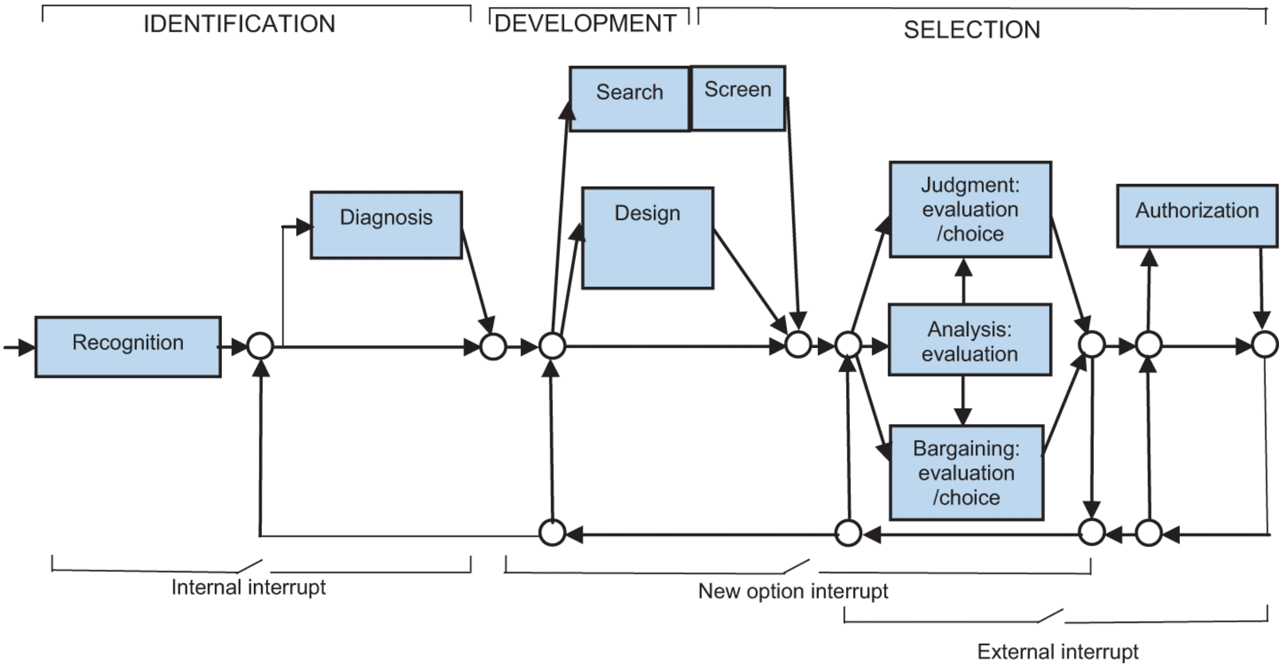

Figure 6 Unadopted Mintzberg Strategic Decision-Making Model (Mintzberg, 1976)

From the point of view of this research, this model was suitable because it displays the decision-making process as a series of choices where alternatives are not always known ahead of time (Aurum, 2003), which is believed to be representative for how decisions relevant to this research are currently made at Evides. Secondly, it draws a distinction between issue-recognition, solution-generation and solution-choosing. These instances are often separated between domain-specialists and management members. Lastly, it lends itself well to adaptation due high number of intermittent steps which can be altered or omitted (Mintzberg, 1973)

Moreover, this model recognizes the process of developing an understanding of the problem by the decision maker. By distinguishing between identification, development and selection stages, it enables observing and modelling decisions as a step-wise process, rather than a singular event of choosing between alternatives (Ahmed, 2014).

This model will be discussed with the network specialists during the interviews to assess its validity in the context of the case study company. In the results section, application of this model on a known decision will be performed and interpreted to assess validity. Lastly, this model will be adapted with the information gathered during the interviews to better reflect the decision-making process at Evides.

2.3. Selection of performance indicators

Performance indicators will be retrievable from the BI tool and will be applied to communicate aggregated number of asset(s), performance and vintage characteristics. Indicators will be selected based on ability to connect cumulative performance readings (registered in the system as breakdown events) with relevant company goals, which will be retrieved from the interviews. In this research, the performance indicators are not studied for their explanatory value with respect to asset performance but as a mean to display information that can support maintenance decisions and potentially aid goal setting. The process of selecting the performance indicators will result from interpreting relevant company goals and will in parts encompass for indicators used at the case study and as retrieved from literature. Implementation will be done with the following, normative, functions in mind (Marques, 2001)

- Concise display of summary for available company data for the object of interest
- Distilling a quantitative reading of company's base-line performance
- Enabling benchmarking capacities between asset groups of similar function and structure
- Attracting attention to outliers and deployment of projects to address the issues

Selected performance indicators will be calculated across different groups of network elements. In that, depending on the utility company's object of interest, following selections can be applied

- Geographical grouping in respect to administrational or technical area division
- Technical grouping in respect to technical composition of the studied assets
- Seasonal grouping in respect to window of observation
- Performance grouping – aggregating assets in terms of their reliability performance

Indicators will be then tailored to decision moments at which network specialists consult data to assess the situation.

2.3.1. Approach to identifying attainable performance indicators.

In this research, the approach from Goncalves, 2015 will be adopted, where the performance indicators are expected to be *clear, simple, representative of data owned, with acceptable degree of certainty and ready to be iteratively adapted over time*. Connectivity to company goals, understandability and availability of data needed will be considered most relevant for the effects on asset management of water connections at Evides, to be measured during the evaluation. The generic performance indicators identified in the literature review (Table 1) will be used as a starting point for this exploration.

Data-demand and company goals will be merged and converted into questions which need to be answered using indicators which will be named during interviews. Based on this and a survey of relevant literature, a selection of indicators will be made and assigned to each question. Should company goals not be stated explicitly, they will be assumed to aim at maintaining the current situation.

2.4. The BI portal as decision-support system

After conducting the interviews and performing thematic analysis, the themes will be translated into design-choices embedded in the BI portal which will serve as a decision-support system.

2.4.1. Preliminary design and assumptions

The portal will be designed with the tasks-division from Table 4 in mind which will result in different windows per user-group (terrain managers and asset engineers). Managers will not be included as a separate user group to reduce complexity of design and because their decision-making process will not be studied in this project.

The primary goals of the portal are aggregation and display of processed data in the form of performance indicators. Selection of displayed indicators will be made per user-group, contingent on company goals and aspects of interests named by specialists in the interviews. The software which will be utilized to produce the BI tool will be Power BI (Microsoft).

The datasets will be connected from Evides databases via an SQL query. Technical and breakdown data will be combined with each other using data-model functionality, creating the data-warehouse. All imported data can be accessed by the users, however, only selection will be directly visible in the front-end to improve legibility. Geographical information will be displayed using a GIS extension of PowerBI and will be able to show connections on a map, together with the technical and maintenance data.

The themes from the thematic analysis will be translated into functional units. This is done to illustrate what is required from the portal for it to be usable in the experiments. These functions are initially too generic to be coded, thus they will be converted into questions which need to be answerable using the BI tool.

2.5. Evaluation and survey

Using information on data-demand and decision-making from the interviews, a prototype of a decision-support system will be built as a BI tool to allow for assessment of its potential contribution towards relevant asset management recommendation-making. This process will consist of two stages. Firstly – specialists will be asked to obtain asset and performance readings by applying a user-selected mix of the conventional tools and the BI tool. Afterwards, specialists will be asked to fill out a survey to evaluate the applicability and value from applying the BI tool in the context of asset management challenges (themes), as distilled from the interviews.

Six company members will be chosen among the recommendation makers within the asset management department at Evides. Majority of the participants will also have participated in the semi-structured interviews. This will be done to maintain alignment between stated data-demand, company goals, users' preference and in order to maintain coherence of aspects measured.

2.5.1. Evaluation design

Considering limitations to possible sample size due to narrow user group at the case study, a quasi-experimental non-randomized pre-test post-test approach (White, 2014) was initially chosen. This is initially selected instead of one-group posttest design to attain an element of control group and better internal validity (Ibid.)

Pretest-posttest designs (PTPTD) are frequently used in behavioral studies where the impact of treatment is to be established (Dimitrov, 2003). In the PTPTD, the same participant is asked to participate in the research twice to assess whether measures taken were effective. This contrasts to other experimental designs, such as posttest-only, where a control group replaces the necessity of conducting the experiment on the same participants. This approach allows further to effectively select the participants for the experiment, without the necessity to assess the equivalency of groups. The disadvantages of this type of test is that participants grow aware of the object studied and can reduce external validity of the results (Marsden, 2012).

This approach was therefore speculated to be difficult in deployment in this research due to the quiz answers requiring numerical or short answers which can be easily remembered between trials. The concern is that the participant will be less motivated to search for the answer second time around (Brogan, 2012). Secondly, the analysis tools currently used at Evides do not offer access to some of the metrics that will be found in the portal. These will be gathered during the interviews and embedded in the portal but network specialists are unlikely to know how to "evaluate" them ahead of time due to limited exposure in the past. This means that the BI tool and current practice can be compared either only in terms of 1) time it takes to arrive at the result or 2) in terms of value of information found. Approach 1) was considered disadvantageous because the quiz questions would have to effectively examine whether the BI tool can mimic what the existing tools can do. Should the questions examine full capacity of both systems, very laborious tasks would be imposed on the participants to arrive at the results using current methods. Approach 2) would be more informative but would require evaluating which specific findings offer better input in the decision-making process. This in turn, would require evaluating quality of the decision itself which is beyond the scope of this research and could not be performed in a company context unless a wider research is agreed upon.

Given the limited availability of the specialists and issues stated above, this part of the research will be converted from experiment into evaluation and assessment. Each participant will be given a choice to use the existing data-system to answer the questions and, should that prove too time consuming or difficult to reach due to data structure, they are free to opt for trying the new tool. This will be done in order to allow the participants to develop a comparison between how the process is conducted now and with the addition of a DSS. These results will later be captured using the survey described in 2.5.3.

Each evaluation will be conducted with 1 participant at the time. First, a presentation of the portal will be given where variables, layout and data-sources will be displayed. The chosen BI software – PowerBI, is a relatively new tool, which entails that participants will have to be shown how to navigate the tool, apply filters and make use of combined data. After the presentation is over, the participant will be shown all the questions and will be asked to start the test.

The participants will be informed that their answers to the test questions will not be evaluated on their correctness and that they will participate in a survey after the test in order to evaluate the applicability of a BI-portal to their daily work activity. This is done to encourage participants to assess the gain for asset management practice resulting from adding the BI tools to their toolkit, rather than tool's accuracy in its development stage. Secondly, evaluating answers' correctness would require existence of validated results to compare against and a discussion on how these answers were attained. Because these values are likely not predefined within the company at the moment of test, it is decided to be avoided due to low pertinence to the research.

Opting for information retrieved from the post-experiment survey is assumed to preserve more impactful reflection on recommendation-making related factors. This is, nevertheless, considered a suboptimal way to measure results.

2.5.2. Question design and deployment

The questions used in the assessment will be designed to evaluate the applicability of BI tool in the context of information and themes synthesized from the interviews. The questions will aim at having network specialists apply the filter mechanisms (technical and geographical) to contextualize findings and to synthesize information from performance indicators to answer the questions. The questions will refer to aspects of network performance that specialists named as relevant in their recommendation-making processes and synthesized into themes during thematic analysis.

Two different participant groups will be made due to different task-groups (as listed in Table 4): terrain managers and asset engineers. For each group, a different set of questions will be designed to reflect the differences resulting from job specifications. These questions can be retrieved from Table 12. Management members will not be included in the test. A number of questions will have sub-questions which can be answered, if the participant manages to answer the initial question. This is done to allow network specialist to develop an impression whether new insights can be found using a BI tool. This information will later be gathered in post-experiment survey.

The evaluation will last up to 1.5 hours which is the time allocation available. During the test, there will be no other specific time-constraints in order to avoid hastiness or undue pressure. The participants will use the same laptop (belonging to the author) to minimize technical complications. On the laptop, there will be available: the EAM environment (standard tool for accessing data), Microsoft Excel and the BI portal (through browser).

2.5.3. Post-experiment survey

The post-experiment evaluation will be completed by each participant on the day of the test. The network specialists will evaluate, based on their impression from the evaluation, how the BI tool can influence and enhance aspects of their recommendation-making process. Insight resulting from thematic analysis will be guiding in the design of the questions and will aim to reflect where facilitation in the recommendation-making process may have occurred.

The survey will be done via a Google-forms where a 5-point Linkert scale will be used. The form can be retrieved from the appendix (103). In the survey, assertions on the applicability of the BI tool will be made in the context of reaching company goals or enhancing the recommendation-making process for water connections. The specialists will evaluate accuracy of the statements using the scale. Because the participants will only have limited exposure to the portal in the course of the evaluation, they will be asked to use the middle point (3) to indicate insufficient time to recognize the functionality. Values below 3 imply a loss in productivity or negative impact on performing work. Scores above 3 will imply value added in the way work is done or the results are attained.

The statements will relate to and reflect the input from the interviews after they are synthesized into themes. Specialists will be asked to evaluate whether improvements can be reached and what obstacles they see in introducing such a tool at a water company. Alignment will be evaluated between the themes, company goals and evaluation of the tool functionality. The participants will be lastly asked to name things which they found appealing about the BI portal’s functionality and also things which they see as deterrent towards implementing such systems within a water company.

3. Results

3.1. Semi-structured interviews

The interview questions were designed into four subgroups and are reported in the same way below. These results precede the thematic analysis and are displayed based on aggregation of answers per question (84) and the summaries. The question lists can be retrieved from Interview questions.

Recognition: Role of interviewees, approach and steps in recommendation making

Network specialists deal with connections in 5 primary cases, as listed below. Due to different tasks (Table 4), function-distinction is added for clarity and connectivity with the design of the BI tool. Management members are not included in the list below because they do not participate in conducting analyses.

- Removal of old connections (technical specialist and terrain managers)
- Installation of new connections (terrain managers)
- Breakdowns (reliability engineers and technical specialist)
- Technical tender offering (technical specialist)
- Replacement and cooperation projects (terrain managers)

Recommendations on removal and installation of connections are made based on aspects other than performance and will not be considered in this project, similarly to technical tender offerings.

For remaining items, interviews showed that the steps in making of recommendations commonly include:

1) Quantifying relevant connections and creating a first overview
2) Querying and extracting technical information on connections
3) Querying and extracting breakdown information
4) Combining technical and breakdown information in a spreadsheet
5) Assessing performance using failure frequencies
6) Assessing extent and consequences of
    a. Breakdowns - via quantifying amount of connections and addresses affected
    b. Measures - via complexity of deployment (financial, social nuisance, labor)
7) Submitting proposal for management decision

For terrain managers, the first two steps were described mostly in relation to assessing inclusion of connections in a cooperation project where pressure mains are replaced. Assessment of the extent and consequences of breakdowns were not a part of the process, only compliance to the policy is assessed.

For the reliability engineer and technical specialist, steps 1-6 lead to proposing measures to alleviate the problem if the issue is considered as severe and needs to be acted on. Assessment of severity is not uniform among specialists but seeks primarily whether the problem has been encountered elsewhere in the network and can be attributed to a cohort of assets. If the problem is a "one-off", no extra analysis is warranted and the reliability issue is approached with regular reparation.

An element of severity assessment is estimating the consequences of the reliability issue. This assessment may be linked to the company risk matrix but no uniform model exists to define "average" consequence per connection breakdown. The company's risk matrix was discovered not to share common denomination with how connections breakdowns are described. In the matrix, consequences are quantified with customer minutes lost and financial repercussions. These units are tailored to failures of pressure mains but neither of them is presently measured for connections. Secondly, an individual connection breakdown could not produce an impactful placement in the matrix on either of the aspects. In absence of a clear grouping mechanism applying currently measurable performance aspects, the risk matrix is used very rarely for connections and is concluded to have marginal impact on recommendation making for connections.

Asset strategy of Evides for water connections is predominantly maintenance strategy which encompasses for:

1) Failure based maintenance where yearly agreements are made as to the expected number of breakdowns and consequent budget allocation. No service level agreements exist. According to interviewees, reactive maintenance is applied for the following reasons:
    - Individual breakdown leads to minor consequences
    - Deterioration processes not entirely clear and not translatable into actionable measures.
    - No systematic failure cause across different breakdowns.

2) Preventive maintenance: replacement of remaining lead connections due to health hazards, cyclical replacement of water meters (outside of the scope of this project), identification of cohorts with suboptimal performance to define susceptible areas. Connections can be included in the planned maintenance of distribution pipes, assessment of which is done based on a scan of compliance with company policy. The policy describes a narrow range of connections based on year of origin and material, with performance not considered yet. Replacement can also occur during collaboration with other utility companies on projects where distribution pipes and connections become accessible due to other utility companies executing network renovations.

Activity: Types of recommendations made

Network specialists were asked about the types and extent of the recommendations they are expected to make. The results are presented in the table below with distinction between specialists' function. The functions of technical specialist and reliability engineer are merged together into "asset engineer" due to high convergence.

Table 5 Aspects assessed in making asset management recommendation w.r.t. water connections at Evides

Aspect	Terrain managers	Asset engineers
Example of a recommendation or activity	• Capacity for installation of new connections (not in scope) • Selection of connections to be removed (not in scope) • Inclusion of connections in cooperation projects • Reporting localized performance anomalies	• Cyclical reliability reports • Premature end of asset life • Addressing structural issues • Identifying and characterizing performance outliers • Contribution towards long-term asset planning
Scope of recommendation	• From individual connection to the whole governed area	• Can vary extensively
Relatedness of connections	• Belonging to the same project • Same network segment (e.g. distribution pipe)	• May belong to the same cohort, often not known in advance

Aspect	Terrain managers	Asset engineers
Geographic extent	• Only within the governed area	• Goal is to narrow down possibly much, can be as much as the whole network

It is observed that asset engineers deal with a broader selection of performance aspects of water connections. By producing cyclical reports, they are frequently in charge of localizing performance anomalies and interpreting the significance for the company. This is however very broad and only major issues seem to be captured in this process. Terrain managers, in the context of this research, are only in charge of assessing inclusion of connections in pressure mains replacement projects. They are also supposed to report performance anomalies, but no consistent performance monitoring for connections per area exists. Geographic extent is well defined for terrain managers and correlates with governed terrain. For asset engineers the extent is very broad (all of the network) and so far, geographic extent is only described per municipality in terms of yearly breakdown frequency.

Descriptive: Parametrization of network performance, current practices, and possible improvements

In this part of the interview, network specialists were asked about their data-demand and the conversion of data into performance indicators. Data-demand was primarily addressed in questions 1c, 1d and 3a and was first analyzed in separation from the decision-making model, with focus on required datatypes and cross-connectivity. This information is later used in adaptation of the model, defining data demand and is lastly synthesized with the results of the thematic analysis.

The interview answers have been summarized to key statements and aggregated per question per each respondent (84). The type and extent of information desired by network specialists can be seen below. Not all information is directly available from the data and needs to be first combined and processed before becoming informative – aspect described in Table 7.

Table 6 Data demand for producing recommendation, as retrieved from interviews

Function	Terrain managers	Asset engineers	Manager Asset Division	Manager maintenance
Most frequent terms	• Type and amount • Location • Maintenance (events) • Compliance	• All available technical data • Issue frequency • Failure mode • Extent • Performance metrics	• Performance anomalies • Performance metrics • Breakdown urgency • Issue range • Compliance	• Amount of issues • Performance outliers • Structured • Failure cause • Suboptimal performance

This information is then described in terms of its database source which can be either 'Connection data', 'Breakdown data' or 'Processed data' which refers also to cross-reference of the first two data sets. Structuring of this information allows to accurately describe type and nature of data in the context of the decision-making model, creation of the data-warehouse, and assessment of value of BI tools in the context of access to data. Characteristics imported from each data set can be found in the appendix (72). Below, the datatype and source can be seen.

Table 7 Type and origin of data needed to perform analysis

Datatype	Data-source
Amount of connections	Connection Data
Technical composition of connections	Connection Data
Locations of the connections	Connection Data
Number of breakdowns	Breakdown data
Type of breakdown	Breakdown data
Urgency	Breakdown data
Singular or Structural problem?	Processed data
Performance metrics	Processed data
Compliance	Processed data

The answers provided by asset engineers, terrain managers and management indicate a lack of convergence in data demand between these user groups (Table 6). Consulting findings on the type of recommendation made by asset engineers and terrain managers, it can be seen that asset engineers address a larger variety of cases which results in preference to retain access to both unprocessed data (as stored in the database) and the processed data in form of performance indicators.

Tasks of terrain managers have smaller variety (Table 4) but require both processed and unprocessed inputs (Table 7) to assess compliance of the connections with the policy. These requirements do not however change frequently and can be preprogrammed. This can allow to replace specialists' need for unprocessed data (location, technical composition) with processed data (PI: conformity).

For the manager of the asset management department, processed data appears as most important and is used to compare performance between cohorts or terrains (internal benchmarking, identifying low performers). This suggests that managers need to primarily be informed about performance anomalies and their impact on the company operations. A manager of the maintenance department expressed data-demand for qualitative summaries of connections affected, failure mode and reparations made. This suggests that, as service provider, the data-demand represents interests in 'how available resources' are used and whether different allocation has to be requested in terms of work-hours and other resources.

In the second part of this section, network specialists were asked about their methods and metrics to describe network performance. Failure frequency was the most commonly named performance indicator among asset engineers. Asset engineers displayed preference for metrics known from the distribution pipes which could be adapted for connections. Further, when speaking hypothetically, the following features were named as relevant in parametrizing network performance, despite not being measured currently:

- Time to and between failures
- Amount of failures
- Frequency of failure within cohorts
- Frequency of failure in respect to age
- Frequency of failure in respect to technical features available across the dataset.
- Costs of rehabilitation, image, loss of customer satisfaction, non-revenue water.

Additional aspects that were said to need measuring were primarily costs and efficiency of work done, defined as time the connection was in use without breakdown of the same type. This was however said to be hardly practical at this point because the failure mechanisms have only been registered for a few years. No formalized cost calculations exist because of the accounting system which does not allow to assign an individual breakdown event to a cost. Terrain managers were in turn most interested in connections' compliance with the company policy and failure frequency. This was described in the context of different geographical extent (e.g. per street, per borough). Both groups wanted to maintain access to the most data possible but to avoid manually pairing the technical data with the breakdown data.

Data-demand was said to not be affected by external administrative issues. A foreseeable result given the specialists' interests for maintaining access to all of the data. Recommendation-making was said to be affected by estimated costs of deployment. The costs are however not known in advance and therefore, a rough estimate is made which is meant to exclude measures which are *certainly too expensive*. No better approximation of "too expensive" was given, seeing as cases which pertain to more than 100 connections, as a rule of thumb, are considered by management as structural.

Current monitoring practices were described by asset engineers as focused on periodic reports and formulating long-term asset planning. In addition, reporting of outliers or known structural problems was mentioned. For terrain managers, no formalized monitoring practice exists.

Last question from this section inquired which additional information could be useful for recommendation making. Most commonly, a better description of costs per repair was mentioned, followed by a post-life review of removed assets as a source of information on deterioration mechanisms. Asset engineers mentioned external factors such as ground subsidence as relevant for connections in densely agglomerated areas but also reflected on difficulties in combining this data in an approachable manner within the software suits used.

Oversight: Linking company goals and making of recommendations

Network specialists and managers described their knowledge and perception of the company goals with respect to AM of water connections in the following terms:

- Removal of all lead connections
- Improved monitoring and cyclical reporting of performance and reliability issues, with as goal:
    - Displaying individual outliers
    - Displaying sub-performing cohorts
- Optimization of maintenance strategy to tamper consequences of aging network
- Optimization of connections' preventive maintenance by:
    - Overview and replacement of non-conforming connections
    - Inclusion of connections in maintenance projects on distribution pipes
    - Update of the replacement policy referring to when connections should be included in a replacement project of distribution pipes
- Creation of a long-term asset plan for connections
- Creation of more transparent rules with respect to maintenance choices
    - Avoidance of multiple breakdowns on the same connection
    - Improved transparency and cohesion in proposed measures
- Improvement in data-quality for technical components and registration practices

Generic company goals have also been recovered using company website and informal talks. These goals encompass for continuity in provision and quality of water, enabling highest customer satisfaction attainable. Minimizing nuisance on account of network reparation and modification was mentioned in the context of why collaboration with other utility companies is conducted.

Amongst the asset management goals for water connections, only the first goal is formally defined. Some of other items are “general goals” of the asset management department, applied to connections. Optimization of preventive maintenance appears to be a strong ambition of the company but has not yet been formalized as a goal. The performance management framework was named insufficiently complete to approach these ambitions structurally with the end targets in mind. This was attributed partially to absence of defined performance goals (e.g. SLA) which could otherwise enforce committing to more preventive maintenance strategy and recommendations. Specialists agreed that sufficient data likely exists to allow for quantification of possible (initial) performance targets.

The effect of the company-goals on the recommendations making was reported in terms of “doing what’s best for the company” but no direct line was drawn between the company goals, the risk matrix and specific decisions made. Risk-matrix is infrequently applied due to unsuitability for connections resulting from it being designed to address primarily large individual issues with distribution pipes. Due to that, substantiation of recommendation made by network specialists to the management lacks ability to utilize company risk-preference as depicted in the matrix. This can then lead to unclarity as to managerial decisions on replacement and preventive maintenance choices.

3.1.1. Results thematic analysis

Below, abbreviated results from the thematic analysis of the interview results can be found. The table with all the steps as explained in methodology can be retrieved from the appendix (Table 16). The themes represent implicit company goals and perception of what is needed to improve asset management practices for water connections managed by Evides.

Phase 1-4: Initial code generation

Based on the recordings and summaries of the interviews, open codes have been generated with respect to answers which occur most frequently. In the processes of synthesizing themes, provisional themes were firstly distilled. Provisional themes encompass for information that was convergent among the interviewees and the complete list can be retrieved from the appendix.

The provisional themes described some of the company-wide ambitions were:

- More data driven approach to asset management
- More recognition of data owned to create internal standards and points of reference.
- More capacity to assess the applied reparation modes
- Standardized yearly reporting of breakdowns
- Recognition of sub-performing cohorts

Phase 5 and 6: definition of key themes and subthemes

In the last two phases, provisional themes have been rewritten and grouped together under common, more broadly defined themes. This selection is meant to reflect objects of interest (concern) among the network specialists and company goals. In the following sections, the themes will be applied to the adapted decision-making model.

Table 8 Synthesized themes from semi-structured interviews

Themes	Sub Elements
Accessibility and quality of data	• Access to data • Data overview • Data completeness
Reliability metrics and dataset fragmentation	• Reliability checks • Reliability in relation to factors • Quantitative metrics of reliability
Monitoring and summarizing of network performance	• Continuity of monitoring • Consistency of monitoring • Identifying reliability anomalies
Interlinking company goals and reliability readings	• Cooperation with other companies • Increase in preventive maintenance • Defining company risk profile and reliability targets • Internal benchmarking
Decision support and drivers	• Data-driven asset management • Decision review • Decision drivers

Aspects captured via the provisional and the final themes firstly display the company need for change in data governance/management (theme: accessibility and quality of data). Accessibility of data appears to be an obstacle in allowing for more frequent application of performance readings by both network specialists and management. Thematic analysis displays that Evides seeks attainable metrics to characterize and monitor performance in greater detail but is at a young stage in development (data is being collected but not frequently utilized). Company risk-profile and performance targets for the asset group of water connections are not well defined and prevent converting performance anomalies into rehabilitation choices.

3.2. Adaptation of the decision-making model

Based on the information from interviews and thematic analysis, the 3 phases of Mintzberg's decision making model require some adaptation in order to reflect the reality of how decisions are made at the case study company. Thereafter, the Evides asset management framework is presented to identify the users of model. Lastly, all the information is synthesized to display the complete decision-making model for water connections at Evides, together with the overarching company goals with respect to asset management of water connections, depicted via themes.

Identification

The trigger for starting a recommendation-making process can be either an external request with a non-trivial reliability issue or a performance anomaly which surfaced from monitoring. For terrain managers this model will refer only to assessing inclusion of connections in the maintenance of distribution pipes during Evides planned maintenance or cooperation project with another utility company. Issues can surface as results of cyclical reports where an increase in failure frequency (as compared to previous years) is noticed. This process concludes the "Recognition" element of the model. Next, attention is given to scanning the maintenance history and brief quantifying of the issue extent to develop a "quick overview" and recognize whether performance anomalies exist. This process constitutes of the first "Diagnosis". Here, the first decision is made whether to act on the issue at all. In case of terrain managers, conformity of the connections with the policy will be assessed and is the only step in the process.

Development

Broader search for information is conducted to recognize whether a structural problem occurred. To do so, technical and maintenance data is exported, cross-connected and translated into performance readings. Comparison with known network standards (from cyclical reports) is done but no formal benchmark values (or service level agreement) exist to define the cut-off points for acceptability. In this stage, severity of the issue is assessed and solutions are generated. Severity is assessed using a number of checkpoints which are presented in section 3.2.1. If the issue is considered not structural but provides nuisance, network specialists propose solutions which can encompass for complete replacement, partial replacement or individual reparation in accordance with current practice. The number of affected connections, their vintage and maintenance history are considered as primary decision drivers but no uniform process exists.

The problem can be considered structural if it affects a cohort of connections, interconnected by the e.g. same material, vintage or mix thereof. No formal rule however exists for what constitutes of “structural”. Should the problem be considered as structural, a suggestion for Management of Change is made (long-term company planning) which is then approached by management and asset owners.

Selection

From the recommended alternatives, management chooses a solution based on feasibility, defined by, amongst other, costs, time horizon and policy. Additionally, urgency and social nuisance possible to be caused by the reparation are considered, together with safety of network, water and customer-minutes lost. Internal mechanisms for approximating these values could not be retrieved and aspects of managerial decisions were not captured in this research. Network specialists can be consulted here but their involvement and impact differ between cases.

Depending on the organizational resources required to deploy the solution, the authorization might be needed from respective asset owners. For application of this model in the context of the studied company, the extents of *Judgement, Analysis and Bargaining*, are merged into “Evaluation”.

3.2.1. Adapted model

Adapting and applying of a decision-making model is done to accurately display stages of the process at which BI tools will be evaluated on added value. Utilizing information from interviews, 'decision moments' are formulated and added alongside to Martin's adaptation of the Mintzberg's model for decision-making (Martin, 2013). These decisions moments correlate with the process described in 3.2. and will be used to delineate specific questions (section 3.2.3) which specialists need to answer using performance data. The complete model can be seen below in figure 7.

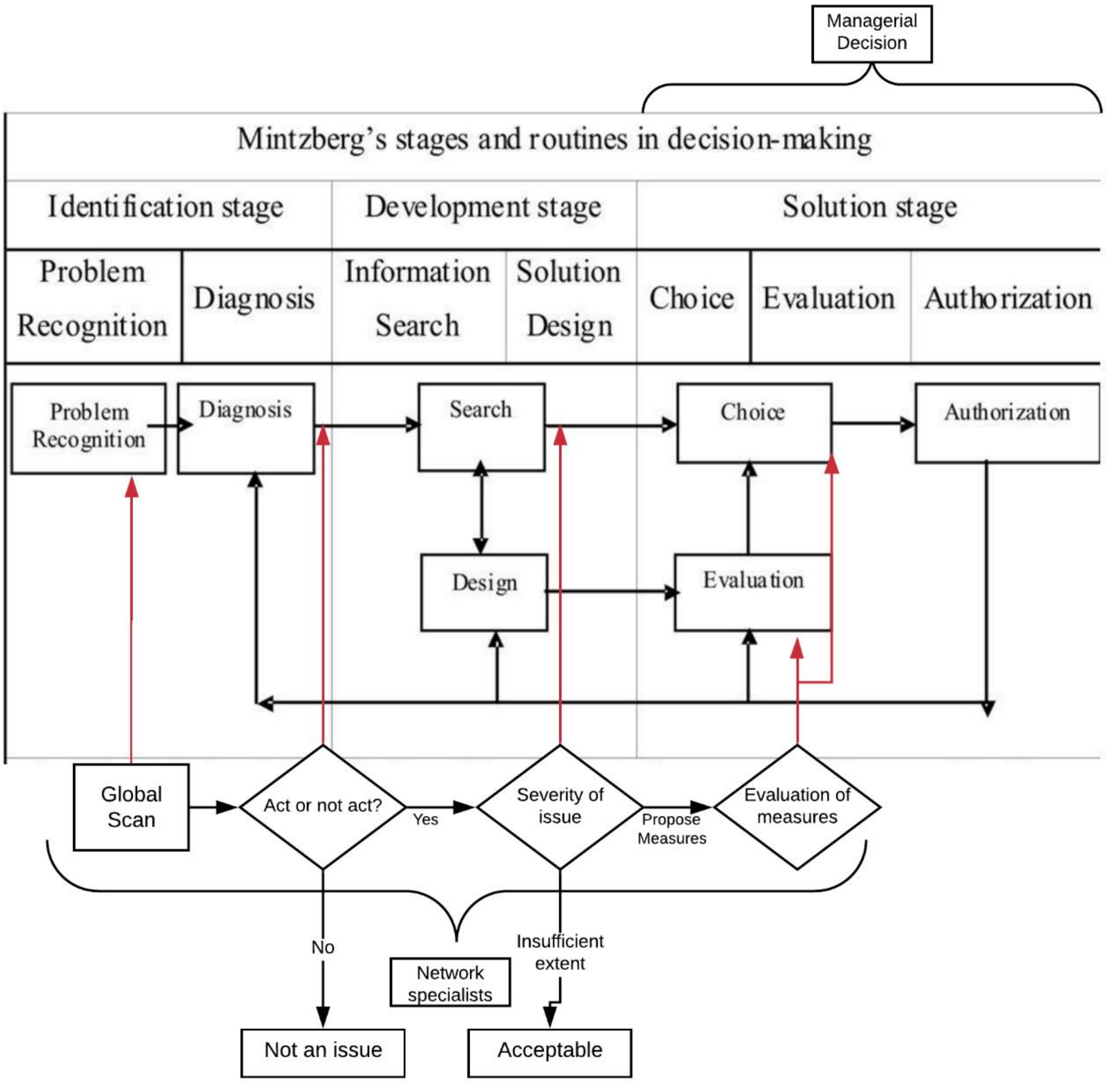

Figure 7 Adapted decision-making model with inclusion of decision moments

Distinction between decisions of network specialists and management is added; **Network specialists** produce recommendations based on available data and are reliant on the maintenance history and domain knowledge. **Management's** decisions are in turn bound by different set of constrains and extend past strictly data-based analysis. The overlap between sections represents where network specialists are consulted in the process leading to choosing a solution.

Three "decision moments" are designed as result of discussion with the network specialists and management. They are preceded by a *Global Scan* where first overview is created.

- 1st decision moment "Act or not act" – should the event be acted on by assessing precisely the scope of the issue and potentially be converted into a project? If not, the "event" is not considered an issue. Findings are substantiated by *Global scan* – a quick overview of issue's scope in combination with network specialists' expert knowledge.

- 2nd decision moment "Severity of issue" – based on the assessment of the severity of the issue, should it be converted into a project? If yes – which solutions are available to a water company to address the given issue? Substantiation is given via analysis of the extent of the problem, number of affected customers, potential damages to company assets, image and planning.

- 3rd decision moment "Evaluation of measures" – which of the measures is most feasible from the network specialist's point of view. Design and deployment of solution is bound by domain knowledge. Choice for the solution and implementation takes place in consultation with the network specialist but is a managerial decision.

Asset management framework at Evides

A three-tier asset management framework at Evides was retrieved and can be seen below. It distinguishes between framework-defining asset owners, performance monitoring asset managers and the service provider in charge of planning and performing of maintenance. The retrieved decision-making model was identified as relevant for asset managers who produce recommendations by analyzing performance and monitor compliance to policy. Consequently, the created BI-tool is meant to reflect their needs by supporting and potentially uniformizing some the recommendation making process by providing the information and overview in a simplified manner. This group constitutes primarily of reliability engineers, technical specialists and terrain managers.

Asset owners are consulted with strategic issues and get updated with cyclical reports. Process and policy recommendations are produced by asset managers and are approved by asset owners. Smaller issues (defined financially) can be addressed by informal recommendation to management and service providers. Larger issues are addressed by creation of a project and proposing individual solutions or submitting management of change request where more broadly scoped advice is given to the asset owners.

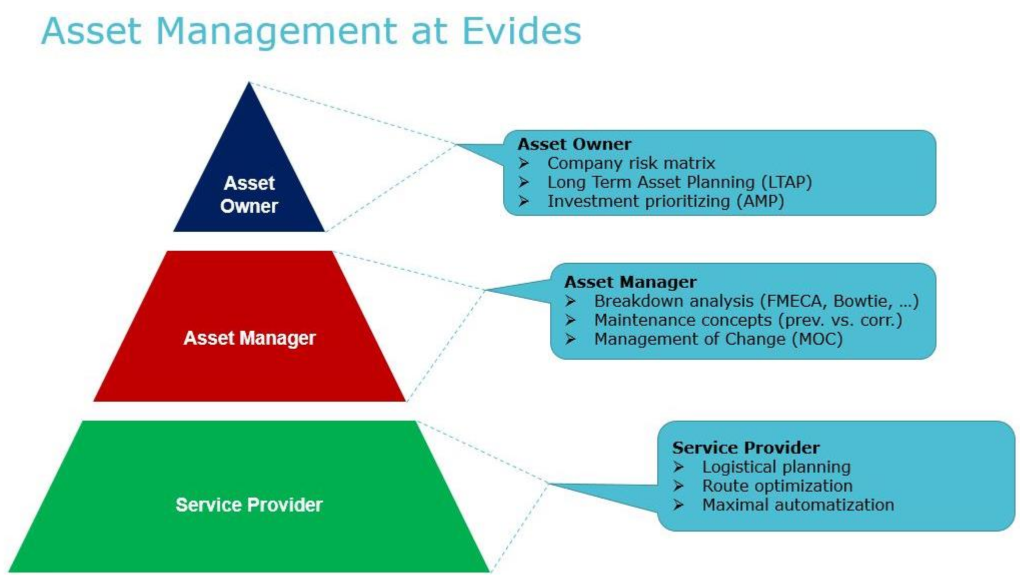

Figure 8 Asset management framework at Evides

3.2.2. Validation of the model

This model was validated by network specialists in context of a known issue. The process shown below presents current practice at Evides where only failure frequency is considered. All indices used were calculated using a spreadsheet upon querying and combining data.

The issue pertained to a batch of connections where the conduit was made of a soft polyethylene type which was discovered to become brittle over time. This issue surfaced when maintenance department signaled a region in which the same connections broke frequently in a similar way (pipe elasticity lost leading to breakage). Evides tasked the asset management department with proposing measures to address the issue. Process leading to that decision is described below using elements from the adapted Mintzberg's model.

Identification stage

1) Problem is reported by the maintenance department (external stimulus)
2) Global scan is performed to contextualize the situation. Given as it is an external report from technicians in the field, this step is automatically followed with the "Act or not" decision moment.
    - Results show that a specific postcode region in Rotterdam experiences a higher number of multiple breakdowns as compared to the net average.
    - Act or not? The issue should be acted on.

Development stage

1) Information search for installation years which might be affected
    - Connections from the years 1956-1959 in the particular region could be affected due to the same conduit supplier. This translates into more than 1000 connections in the risk group.
    - Severity of the issue – large, measures should be proposed.
2) Different potential solutions are generated, among them:
    a. Replacement of all connections from the period
    b. Replacement of connections with more than 3 breakdowns from the area
    c. Acceleration of replacement projects for the area with elevated multiple breakdowns
    d. Adjustment in reparation mode (replace instead of repairing) for future breakdowns
    e. Marking of the vulnerable connections in the system for easier recognition

Solution stage

1) Measures are evaluated
    - Measures A and C are too expensive or unrealistic
    - Measures D and E are implementable and can be budgeted for more quickly
    - Measure B requires a policy change and longer budgeting cycle
2) Managerial decision is confidential.

3.2.3. Themes within the decision-making model

Themes distilled during the thematic analysis were subsequently applied to the section added to the decision-making model. This was done by combining the extent of information network specialists defined as desired (data demand), with the goals they described for each "decision moment". This projects the company goals (expressed here implicitly with themes) over how the decisions are presently made at Evides. Data-demand correlates with questions network specialists need to answer and will allow for defining which performance indicators are needed to assist the user in substantiating the decision. Upon completing evaluation, this combination will display if and at which stages a BI tool can facilitate the recommendation-making of network specialists.

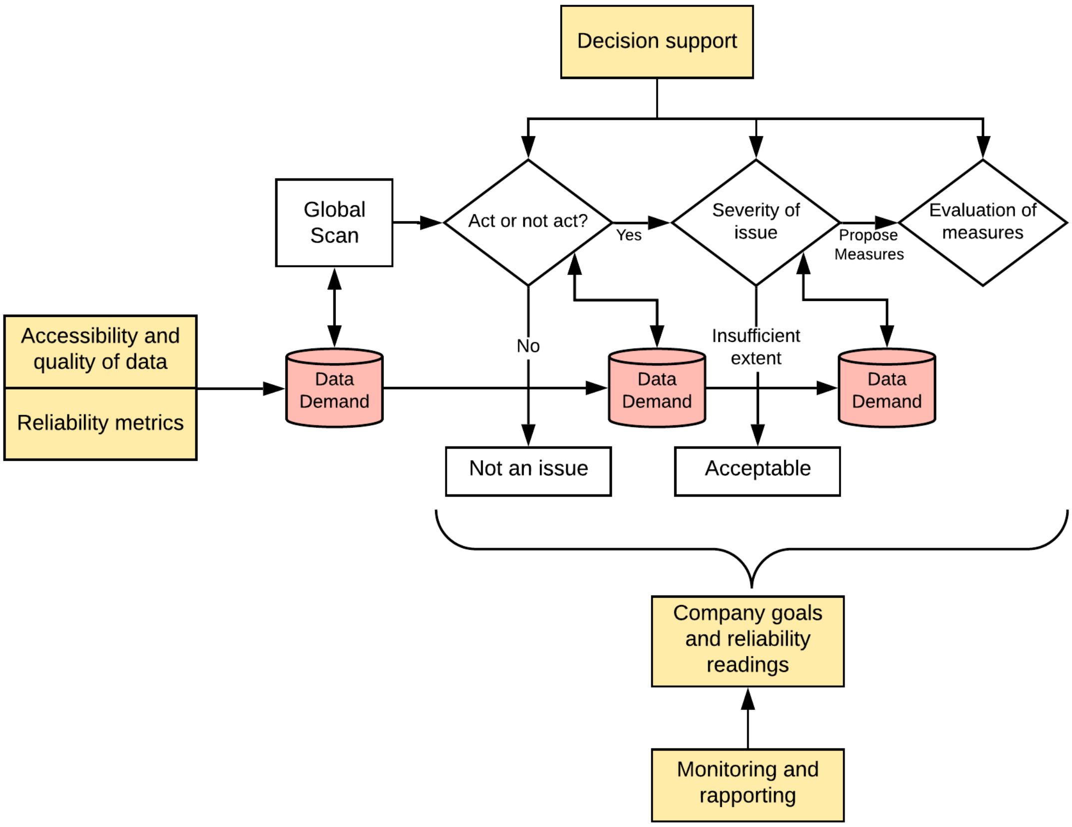

Figure 9 Implementation of synthesized themes within a section of the decision-making model

Having complete information about the data types in data demand (Table 6) the decision-making model (34) and positioning of the themes, data-demand was translated into specific questions. These questions need to be answered by network specialists using attainable performance information. These questions are then associated with performance indicators which can provide the necessary insight. By doing so, the selected performance indicators connect performance data with company goals regarding asset management of water connections. These questions were partially communicated by network specialists during the interviews and partially derived in the process of thematic analysis. The global scan is not described in this section because it represents collection and processing of data needed to perform activities under decision moments 1) or is related to observation performed during creation of cyclical report.

1) Act or Not Act
   a) Is the failure frequency higher in the given area/cohort than in the rest?
   b) Do multiple breakdowns on the same asset(s) occur?
   c) How many failures are being considered as relevant and how many customers are affected?
   d) Is the time-to-failure considerably lower for the cohort?

2) Severity check
   a) How many connections can be affected by the problem (and have not been yet)
   b) Does selected area/cohort seem to have a common element leading to worse reliability performance?
   c) Do the historical maintenance events display possibility of a structural issue due to amount or frequency of breakdowns?
   d) What is the extent of consequences (public nuisance, customer minutes lost) of the issue?

3) Evaluation of the measures

   a) How many connections would need to be replaced?
   b) Are connections available on the same pressure main and could be removed during scheduled maintenance event?
   c) Financial and technical plausibility is assessed.
   d) Managerial decision outside of the scope of this research.

3.3. Application and selection of performance indicators

In the interviews, network specialists disclosed that presently only failure frequency is calculated and consulted (decision moment 1). To create more overview, network specialists assess the scope and extent of the issue by quantifying the connections which could be affected due to belonging to the same cohort (decision moment 2). To extend the scope of performance overview and allow Evides to monitor the performance using metrics that relate to their AM ambitions, new indicators and quantifiers are proposed. The indicators where retrieved during literature review and discussed during the interviews with the specialists. Available data allows for calculating these indicators with relative confidence. The quantifiers have been selected based on how network specialists assess the scope and severity of the issue. These indicators and quantifiers can be seen below.

Table 9 Left: selected performance indicators; Right: selected cohort quantifiers

Performance ind.	Unit
Failure frequency	%/ (T)
Continuous failure frequency	%/ (T)
Mean time between failure	[Y]
Mean time to failure	[Y]
Breakdown rate	%

Cohort quantifier
Amount of breakdowns
Amount of connections
Amount of connected addresses
Average age
Amount of connections with more than one breakdown

Failure frequency at Evides is commonly calculated by dividing the number of breakdowns by the number of assets and their average (current) age. This is done to observe frequency of failure during asset's lifecycle. Continuous failure frequency replaces the assets' average age with the average age at the moment of breakdown. By doing so, continuous failure frequency will be noticeably higher than regular failure frequency for assets which failed prematurely. This can be further corroborated by comparing the mean time to failure with connections from other areas but the same year of installation.

Breakdown rate is calculated to allow the company to see how many assets in the analyzed cohort have already failed and quickly display the 'general' performance. This indicator, combined with mean time between failure and amount of connections with more than one breakdown, can help the company quicker discover if more structural problems can be suspected.

The indicators will be embedded in the BI tool and calculated automatically for selected area/cohort. Because majority of company goals with respect to asset management of water connections at Evides appeared not to be numerically defined, connection between company goals and performance indicators is assumed based on the indicators' capacity to answer questions stated in 3.2.2.

In the table below, column "Activity" is added to display how a network specialist can process the information to attain answer to the questions.

Table 10 Performance indicators and mode of application to answer questions belonging to 'decision moments'

Decision moment	Proposed Indicator	Activity
1a	Failure frequency	Compare with network and municipality average
1b	• Multiple breakdowns • Mean time between failure	Compare with network average
1c	• Failure frequency • Number of connections • Number of connected addresses	Expert's knowledge Report as a finding
1d	• Mean time to failure • Failure frequency • Continues failure frequency	Expert knowledge Compare failure frequencies
2a	• Number of breakdowns and addresses • Display connections on a map	Assess size of the cohort
2b	• Display cohort's characteristics per area (table) • Display number of failure's for selected cohort • Number of connected addresses	Compare with network average Compare with information from cyclical reports Expert knowledge
2c	• Number of failure's for selected cohort • Failure frequency • Breakdown rate • Number of connected addresses	Compare with network and area average
2d	• Number of connections • Number of connected addresses	Expert knowledge
3a	Number of connections	Sum, compare with company policy
3b	Table for connections and pressure mains	Expert knowledge
3c	• Number of breakdowns • Number of connections	Expert knowledge
3d	-	-

Majority of questions delineated under 'decision moments' can be approached by comparing available indicators with a goal of pointing out outliers. Failure frequencies and basic aggregators of assets and breakdown events are applied to facilitate specialist's ability to spot anomalies. This is contingent knowledge of network's averages. Absence of numerically defined performance targets and preferences to avoid impedes ability to identify where company goals are not reached.

Application of the steps shown above using the created BI tool is displayed in the next section, using the same example as displayed in the model validation.

3.4. The BI portal as decision-support system

The themes from the thematic analysis were interpreted into "Functions" which represent implementation-mode attainable within the BI tool. Themes are interpreted only from the perspective of utility to network specialist, not general utility of the tool, such as data cross-connectivity etc.

The functions are extended with questions contextualizing the decision-moment with attainable observations of network performance. These observations are describable using indicators presented in 3.3. This combination is done to display connection between the company goals (as presented via themes), the performance indicators and the design of the BI tool which will serve as a decision-support system by displaying relevant information in accessible way.

Table 11 Conversion of themes into functions, linked onto question item to be answered using the BI tool

Theme	Function	Question to be answered
Accessibility and quality of data	Daily data updates Breakdown data overview	What are the recent breakdowns? What has happened, has it happened for the first time, where has it happened?
Reliability metrics and dataset fragmentation	Performance indicators in respect to filters Aggregation per failure mode	What is the baseline reliability? What is performance of individual technical components?
Monitoring and summarizing of network performance	Summarization per network segment Assessment of compliance	What is performance per region, cohort? How many non-compliers are there in the region?
Interlinking company goals and reliability readings	Display of reliability baseline Display of outliers Evaluation of inclusion of connection in pressure mains projects	How does it perform compared to (…)? Which are the connections that perform suboptimal? What is the performance of connections on given distribution pipes?
Decision support and drivers	General functionality	-

Questions from table 10 were then associated with charts and display units available in the BI software capable of providing the desired overview. Lastly, allocation within the portal was chosen and can be seen in Table 18 in the appendix. In total, 3 user-specific windows were designed – Overview of recent breakdowns (all users), Overview of terrains (Terrain managers) and Overview of Performance indicators (Asset engineers). In the next section, the layout of the portal and functionality are displayed in the context of issue described in 3.2.2. and using performance indicators from 3.3. This is done to display functionally where water company may benefit from applying a BI tool. Additional examples can be retrieved from the appendix.

3.4.1. Example of application of the portal

In some cases, requests for reliability checks come from the maintenance department at Evides. Technicians having worked at the same company for long enough, recognize which regions are more prone to failing. Some of the connections fail multiple times which warrants more attention.

Should an engineer want to assess the reliability issues, the steps delineated in 3.2.3. would be followed. The specialist would then need to first download all maintenance and connection data for the given area. Thereafter, they would connect the records onto each other in a spreadsheet, using functions such as VLookup. At that point, a pivot table can be utilized to begin analysis. Performance indicators could then be scripted and relevant curves generated to observe e.g. breakdown frequency per year of installation. This is the process used and displayed in the validation of the model, as shown in 3.2.2.

Application of BI portal.

If utilizing the BI-tool as designed for this research, the asset engineer would be using the window "Overview of performance indicators". This window is presented in full in Figure Figure 14 and steps taken in this process will be described in the context of that image. The values of performance indicators displayed in Figure 14 represent averages for the total of delivery region for Evides and serve as "performance baseline", used later in comparative assessment.

Because the area of interest was communicated using a fragment of postal code, this information can be directly input using drop menu called "Postcode 4". The failure frequency (here referred to as *Faalka*ns) shows an increase from networks average of 0.34 % to 0.61 % which warrants immediate attention. Further, share of connections with more than 1 breakdown (*ANSL met meer dan 1 storing*) increased from the network's average of 1.8 % to 3.6 %. Lastly, the number of addresses in the area is displayed. This is a large area and aspects mentioned warrant attention and selecting to act on the problem (1st decision moment) to assess more closely the severity of the issue. Note that no premature failure is observed seeing as MTTF is higher for this area than for the rest of the network. All of the information can be seen in the figure below and has been obtained by selecting the postal code.

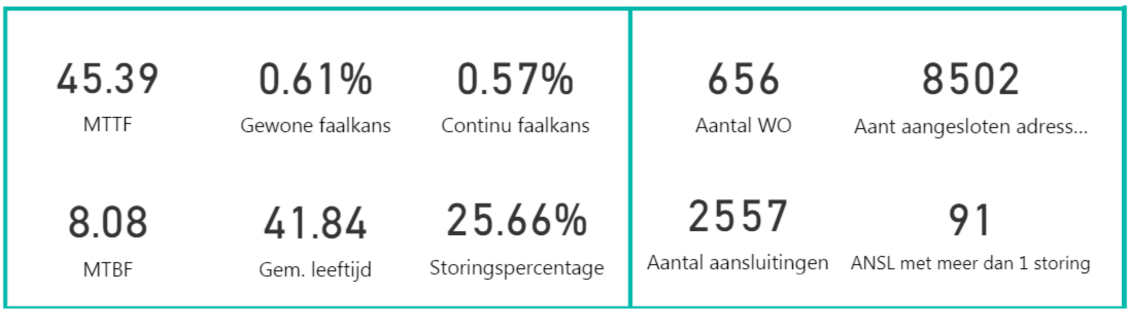

Figure 10 Performance indicators for the region

Left box MTTF= Mean time to failure; Gewone faalkans = Failure frequency; Continu Faalkans = Continuous failure frequency; MTBF = Mean time between failure;Gem. Leeftijd = Average Age; Storingspercentage = Breakdown rate
Right box Aantal WO = Number of breakdowns; Aant aangelosten adressen = Amount of connected addresses;
Aantal aansluitingen = Amount of connections; ANSL met meer dan 1 storing = Connections with more than 1 breakdown

Network specialist can then consult the breakdown rate curve (bottom left of the Figure 14), where it can be seen (for the given region) that installation year of 1958 has the highest breakdown rate (here: *storingspercentage*) and represents 219 breakdown events on 324 connections (nearly 5-fold increase to network average and 2.5 increase to the area average). This means that a cohort is identified based on the installation year and attributes from 2nd decision moment (severity check) can be obtained.

The image below shows values for cohort of installation year of 1958 for the given the postcode area and gives ground to believe that this is a structural issue, seeing as the rate of multiple breakdowns is now at 11% and 900 addresses might be affected by this situation in the area. This concludes the severity check and defines extent of possible consequences as sizeable.

50.54 MTTF	1.07% Gewone faalkans	1.34% Continu faalkans	219 Aantal WO	900 Aant aangesloten adress...
7.54 MTBF	63.00 Gem. leeftijd	67.59% Storingspercentage	324 Aantal aansluitingen	35 ANSL met meer dan 1 storing

Figure 101 Performance indicators for the given region and installation year of 1958

Left box MTTF= Mean time to failure; Gewone faalkans = Failure frequency; Continu Faalkans = Continuous failure frequency; MTBF = Mean time between failure;Gem. Leeftijd = Average Age; Storingspercentage = Breakdown rate
Right box Aantal WO = Number of breakdowns; Aant aangelosten adressen = Amount of connected addresses; Aantal aansluitingen = Amount of connections; ANSL met meer dan 1 storing = Connections with more than 1 breakdown

Evaluation of measures (3rd decision moment) can be done in the context of the information attained above and application of remaining tools. Firstly, one proposal could stipulate that only connections with more than 1 breakdown need to be replaced. This means that 35 connections would be taken under considerations. By using slicer "Aantal WO per ANSL" from the mid-right corner of Figure 16, the user can choose only the connections with a given number of breakdowns. Thereafter, a list is compiled with the 35 relevant connections. Utilizing the table from the left top-corner, user can scroll between data levels and display connections per distribution pipe they are attached to, the table can be seen below.

Materiaal - Gemeente - PC3 - PC4 - DISL - ANSL - WO

assetnummer_disl	Gemeente	Aantal ANSL	Aant aangesloten adressen	Aantal WO	Gem. Leeftijd	Continu Faalkans	Gewone faalkans	Storings-percentage
LEID-360080891	Rotterdam	7	7	21	63.00	5.81 %	4.76 %	300.00 %
LEID-433543928	Rotterdam	5	38	22	63.00	7.99 %	6.98 %	440.00 %
LEID-15056393	Rotterdam	2	12	28	63.00	27.32 %	22.22 %	1400.00 %
LEID-430587358	Rotterdam	2	3	4	63.00	4.23 %	3.17 %	200.00 %
LEID-433486416	Rotterdam	2	2	4	63.00	4.62 %	3.17 %	200.00 %
LEID-9717557	Rotterdam	2	9	22	63.00	20.92 %	17.46 %	1100.00 %

Figure 12 Display of connections' performance from perspective of pressure mains

This table allows the network specialists to quickly define that the first 3 distribution pipes have cumulatively undergone 71 of the 156 breakdowns and represent 14 of the 35 connections of interests. Should preventive maintenance on any of said pipes occur, the connections should be included. To assess the problem visually, the GIS environment embedded in the portal could be utilized to display physical proximity of the 35 most urgently relevant connections. This can be seen in the figure below, which can be obtained by pressing on the green button from the right bottom corner of figure 14.

Figure 13 Display of geographical distribution of connections with multiple breakdowns

Financial implication of the reparation mode would be assessed outside of the portal and is done using network specialist's expert judgement. The specialists could lastly create a data-export using the BI portal, containing all of the affected connections and their respective placement. Management would make the final decision as to when and in which way the connections would be addressed.

To conclude, this analysis would require from the network specialists considerably less time than in case of standard tools and it offers improvement in detail of the observation, limiting the area of observation from 2.5k to 324 connections quickly. This informs the company more clearly as to the scope of potentially beneficial preventive maintenance and customers which could be affected should maintenance not be performed. This relates to company goals to avoid multiple breakdowns, display performance outlier and cohorts. Because the performance indicators are the same for all of the network, analysis displayed above could be performed consistently across the whole asset population. This relates to the goals retrieved in the scope of thematic analysis, such as "Monitoring and summarizing of network performance" and "Reliability metrics and dataset fragmentation". This was previously not equally attainable to a water company, seeing as spreadsheets are not suitable for being shared while preserving data structure behind, problem replaced with the data-warehouse concept, active behind the BI portal.

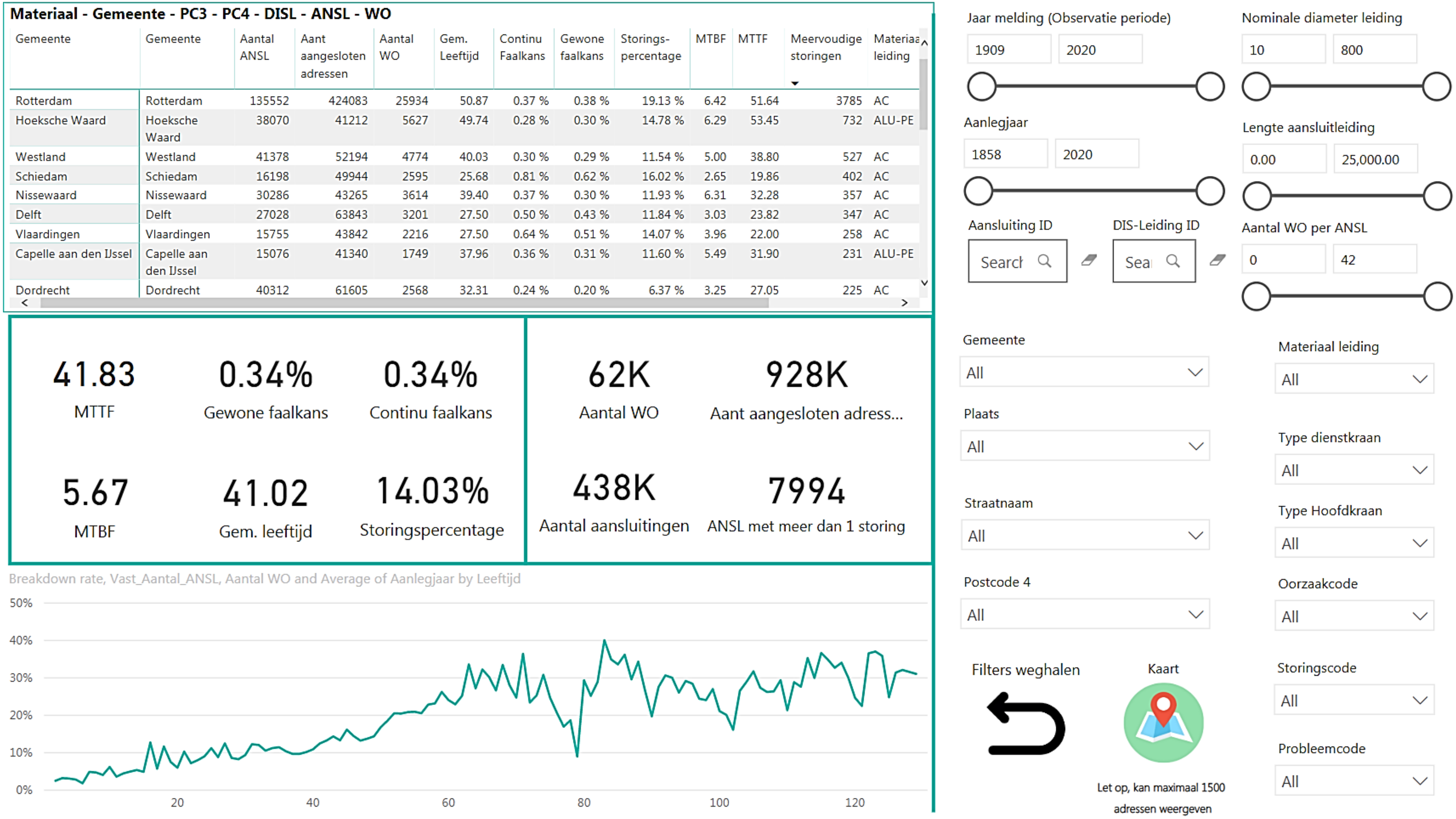

Figure 14 A window from the designed BI tool, section: overview of PI's

3.5. Evaluation and survey

Evaluations were conducted using questions developed after synthesizing results from the interviews. The questions were divided among the asset engineers and terrain managers due to different function goals (Table 4). Each question was linked to a theme as known from Table 8. Questions were designed to also allow evaluation on how accessible data is and how implementable this approach to performance analysis would be terms of ease of sharing and communicating between company members.

The questions were not known to network specialists prior to the quiz. Answers to the questions were calculated ahead of time, using the BI tool and partially corroborated with information from EAM. This was done only partially due to inability to operate on a large dataset with other software available in the company environment. Below, question lists for terrain managers and asset engineers respectively can be seen.

Table 12 Assessment question list for terrain managers

Question no	Task	Theme/ Sub-theme
1a	How many connections which do not conform to the policy are there in your (terrain manager's) region?	Interlinking company goals and reliability readings
1b	Create a list with these connections, display the amount of occurred breakdowns.	Accessibility and quality of data
2a	Another utility company is working on a project on the Nieuwe Maas (Schiedam) street. How many Evides distribution pipes can be found there?	Monitoring, cooperation with other companies
2b	On which distribution pipe were there the most breakdowns of connections?	Decision support and drivers
2c	Create a sheet with the connections' ID for the distribution pipe with the most breakdowns.	Interlinking company goals and reliability readings
2d	What's the average breakdown frequency for the connections on that street?	Monitoring, decision support and drivers
2e	If the distribution pipe is replaced, how many addresses would be affected	Monitoring (Social nuisance, customer satisfaction)
3a	How does your region perform in terms of breakdown frequency for connections (number of breakdowns or amount of connections) in 2018?	Monitoring, Reliability metrics and dataset fragmentation
3b	And in terms of mean time between failures?	Reliability metrics and dataset fragmentation

Tasks 1a, 1b and 3a could be completed by terrain managers using the conventional techniques. For questions 1a and 1b this was done using filters previously set up by specialists in the EAM environment. The answers in both cases converged with the answer model. This shows that the specialists developed techniques needed to answer the questions, however, records will only be displayed for a user-defined selection of assets. This provides sufficient overview when data is requested for given region but does not offer integrated overview which could be displayed e.g. per region. Therefore, the assessment is fragmented and would require reintegration to display the non-compliant connections for the whole region. This suggests that continuity in monitoring may be impeded by the current techniques. Question 2a could be answered using the GIS environment upon manual summation. Question 2e was attempted by both specialists but data could not be accessed easily enough and would require manual summing up. Question 3a was answered based on the cyclical reports and reported figures.

The remainder of questions was directly approached using the BI tool due to limitations imposed by the conventional tools where the breakdown data cannot be imposed over technical data easily. The specialists were able to use the tool and arrive at values from the answer model. This suggests that the tool can improve interaction with data by simplifying the access to it and remaining intuitive. In question 2 simulated a situation in which a cooperation project is conducted and evaluated. Increase of participation in such projects and inclusion of connections replaced preventively was retrieved as one of company goals. This process appears to be done more completely using the tool and from the terrain managers' point of view, the tool can contribute to more transparent overview of the situation.

Questions designed for asset engineers encompassed for bigger diversity of issues, result of the information attained during interviews. Primary objects in the assessment were how readily available the data is to create overview of the situation. It was assumed that ultimately, the specialist should be able to also extract the relevant data and operate it other environment, leaving the freedom of choice in terms of tools used.

Table 13 Assessment question list for asset engineers

Question no	Question	Primary Theme/ Sub-theme
1	Which municipalities with more than 100 connections are characterized with the highest breakdown rates	Monitoring, Reliability metrics and dataset fragmentation
2	How do connections with main valve (hoofdkraan) 025HH compare in performance between municipalities Dordrecht and Capelle aan den Ijssel?	Monitoring, Reliability metrics and dataset fragmentation
2a	And in the last two years?	Monitoring, Reliability metrics and dataset fragmentation
3	Compare the mean-time-between-failure for service-valves KK and MK, which municipality appears to have most problems with either of these valves	Monitoring, Reliability metrics and data fragmentation
3b	Are repeating breakdowns more common on one of the two?	Monitoring, Interlinking company goals and reliability readings
4	For copper connections: what are the first 2 points in the connections' lifetime when the breakdown rate observes a peak?	Monitoring, Reliability metrics and dataset fragmentation
5	In the period between 2015 and 2019, which municipality experienced the highest failure frequency, limited to problem code S02-ANSL (leakage)	Monitoring (Social nuisance, customer satisfaction), Reliability metrics and dataset fragmentation
6a	Between CU, HPE and PVC – which one has the highest breakdown rate?	Monitoring, Reliability metrics and dataset fragmentation, Interlinking company goals and reliability readings
6b	The earliest breakdown rate peak before age 30?	Reliability metrics and dataset fragmentation, Interlinking company goals and reliability readings

Question 1 could be approached by the network specialists with the conventional tool and the answer would be derived from recurrent reports and knowledge of the network. Remaining questions required cross-referencing the breakdown data with technical data. This displays that in the line of work of asset engineers, cross connecting data will always be needed as long as database registration mode does not change. Asset engineers were able to answer all the questions using the BI tool and admitted discovering new insight as to performance aspects, despite of the brevity of the session.

3.5.1. Post-experiment survey

After completing the experiments, the participants were asked to fill out an online survey in which they evaluate applicability of a BI tool. The survey utilized assertions on added value of a BI tool as a DSS in the context of asset management of water connections. The assertions were designed using the themes from the thematic analysis and factors which were named prohibitive in improving aspect of AM at Evides. The complete versions of assertions can be found under the following link: Post-experiments questions, below, the assertions are displayed in short form for readability. The results can be found in the table below. The abbreviations for the participants TM and AE stand for 'terrain manager' and 'asset engineer' (reliability engineer or technical specialist) respectively.

The closer the score is to '5', the higher the impact of the BI tool on the given area. Score of '3' means that the specialist had insufficient time to familiarize himself with the functionality. Scores below '3' imply that the work efficiency will actually suffer from applying the BI tool.

Table 14 Appraisal results for capacities of BI in the context of developed themes

Assertion (short form)	**Participant**					**Average**	**Std. Dev**
	TM1	**AE1**	**TM2**	**AE2**	**AE3**		
Accessibility and quality of data						**4.55**	**0.37**
Ease of access to data	5	5	5	5	5	5	0.00
Time saving	4	5	5	5	4	4.6	0.49
Facilitate data cross-sections	5	5	5	5	5	5	0.00
Review of data quality	4	5	3	2	4	3.6	1.02
Reliability readings and dataset fragmentation						**4.7**	**0.65**
Substantiation of recommendation	4	4	5	5	4	4.4	0.49
Enabling data-driven approach	5	5	5	4	5	4.8	0.40
Spotting areas in need of attention	5	5	5	5	5	5	0.00
Improved transparency	4	5	5	4	5	4.6	0.49
Monitoring and summarizing of network performance						**4.3**	**0.67**
Review of co-operation projects	5	3	5	3	5	4.2	0.97
Ease of sharing	5	3	3	4	5	4	0.89
Connections with multiple breakdowns are easier to find	5	4	5	5	4	4.6	0.49
Performance indicators can facilitate benchmarking	4	5	4	4	4	4.2	0.40
Decision support and drivers						**3.85**	**0.80**
Spotting outliers	4	4	5	4	4	4.2	0.40
Creation of cohorts	5	3	3	5	3	3.8	0.98
Potential improvement in depth of research	4	4	5	4	3	4	0.63
Usage of maps allows easier combination of technical and geographical data	4	4	5	2	2	3.4	1.20

Results show that for Evides, the biggest immediate benefit was recognized for how data can be accessed and interacted with using the prototype BI tool. The large convergence under the theme “Accessibility and quality of data” confirms that all participants agreed on accessibility being an issue in enabling utilizing performance data more frequently. Review of data-quality was rated lowest and displays that the mechanisms needed for it were not developed. It should however be noted that the tool was not designed with data-quality monitoring in mind and at Evides, data-quality is monitored by data-stewards who were not involved in the project.

Specialists agree that the BI tool created can facilitate spotting areas in need of attention and can provide overall improvement in transparency and substantiation of decisions. These factors do not define whether the company is ready for data-driven decision making (umbrella term) but the results do suggest that certain obstacles in the process could be removed using BI. Lastly, the managerial practice can benefit from being transparency and cohesion between decisions.

In theme “monitoring and summarizing network performance” it can be seen that terrain managers who are in charge of evaluation cooperation projects and inclusion of connections uniformly agree as to potential improvement from using BI. The company needs to possess a framework defining which performance aspects actually get considered, however, conformity assessment can certainly be streamlined using the tool. It is also apparent that benchmarking can be done more easily, a finding perhaps in line with the example of tool’s application as presented in Chapter 3.

The theme “decision support and drivers” was on average evaluated the lowest but also with the biggest standard deviation. This suggests that in absence of fully defined performance-assessment framework, agreement lacks as to what drives decisions at this moment. This section had the most answers “3” which implies that recognition of functionality would require more time. Lastly, the review of GIS environment was polarizing. This can be attributed to different fluency level between analysts in using conventional GIS tools which do remain far more powerful and cannot be replaced with the Power BI capacity. However, for terrain mangers, the display of maps seemed to add sufficient value and can likely save time by unifying environments in which data is displayed.

4. Discussion

4.1. Data demand and company goals

Two aspects of data-demand considered in this research need to be revisited before drawing conclusions on applicability of BI tools – 1) how different is the data demand between network specialists and 2) how well-defined the company goals have to be to allow connecting them with specific data fragments.

Data demand

The answers provided by asset engineers, terrain managers and management indicate a lack of convergence in the data demand (Table 6). Retrieved data demand, alike to performance analysis presently done at Evides, appears to be comparison-driven. In the absence of defined performance targets, it is evident that data is interacted with in search for anomalies rather than monitoring particular objects of interests and signaling. This suggests that data-utilization at the company, where preparing and processing is done each time "from scratch", is currently very laborious and results in only primary descriptive analytics being analyzed due to limitations in organizational resources. Compliance assessment done by terrain managers and management is the only exception and has been shown to be uniform. Alegre et al. (2018) suggested that long term balanced design planning for AM of urban water systems requires to begin from formulating objectives and ends in evaluation of efficacy of applied measures. Absence of these objectives for water connections suggests that the only truthful objective at this moment is compliance with existing policy on safety and health (removal of lead connections) and with the replacement policy referring to one specific cohort.

Current data demand at Evides appears thus dispersed and centered firstly on raw data which then is processed to allow identifying underperformers, extent of the issue or policy compliance. This suggests that the current limitations in utilization of performance data in decision making may result from difficulties in accessing and processing the information. In the absence of cross-connectivity, the company seems to have difficulties streamlining the advancement from raw data to descriptive data, such as performance indicators which could create real support potential for AM decisions. However, this suggests that with a BI data warehouse in place, the demand could shift from raw data to processed-data (descriptive and diagnostics information), thus displaying a potential for change in how data is interacted with and leveraging for more goal-centered practice. These findings were confirmed by the conducted evaluation and suggest that interaction and utilization of data in AM processes can be improved with application of BI tools.

Data demand for the manager of asset management department suggests that he would want to be primarily informed about performance anomalies and their impact on the company operations. This entails that the data demand would need to encompass for integrated indices such as the combined number of affected customers and time in which assets were not available. This data is however not measured, in which light only underperformers can presently be indicated. Lastly, the manager of maintenance department expressed a demand for qualitative summaries of connections affected, failure mode and reparations made. This suggests that, as service provider, data demand represents interests in 'how available resources' are used and whether different allocation has to be requested in terms of man-hours and other resources.

The differences in data demand between managers of asset management and maintenance departments correlate with the 3-tier asset management framework and the managers' respective roles of asset manager and service provider. In this research, insufficient insight was developed to speak of data demand from asset owners. This is an important shortcoming because it could allow for observation on data-alignment needed between the 3 tiers and its implication for reaching company goals. Because asset owners define service-level agreements, implicitly representative of company performance goals, their data demand could better illustrate which indicators need to be followed.

Company goals

Stated company goals, as retrieved during interviews, can be found in results under section Oversight. Themes distilled via thematic analysis represent aspects needed to enable professionalization of asset management of water connections at Evides. The contrast between the explicit and implicit goals displays that the company's asset strategy for water connections is not yet fully defined, whereas company ambition for inclusion of data in formulation of the necessary framework is clear. Aspects captured under the themes which refer to monitoring and performance analytics (reliability metrics and dataset fragmentation) suggest that service-level-agreements have not been defined partially because some of the asset performance knowledge is not yet developed. Elements retrieved under other themes encompass for distilling a risk profile – an aspect needed for performance assessment and acceptability. This suggests that Evides has found itself in an impasse of needing to utilize performance data more frequently in AM but cannot at times distil clear focus and overview of the current situation.

The stated company goals represent in some cases "general asset management goals" and lack specific milestones. This approach suffices in the current, reactive, maintenance strategy but may impede proactive efforts. This contrasts strongly with some of the stated company goals such as "optimization of maintenance strategy to tamper consequences of aging network," creating dissonance between measurability of ambition and current situation. Evides' emphasis on inclusion of connections in preventive maintenance projects suggests that the company wants to break the above-mentioned impasse but wants to do it with caution and firstly, only when opportunity arises. Cost-efficiency is a common asset management goal (Too, 2010) and is often defined as a mean to achieve the designed asset life-duration at minimal costs. This however cannot be accomplished with fully reactive approach where the design asset life-duration is effectively an observed average rather than results of effort. Avoidance of multiple breakdowns suggests that the company wants to revise its maintenance concept (how reparation is performed when breakdown occurs) and therefore requires better evaluation of how current maintenance choices affect an asset's remaining lifetime. This was captured in the thematic analysis under "Decision support and drivers" and suggests that parts of the needed framework can be weaved using already owned maintenance data.

This situation nevertheless poses limitations in interpreting the company goals and assessing application of a decision support system for its capacity to support said goals. Absence of structured asset management plan for water connections limits the ability to evaluate alternatives and priorities in asset rehabilitation and preventive maintenance. This was also seen when interviewees answered the questions on company goals in normative terms, instead of relating to existing guidelines. This is believed to have elevated the perception of agreement among network specialists, given as there exists little goal-prioritization. For Evides, this implies that data culture needs to be enabled where access to metrics is simplified and readings are transparent for the whole asset group rather than only e.g. known outliers. This also suggests that in terms of applicable decision-support system, a knowledge system cannot yet be utilized at Evides. Creation of better overview and accessibility to data is however likely a good first step in this direction.

Data demand and company goals

Aspects discussed in the paragraphs above suggest that shortcomings in both data demand and company goals partially result from how data is stored and used at Evides. Some of the biggest performance monitoring and framework problems at Evides thus appear to result from issues with consistency and completeness of overview.

The current performance management practice, centered around comparative assessment of failure frequency, can likely be improved on in linking the data owned and company goals. However, it requires a definition of acceptability which is presently missing and leads to inability to structurally manage the performance of different asset groups. This suggests that for data demand and company goals to be better aligned, performance baseline should be cyclically registered in terms of known indices (primarily variations on failure frequency) requiring from network specialists less intuitive and ad-hoc decisions which cannot be individually substantiated in the data. Secondly, financial data needs to be connected to the created BI tool and approximation is needed for customer-minutes lost resulting from individual breakdown. Combination of reliability, customer minutes lost and financial consequences reflects interaction between asset management goals and business goal. Research shows that a good match between these allows the company to improve budget allocation and improve overall asset performance (Too and Tay, 2008). Emphasis on business goals is not explicit at Evides but seeing as financial aspects play an important part in deciding for preventive maintenance, clearer business targets are needed to distinguish between capital expenditures which aim at lowering risks in the future (e.g. preventive maintenance) and operational expenditures needed as results of breakdown-driven maintenance strategy.

A valuable discussion topic is whether application of BI tools as DSS can accelerate creation of a performance management framework at a water company. With the heavy-lifting in terms of data cross-connectivity automatized, time of network specialists could be dedicated to identifying and creating of relevant standards. In chapter 1, decision support systems were discussed in terms of differences between knowledge and data-driven systems. The created DSS could originate as a data-driven system where performance is assessed by internal comparison and aimed at displaying outliers. This could ultimately lead to development of a knowledge-driven system and further automatizes priority-setting in terms e.g. areas in need preventive maintenance. This finding correlates with those of Hall et al. who in their paper on decision support methodology for performance based asset management (2003) discovered one of the biggest benefits of a DSS being that in the process of designing and deploying such a system, specialists learn about the functioning and intricacies of system's performance much faster. This appears to be however a shortcut rather

4.2. Adapted decision-making model

The decision-making model adapted for this research proposes a large number of simplifications and offers limitations of its own. Mintzberg's model is effectively a step-by-step decision-making map where it is possible to re-address previous steps during reviews at later stages. This assumption proved only partially applicable at Evides where small-scale decisions can be reevaluated but not retracted or updated easily. Structural decisions are made during yearly budgetary agreements and their deployment happens in the consecutive years. This means that the decision-cycle is quite long and interests of other stakeholders can change due to different prioritization within the company. In this light, analyzing managerial decisions that follow the recommendation could not be reasonably implemented in the model or the research itself.

The model's author himself argues that bounded rationality decision-making performed in this way is not common in reality and that this model approximates how the process should be conducted to optimize the outcomes (Mintzberg, 2001). This model in particular assumes a patter known as "thinking first" where the following steps are followed: Define → Diagnose → Design → Decide (Ibid.). This pattern appears well suited for production companies but overlooks initial goal setting and is by definition reactive. This corresponds well to asset management of water connections at Evides but it only replicates the problem encountered earlier in the project – lack of defined performance management framework. This can lead to ambiguity in priority setting and decisions made by managers, promoting a "one-size fits all" approach. Such managerial practice at Evides results in part from difficulties in processing and translating performance data into more transparent guidelines and defined end goals on a company scale.

Current decision making at Evides, as modelled, appears thus more value driven than data driven. In absence of more automatized systems for data processing and lack of numerically stated standards for performance, network specialists have to often act on intuition due to lack of time for data preparation. The delineated decision-moments capture only anomalies from the network average but do not offer provision on which anomalies have to be addressed to offer better performance in the following years. The revealed approach appears therefore well suited for avoiding 'catastrophic' reliability issues but not for structural improvement in network performance. Considering that data-driven decision-making is one of the retrieved company goals, it is clear that this problem is internally recognized. Relevant policy and framework need to however be updated to allow managers to consistently consider performance data in decisions and priority setting.

As a part of the research design, this model did not encompass for decision-making needed for implementation of selected measures, as chosen by management members. In that sense, the model portrays the process leading to the decision as separate from the rest of organizational practices needed for implementation. Addition of the 'decision moments' in the model displays the link between choices made by the network specialists, the available data and the generic AM goals. It does not however display how these choices translate into implemented measures and help reaching company goals. The absence of complete description on managerial selection in the model limits therefore the plausibility of evaluating what is being affected by the BI tool on the company scale and not only division scale.

4.3. Selection and application of performance indicators

Performance indicators were selected for implementation in the BI tool based on the objects of interest to network specialists, as presented under 'decision moments', and the retrieved company goals. This was done to effectively allow the indicators to serve as bridge between information registered and company goals.

This approach in selecting indicators leads to limitations where network specialists prefer to work with known indices, partially as result of insufficient data registered to create new indicators with good consistency. This was the case with e.g. asset-availability, where registration of a breakdown event and reparation would at times be days apart, while the reparation was actually done within the same day. Inconsistency in data registration therefore lead to limited capacity in applying more refined indicators, and further displays the importance of data governance for performance management. This also applies to the financial data which in case of Evides, was not possible to be connected to specific events.

Company goals such as e.g. "avoidance of multiple breakdowns on the same asset" and "identification of underperforming assets" are relative in the absence of defined service-level agreements. Therefore, they could not be directly translated into singular indicators to support decisions made or quantified the extent. Instead, an indicator was designed to calculate amount of connections which had more than one breakdown and allows to identify areas where this occurs more commonly. This could be seen with the example displayed in the results section. In there, despite of the performance indicators being generic, comparisons allowed to narrow down the area of research and the scope of the problem in a very short time. Ideally, such functionality would translate into repair choices for technicians where signaling of "not the first breakdown within X years" would translate into replacement instead of repair. An indicator on mean-time-between-failure can then be applied to characterize the occurrence more finely and point out the definite outliers. However, what appears to be of more interest to the company is that multiple breakdowns did occur and MTBF proved to offer limited insight due to data-registration issues at times. Underperforming assets can be identified by comparing failure frequency between user-selected cohorts, providing a comparative assessment and allowing the company to better identify the baseline performance. Lastly, a 'continuous failure frequency' is applied, which considers the asset's age at the failure moment and will be higher than regular failure frequency for assets which fail at younger age.

Application of failure frequency-centered measurement suggests that currently, Evides' sole objective with the performance indicators is monitoring situation in the network rather than observing impact of measures taken. Because a certain amount of connections does get replaced preventively, it could be valuable to report yearly what share that is and to what extent this has altered the performance of the affected area. Secondly, because one of the retrieved company goals is customer satisfaction and continuity in the delivery of water, focus on customer minutes lost could be shifted to 'customers who experienced an interruption in water delivery'. Such indicator could correlate better with company ambition to maintain good image and secondly, could help avoid the problems with accurate calculation of the minutes lost. Lastly, given the company ambition to avoid multiple breakdowns on the same connection, the created indicator (quantifier) could be improved with an indicator of 'rework' which would signify that in an arbitrary period, the same element has broken for the second time. At this point in time it was not yet possible to find these connections easily due to the majority of registered breakdowns not having any description regarding broken parts.

Application of performance indicators in decision-making at Evides turned out not to be consistent and improvements are contingent on creation of framework allowing to quantify acceptability. This appears particularly relevant when selecting among rehabilitation alternatives and the assets to be replaced preventively. Literature stipulates that performance management must have a clear, attainable end-goal (Goncalves, 2015), which lacked at Evides. In this sense, the constructed indicators cannot yet provide support in individual decisions but can serve to describe performance of user-selected sections of the Evides network. This can lead to defining which values for the given indicators are acceptable and allow more data-driven decision making but could not yet be realistically evaluated in the context of decision-support at the case study. It is important to note that performance indicators were not tested or designed for their explanatory value; instead, they provide means to quantify performance of water connections based on data owned to evaluate if they can provide better linking between performance and company goals. Therefore, with the retrieved company goals, selected indicators can correctly inform specialists about performance anomalies and contribute in the 'recognition' and 'development' stages from the Mintzberg's decision model, as seen in evaluation results.

It should be noted that despite of small number of indicators implemented within the BI tool, their contribution in helping a water company monitor reaching its goals can be two-fold. Firstly, within BI tools, the formulae and calculating process can be uniformized and automatized, improving cyclical reporting and consistency. Secondly, the network specialists can calculate the same indicators across user-selected cohorts. Within the same BI tool, specialists can then compare characteristics and performance of e.g. assets which failed in the same way, vintages and materials. Performance can then be described more consistently and aid a water company in generating more data-driven framework and standards.

4.4. Design and functionality of BI tool

In designing the BI tool for this research, emphasis was put on accomplishing the basic functionality where breakdown and technical data are correctly cross-connected and allow for calculating of the indices. This meant 1) acquiring, combining and curating data, 2) placement and layout of performance indicators in respect to specialists' object of interests (decision moments), 3) selecting and embedding data filters, 4) embedding data-levels in tables, and 5) creating GIS environment.

Data-governance practice at the case study company had posed limitations on 1) where due to data-validation cycles happening at the end of the year, some of the data imports contained placeholders instead of actual values. This rendered parts of the dataset unusable and shows that consistent and reliable application of BI tools is only plausible if data validation cycles are sufficiently frequent or observation span does not include some of the last year events. It was also observed that sometimes multiple breakdowns events are created in the system for the same occurrence, greatly lowering values of indicators such as mean-time-between-failure and disturbing the reading. This issue, despite of displaying lacks in data quality, can lead to recognition of possible improvement in registration process.

Activities conducted in 2) and 3) were defined by information gathered in the interviews and data available. Because the network specialists asked for all of the data to remain available and utilizable, legibility of the portal layout was deterred. Part of this problem was solved by introducing the sandbox section where specialists have access to all of the (cross-connected) data and can design own tables and graphics. This solution was also found advantageous by network specialists because their ideas on how BI tools can be applied only started to surface after more complete versions of the tool were published. This suggests that the design choices should not be fixed or sufficient flexibility should be left to the end user.

The design stage could have been improved by more iterations during the design-cycle with the specialists. This suggests that a water company needs to strongly involve domain specialists in development of BI tool in order to limit ambiguity in implemented solutions. This also projects higher costs that a company would bear to successfully deploy the desired tools.

The software limitation in displaying maximum of 5000 items on a map was sufficient for small-scale applications but offers no alternative to actual GIS environment, as seen in the results of the tool appraisal. Embedment of GIS in BI solutions presents high level for simple visual representations (Posthumus, 2008) but offers limited analytical functionality due to not processing shapes but only points. This method lends itself well to representing water connections but offers little value in displaying statistics per area.

Lastly, the tool proved to work fluently, despite processing roughly 20 million data points. This type of analysis was previously attempted in a spreadsheet but was not possible. Application of scripting languages can allow for similar manipulations but was said to be less consistent and lacks the front-end to allow more domain specialists to apply it in the scope of their analysis.

4.5. Application and influence of BI tools at water company

Evaluation conducted at the end of the study and summarized in Table 14 gives promising results with regard to applicability of BI as a support tool for some of the asset management practices at a water company. However, applicability of BI as a decision-support system specifically is only plausible if sufficient framework and decision-making regime are employed. This was noticed in case of Evides where the tool was favorably reviewed for simplifying access and usability of data but as of yet, no direct link on decision making and implemented measures could be rationally stated. This suggests that BI can support decisions only at a point that rules of thumb are replaced with clear levels of acceptable performance and discovered anomalies give ground to altering policies and budgetary planning.

The results display the biggest added value of BI for Evides on the data-warehouse concept, where merged data can be kept and later retrieved and processed by the end-user. This is visible by scores obtained on assertions on “ease of accessing data” and “facilitate data cross-sections”. This suggests that water companies, typically in possession of large volumes of data, can benefit from applying BI tools to better recognize the extent and type of that owned. It should be noted that ‘review of data quality’ scored the lowest in the given theme, displaying that more mechanisms need to be in place to consistently monitor the data quality. This reservation also suggests distrust in own data within the company – specialists know that some of the data is poor so they have a need to doble-check what they’re basing decisions on. More rigorous control of data quality on the back-end would reduce the need to control it in the front end.

The BI tool has been reviewed favorably for enabling a data-driven approach and spotting areas in need of attention. Both terms are broad but correspond to the company ambition of introducing more data into policy and decision-making processes. This is a promising causal-relationship where companies need to first simplify access to data before reasonably increasing its influence on decision making. Substantiation of recommendation and improved transparency have both been reviewed favorably and can give ground to considering application of BI tools as source of information, also for policy making. In the theme “Monitoring and summarizing of network performance”, the specialists emphasized the capacity to recognize connections with multiple breakdowns and improved benchmarking ability using the created BI tool.

These findings correlate with the data driven DSS as mentioned in the literature review, where comparative results are obtained. In the designed tool, no effective support mechanics were employed to steer the user between different alternatives. However, it can be assumed that the user applies own cognition (Keen, 1980) and would first consider the assets with e.g. highest failure frequency to need replacement, should opportunity be presented. The situation at Evides, where no internal service level agreements exists for connections, is perhaps not unique as compared to other water companies and internal standards will only be developed overtime by displaying performance anomalies and addressing them by policy changes. It is therefore speculated that application of BI at a water company will often originate as data driven DSS and will eventually converge towards knowledge driven where e.g. assets can be automatically marked for ‘replace once possible’.

Lastly, theme ‘Decision support and drivers’ has been reviewed the lowest but also with highest standard deviation. From results it appears that application of GIS within BI seems to yield little added value to asset engineers but more to terrain managers. This suggests that for more complex applications, the GIS module within PowerBI does not supply sufficient capacity in terms of shapes, layer processing and computation. For overview purposes, such as done by terrain managers in monitoring, this environment can suffice to develop an overview. Creation of cohorts was not extensively tested and it is concluded that the portal was insufficiently developed to realistically assess this capacity.

The application of BI at water companies can now be also put in the context of Figure 2 where dimensions of asset management strategies were displayed. Performance (analysis) is situated as one of the dimensions and spreads across the operational, tactical and strategic level. These performance analyses can be aided with BI by identifying underperformers more quickly and provide engineers with more complete overview of e.g. breakdown frequency per model of subcomponent and the year of installation. This information is believed to be valuable for all 3 strategy levels. On the operational level, it can inform the maintenance department to replace given component if encountered during maintenance, on the tactical level it can be translated in preventive maintenance planning and on the strategic level, policy can be updated to schedule replacement preventively. In the case of Evides, this overview was not attainable using conventional tools.

Limitations of the experimental design

In this research, a pre-test posttest approach was initially selected but effectively an evaluation and appraisal were deployed instead of an experiment. Some of the factors leading to this outcome are time-shortage on participants' availability, insufficient training offered, incomplete design of the portal and the bias present in the test. This bias resulted from designing both the quiz questions and the evaluation questions based on the features network specialists have named as relevant during the interviews. In that, the added value of the BI tool was appraised but the evaluation has also measured whether the desired features were well implemented. This is a logically coherent process which supports a claim about cause and effect but bears little validity for external application. This renders the appraisal of the tool to be Evides-specific. Because no other water companies have been studied for similarity in terms of goals and data owned, no inferences can be made on the general applicability of the findings. Should it be assumed that Evides is representative of the *average* water company, the acquired findings are still merely opinions of tool users which can be skewed by a number of variables that could not be controlled.

Limitations of the research design

Looking back, the research design of this project resulted in substantial limitations on how it was conducted and the applicability and universality of results attained. Aspects pertaining specifically to the case study are described in the next section.

Gathering information via semi-structured interviews was a sound choice but in the absence of internal standards for water connections, it contributed to lack of detail on aspects and examples to be affected by the BI tool. Company goals, gathered explicitly via interviews and implicitly via thematic analysis, display that internal standards for water connections are only being created now. In that sense, this research could have contributed more academically should it have studied the methodology needed for establishment of asset management framework for performance management of a 'new' and relatively complex asset group.

Because it transpired that the majority of maintenance choices for water connections at Evides are presently breakdown-driven, enabling a shift towards preventive maintenance by assessing more information is a theoretical finding. It yields great potential from the perspective of the tool but requires equally much work in terms of policy and managerial practices. This pertains also to the separation of recommendation made by network specialists and final managerial decision, standards for which were not delineated in this research. The selected performance indicators presented sentiment to indices known internally but also resulted from limitations in the data owned. In that sense, this research did not answer the question of 'what' the company should measure to improve performance management but rather 'how' to measure and monitor performance more consistently and efficiently. This is nonetheless believed to be of value to water companies who may not have the same capacities as private enterprises and, as result, their application of business analytics is delayed. Lastly, the risk matrix of Evides was initially supposed to play a larger part in the analysis but, due to infrequent application and lack of relevant framework, global gains from the analysis were seen as marginal. Relevance of the risk matrix would be incomparably higher in creating the needed framework – aspect outside of the scope of this research.

Creating a BI tool with curated datasets, defined and calculated performance indicators, and good user-experience proved to be too extensive. Software aptitude in consolidating numerous data sources, something presumably needed by utility companies, was reviewed favorably for enabling data-driven approaches but is usually developed by a team of seasoned practitioners. This led to very time-intensive work to attain basic functionality and should be noted by companies who may want to create similar solutions. Because the BI tool was built based on the interview content, it could in theory deliver a lot of value to the particular company but offers limited capacity for universal testing and assessment. Secondly, designing of the portal could have only happened after the interviews, through which both the planning and clarity in structure of this research were difficult to attain.

The results obtained through the evaluation are representative for asset managers at Evides while external validation would be required for more generalizable conclusions. If proper experiments were conducted, the results would still be biased given that core information leading to design choices were acquired from within Evides. This does not however discredit the results of this research fully. BI systems are stakeholders-centered and, with the increasing complexity of needs at modern utility company, combining domain knowledge, data governance and strategy will always play a part in successful deployment. In that sense, this research has also confirmed that advancements in asset management at established companies cannot happen from creating a tool or data-science alone, but that organization needs to participate in a general turn from reactive maintenance to integrated asset management and eventually – to infrastructure management.

Suitability of Evides as a case-study company

Application of BI for support in recommendation-making and ultimately – performance management at a water company, appears to be most plausible if organizational structures allow to internalize the performance readings and interpret them within existing framework. This entails that performance is ranked by known indices and bound by service level agreement (SLA) between asset managers and owners. This was not the case at Evides where no formal SLA exists for water connections and the line of sight can be incomplete between company asset management goals and what is being measured and assessed. This has further posed limitations on evaluation of the BI tool as a decision-support system – without structured targets, the tool can merely inform the specialists but not 'guide' per se. This is a foreseeable situation where full automatization of decisions should never be expected, but the supportive aspect of the system should represent company's internal targets and priorities. In that sense, the tool does comply with assumed company targets (preference to avoid detriment in performance) by allowing to order the results by metric of choice and identify underperformers. This appears however to be insufficient to talk about decision support.

In that sense, some of the asset planning at Evides is of inadequate maturity to warrant quick improvements from application of BI, rendering the company ultimately suboptimal for assessment of impact of BI on selected asset management practices. In turn, Evides would have been superiorly suitable for analysis on what is needed for BI to be implemented from the perspective of asset. It should however be noted that creation of performance management framework using BI solutions can provide for the figurative '*two birds with one stone'* and has been shown to bear potential by allowing a company to better display and understand its baseline performance with the goal of identifying anomalies. This suggests that the maturity of asset strategy is not strictly critical for implementation of BI as DSS (or other goals) but that the goal setting has to reflect the company capacity in terms of current policies and data governance.

Answers to research sub-questions

Compiling the findings from the results and the aspects discussed above, research sub-questions will be answered. The answers will lastly be compiled into the answer to the main research question.

Answer Sub-question 1

1) *How are recommendations regarding asset-strategy currently made at Evides and how is performance-related information collected, used, and evaluated in the asset management process?*

Recommendations on asset-strategy for water connections at Evides encompass for stepwise evaluation of the extent, occurrence rate and possible solutions to performance issues. Choice of a solution falls onto managers; in case structural problems are detected, decisions on adjusting the company policy are made by asset owners. Proposals leading to said changes can be submitted by network specialists.

In the course of the interviews and company research, 3 instances of decision-making have been identified and are described below in the context of the Mintzberg model. This model can be retrieved from the results section and has been found to correlate sufficiently well with processes at a water company. Embedded decision moments signify also *data demand* – instances when specialists interact with the available data. This system is lastly described using themes developed applying thematic analysis. These themes represent main objects of interest to Evides in terms of asset strategy.

Reliability analysis is preceded by downloading technical and maintenance information from the company database through a front-end client. Due to being stored in a separate database, technical data needs to be combined with maintenance data by the user. Performance readings can then be calculated using a spreadsheet to formulate an overview. Commonly, breakdown frequency is calculated and, depending on context, can be evaluated in function of pipe's length and age. Alternative information and support systems exist for distribution pipes but are not applicable for connections.

Answer Question 1a

1a) *What are company's current priorities [goals] with respect to asset management and strategy for water connections? Which aspects are network specialists and management most concerned with and are these aspects well depicted in the company's risk matrix? Who are the users of the tool to be developed for water connections?*

The current company goals with respect to connections, apart from following the strategy described in the results, are the removal of the remaining lead connections and avoidance of multiple breakdowns on the same connection. These findings suggest that currently Evides effectively focuses on compliance with external obligations (removal of lead due to health hazard) and internal expectations on cost efficiency of maintenance. This suggests that presently the only developments in performance management of water connections at Evides concern monitoring and describing network performance and that the company primary enacted ambition is avoidance of big performance declines.

The current asset strategy at Evides for water connections was discovered to be maintenance strategy and relates primarily to deployment of corrective maintenance and addressing reliability anomalies. In the results sections, the extent of preventive maintenance performed is described in detail.

Company priorities with regard to asset management of water connections encompass in turn for formulation of long-term asset planning to counteract age-related deterioration and enabling data-driven approach by involving performance data in decision and policy making. Company members expressed interest in obtaining better overview of connections performance across the whole network and to better capture baseline performance in order to enable benchmarking.

Interviewees agreed that access to data is currently difficult at Evides due to the way it is stored and the need for manual cross-connecting of breakdown and technical repositories. It was discovered that reliability monitoring is not continuous and data-connectivity needs automatization for the monitoring to be performed less ad-hoc (or only with cyclical reports). Lastly, it was discovered that service-level agreements stipulating required network performance for water connections do not exist.

The company risk matrix which could be used for interpretation of performance anomalies, given as it represents the company's "general risk profile", is used very rarely due to discrepancies in the classification of performance. The matrix is designed with pressure mains in mind and operates solely with units of customer-minutes-lost and financial consequences of breakdown. None of the above are retrievable for connections and no sound approximations were present at Evides at the time of writing this report. A framework is proposed to create a 'reliability bandwidth' to help position cohorts within the matrix. This is described in the recommendations section.

Users of the tool

The BI tool aims to facilitate performing of some the descriptive and analytic tasks of network specialists. In that, three primary subgroups of users can be delineated:

- Reliability engineers and technical specialists at water companies for whom a significant element of reliability analysis consists of the data collection.
- Terrain managers at utility companies who need to readily access area-specific information with regard to maintenance history and technical information about connections to retain overview and provide recommendation on inclusion of connections in preventive maintenance projects, based on compliance with policy.
- Employees of the maintenance department. Depending on the function, this can be:
    - Developing numerical oversight over employee hours spent on given breakdowns
    - Evaluation of delivery areas from the perspective of resources spent
    - Numerical substantiation in defining problematic areas and evaluating the findings with technicians' field-experience.

Answer Question 1b

1b) How do recommendation-giving strategies and performance data link to the water company attitude towards risk, threats and opportunities?

Utility companies are risk averse and focus on continuity of service and minimization of social nuisance. The maintenance approach differs between asset groups: for pressure mains Evides applies a mix of pro- and reactive maintenance, while for connections it is primarily reactive. Therefore, the majority of decisions currently made with regard to water connections are executed either due to uniqueness of the case or due to a window of opportunity such as another utility company performing a project in the area of interest. More assessments would be possible should time availability of the employees be higher or time cost of analysis lower.

Presently, Evides' primary opportunity is expanding cooperation with other utility companies on projects where excavation takes place. Currently, the recommendation-giving strategy for such project assesses compliance with technical requirements. Because no other standards are enlisted, and data is difficult to processes globally, only a narrow group of connections get replaced.

Evides' primary threat is the aging infrastructure and meeting the yearly replacement rate needed to cap the average connections' age at an acceptable level. Evides presently works on long terms asset planning for connections to address this threat.

Answer Question 2

1) *Based on the findings named in 1), how can the monitoring, analysis and communication of performance information be improved by means of business intelligence tools such as Power BI?*

BI tools, and Power BI specifically, were discovered to be capable of aiding these tasks two-fold. Firstly, on the back-end (via data warehouse) data-arrangements can be made without knowledge of a programming language and updates can be scheduled automatically for new breakdown data. This lowers the 'entry-barrier' for usage of data and promotes greater maturity of data used, enabling specialists not to have to begin with raw data each time.

On the front-end, implementation of performance indicators allows for continuous display, alarm-triggers and summary. This information can be programmed to be shipped to relevant stakeholders cyclically and 'fill in the gap' between regular reliability reports written at the case study company. This process can help shortening the cycle between when an event occurs and when it is recognized and possibly acted on.

In the context of the decision-moments listed under 1a), BI tools can help in answering the first 2 moments more promptly – Act or not and Severity of the issue. Due to the elevated availability of descriptive data and consistency in calculations, knowledge and findings can be communicated faster. This also means that monitoring can be done by multiple people and for diverse contexts. From stakeholders' perspective at a water company this can entail for e.g. Operation & Maintenance department to see whether the workload is intensifying with seasonal changes whereas for Asset Management department, it is important to monitor if breakdowns occur more frequently in specific areas and whether this needs to be addressed through policy.

Lastly, the performance indicators relevant for network specialists can be summarized and translated into key performance indicators relevant for management. This process would require connecting e.g. financial data to assess cost-efficiency of renovations and general expenditure pattern, helping managers recognize budget allocation needs ahead of time.

Answer Question 2a

2a) Which performance indicators should be used and monitored, given the available information and priorities in assessing the current performance?

Performance indicators used in a BI tool should reflect quality of interest for the company. Organizationally, the company needs to translate obtained values into internal standards to signify where the action is needed. For Evides, performance is recognized primarily by using failure frequencies against time length and consecutively, identifying anomalies. Organizationally, Evides also aims to avoid multiple breakdowns on the same connection. This leads to choosing the application of failure frequency indicators (in function of time) and quantifying, as per user selected characteristics, the total numbers of connections, breakdowns, non-conformers and instances multiple breakdowns on the same connection. From the data available within company systems and in conjunction with the results of the interviews, the following indicators have been selected and implemented:

- Failure Rate
- Continuous Failure Rate
- Breakdown Rate
- Amount of Breakdowns
- Mean Time to Failure
- Mean Time between Failure
- Count of connections with more than one breakdown
- Compliance with the company policy

The equations used to calculate these indicators have developed within company and can be retrieved from page 86. In the noted form, they differ from definitions in the literature due to a dynamic failure rate and unknown statistical distribution of failure.

Insufficient data existed to quantify the following aspects with a sufficient degree of certainty:

- Customer-minutes-lost per breakdown of failure mechanism
- Non-revenue water as consequence of a breakdown
- Assets availability
- Financial assessment of breakdown reparation per reparation
- Assessment of reparation mode use

Data needed in order to establish values for these indicators has not been accessible during this research and does not get collected in the course of regular works. Suggestions for improvement of this practice are included and elaborated on in the recommendation section.

Answer question 3

How does the created BI tool affect the usability and consideration of available utility data in asset management choices about water connections? How applicable and adaptable is BI portal to process and share the relevant database content for implementing/quantifying the PIs?

During the evaluation, network specialists assessed the added value of BI tools in the context of aspects relating to accessibility and quality of data, reliability readings and data fragmentation and monitoring and summarizing of network performance. These themes are believed to relate the most to the usability and consideration of available utility data in asset management choices about water connections

Based on the results of the tool's appraisal (Table 14), BI tools offer most potential in accessibility and quality of data. Application of BI, by combining and pre-processing data, can enhance creating overview of data-owned and structuring data for application in asset management processes such as a performance review. Simplifying data-preparation can allow network specialists to more frequently and more transparently utilize data in their assessments. No direct link to management choices was shown in this research due to lack of defined rules on how these choices are made.

While usability of data can increase using BI tools, it remains evident that a defined assessment network needs to exist to allow for impact of data on the decisions made. In case of Evides, this information is consulted but not binding due to absence of standards of acceptability of performance.

Evaluation showed that according to network specialists, BI tools can be a starting step in introducing data-driven practices by offering better overview of data-owned and its anomalies and to improve transparency in decisions. This is believed to encourage network specialists to more frequently utilize performance data in their analysis due to better normalization of quantitative metrics and automatization of data-prepping.

The results of BI tool’s appraisal suggest that sharing of data and findings between users is simplified using the created tool. This can offer value to a water company by allowing user-access to integrated datasets which they cannot corrupt but can still process and share further.

Application of BI tools for geospatial analysis was found less advantageous for analysis but can prove useful in visual communication of network performance. Creation of cohorts using BI tools seems promising but was insufficiently prepared to be tested in this research.

5. Conclusions and recommendations

5.1 Answer to main research question

The main research question in this project was:

"*How does a purpose-designed BI interface, based on selection of performance indicators derived from company data, facilitate advice-forming by water network specialists in respect to water connections?*

Based on the results and discussion, the following answer is formulated:

Considering advice-forming to be the total of the decision process described in chapter 3.2, the BI tools were shown to mostly benefit asset managers in accessing and pre-processing performance and technical data and incorporating larger datasets in their analyses. The designed BI tool was shown to promote interaction with data in user-defined ways, switching away from database-architecture centered approach where raw data needs to be combined each time. Based on the results of the evaluation, domain specialists benefit from this by lowering the data-time needed to begin with performance analysis, simultaneously improving consistency in measurements. Secondly, the BI tools have shown to offer a good starting-step towards more data-driven practices and have potential to improve cohesion between decisions and goal setting. For performance management, this can mean more transparent goal setting, monitoring and decision-evaluation to facilitate Plan-Do-Check-Act approach. By enabling performance-based goal setting, transparency of domain specialists' decisions can be elevated and substantiated in e.g. internal benchmarks. This is relevant for Evides because elements of asset strategy for water connections are being presently defined and transparency is important to managers. Lastly, the created BI tool has been shown to improve localizing underperforming assets (e.g. multiple breakdowns, known faulty cohort) – assets for which Evides wants to improve its policy and avoid in the future.

BI tools have also been shown to help in evaluating projects where pressure mains are preventively replaced and connections can be decided to be included. In context of Evides, this is currently done by assessment of compliance with company policy. Application of BI allows to replace manual assessment with automatized display, promoting stricter adherence to policy and extending consistency in preventive maintenance. Within the created BI solution, the decision on inclusion of water connections can also be extended with the reliability history, should relevant norms of acceptability be defined. In total, this can allow to improve the rate of preventive maintenance done, counteracting the primary threat to Evides: aging infrastructure.

The created BI tool was also evaluated in the context of monitoring data quality, embedment of geo-spatial characteristics by applying GIS extensions and ability to create cohorts for defining reliability profiles. These activities have been evaluated by domain specialists' as less useful or insufficiently explored by them to warrant conclusions. It is believed however that with more use-case centered design and user-training, some of these processes could be still beneficially migrated to BI and allow improvements in analyzing descriptive analytics.

5.2 General Conclusions

Over the course of this research, the company asset management goals and strategy with respect to water connections were identified as compliance to policy and reactive maintenance strategy. For water connections, Evides presents a cost-efficient attitude in maintenance and seeks opportunities to conduct preventive maintenance, if applicable, alongside to works on distribution pipes. Current recommendation making for this process encompasses for a number of checks whether performance anomaly occurs, no arbitrary performance-assessment guidelines exist. The designed prototype BI tool was evaluated as beneficial in defining assets which should be replaced first. Evaluation of assets' performance was done using indicators describing failures in terms of frequency, distribution and by comparing values to networks averages. Appraisal has shown that the designed BI tool can improve usability and consideration of available utility data, adherence to policy and lastly - that sharing and communicating of the findings can be streamlined using the capacity to extract filtered datasets. Absence of numerically defined performance management framework at Evides (for connections) has limited the capacity of assessing the created tool as a decision support system.

Based on the findings from this research, the author believes that implementation of BI tools can help utility companies streamline preparation and structuring of data which take place prior to performance analyses. In conjunction with recognized performance indicators, this can help organizations steer towards clearer performance goals and monitoring. Logistically, utilization of a data warehouse concept eliminates some of the need for domain specialist to prepare data each time, allowing for better allocation of the specialists' time. The ability of a BI tool to implement larger datasets without performance loss was confirmed in this research and can allow for asset management decisions to encompass for broader scope of data used. The author of this research believes that by combing these, a company can create a better alignment between assets' performance data and organizational goals.

This research gives grounds to believe that application of BI tools can support network specialists in recognition of the performance anomalies and can offer improvement in availability, consistency and quality of internal benchmarking. A possible implication hereof is that by applying BI tools, future asset management recommendations can more accurately define items in need of preventive replacement.

Water companies possess large volumes of technical and breakdown data, which can offer more structured insights into performance and breakdown frequencies in respect to technical components, placement, and age. Application of BI solutions has been shown to enable some of these observations and has potential to allow for the executors of operational, tactical and strategic asset management to communicate using similar metrics and datasets. This ability can render preventive maintenance more attainable to water companies through better scoping, consistent monitoring and cohesion of decisions. Implementation of BI requires however an organizational framework to translate readings into actionable unit before it can be effectively used as a decision support system.

In order for a (utility) company to benefit from application of BI as decision support system in asset management, the organizational framework should be tailored for effective performance control and maintenance planning for each asset group. This was not the case at Evides and led to ambiguities in directly connecting the findings with the company's risk preference. In order to alleviate this problem, a suggestion for a framework for performance management with usage of BI is made below. Note that this recommendation is rooted both in observations made throughout this project and explicit findings:

1) Company performance goals should be set out through performance indices attainable from owned data and stipulated by Service Level Agreements established between asset owner and

asset managers. Indices are agreed on in terms of frequency of measurements and reassessment points on cyclical basis.

2) A data warehouse for back-end of the BI tool is established between ICT and asset specialists and is created initially per asset group. Performance indices are programmed within the BI environment.
3) The organization defines how an asset's risk profile is established for assets with and without maintenance history. It is suggested to opt for two mechanisms:
   - For assets with breakdown history, the profile is based on the occurrence time and number of breakdowns.
   - For assets without breakdown history, the profile is a sum of yearly failure-rates of its components, calculated from owned performance history.
4) The front-end of a BI tool is designed with participation of stakeholders, design is based on use-cases.
5) The organization interprets the performance reading per relevant group (e.g. geographically, vintage) and decides whether the strategy and goal setting are representative of the firm's capacity. This can lead to reevaluation of aspects named under 1).
6) All of the above are contingent on good quality data with cyclical checks preceding policy and governance updates.

Recommendations for future research

As mentioned in the discussion, this research was focused on a single water company, making it difficult to extrapolate findings to general observations regarding the applicability of BI systems within such a utility provider. Part of this outcome was also caused by the method of assessment where no proper experimental design was conducted. Future studies can aim to fill in this gap by applying a similar methodology to other water companies in the Netherlands to observe whether differences in how internal systems are organized can result in other benefits (or disadvantages) for a water provider. Narrowing down the scope in development of a BI tool and focusing on providing the necessary training to allow for real experiments could offer the more valuable insight on added value of the tools in the context of asset management at a utility company.

Due to the absence of sufficiently defined performance goals at the case study company, this research did not manage to answer the question on how these goals could be approached better by using BI tools. It is therefore recommended to apply similar methodology at a company with more mature performance management framework and goals to assess the effects of BI tools more effectively. This analysis could be expanded on by providing an overview of the financial performance maintenance strategy and its contribution towards an integrated asset strategy. This was not feasible to include in this research due to reasons mentioned in the Discussion, but it could provide deeper insight in possible improvements to performance and asset management at utility companies, as a result of application of elements of BI in decision-support systems.

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Appendix

1) Technical and breakdown information regarding connections, available within data systems at Evides

Table 15 Scope of information available on water connections within Evides database

Technical and Geographical	Breakdown event
• System number	• Breakdown code
• Class	• Problem code
• Status	• Cause code
• Date installation	• Action performed to repair
• Date last revision	***Added After 2014***
• Network subgroup	• Workorder number
• Location X and Y	• Short description
• Address	• Comments from technician and service center
• BAG number	• System number
• Tapping mode	• Type breakdown
• Type wall insertion	• Project number
• Diameter service valve	• Work status
• Type service valve	• Work urgency
• Type main valve	• Date breakdown
• Diameter communication pipe	• Address
• Material communication pipe	• Name sent technician
• Length communication pipe	• Service provider
• Amount of connected addresses	

2) Interview questions

Introduction:

As a part of my graduation project at TU Delft, this interview is meant to help collect information on data-demand and decision-making process of network specialists in the context of asset management of water connections.

This interview contributes toward substantiation of establishing performance indicators which will be enclosed within a BI portal. The function of said portal is to simplify access to data and performing of analysis needed to form a recommendation. Further, contributions towards normalization of performance analysis at Evides can be made.

After each interview, a summary will be produced and given in for approval.

Definitions:

- "Connection" encompasses for a system of valves and a conduit, between a saddle on the distribution pipe and the last valve. "
- 'Request' refers to a recommendation requested from an employee of Asset management Infrastructure department. This request can be submitted by other departments or management.

- 'Event' is an issue discovered in the network which gives ground to requesting a recommendation. This can be e.g. breakdown, removal, change or installation.

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1. ***General questions with regard to the role and function of the interviewee***
    a. What is your name and function within the company?
    b. When do you come across water connections in your work?
    c. Which steps do you complete before producing a recommendation with regard to water connections?
    d. What aspect can influence the opinion you give?
2. ***Types of recommendations made with regard to water connections***
    a. Can you give an example of a goal of a recommendation asked in relation to one of the events named?
    b. What is the average scope of the advice requested?
    c. How are the connections involved related onto each other?
    d. What is the geographical range of the requested recommendations?
3. ***Parametrization of network performance/terrain performance***
    a. Which information is used to develop insight in connections' performance?
    b. Which administrative and organizational aspects play a part in the data demand?
    c. In what way is the performance and condition of connections monitored?
    d. Which additional information and data could be relevant?

4. ***Company goals, recognition of company goals with respect to policy, risk management with respect to asset management of connections at Evides?***
    a. Which company goals are specific to asset management of water connections? Are there general goals applied? Is there a relation between company goals, evaluation of connections performance and the recommendations made?
    b. Which opportunities and challenges do you see with respect to asset management of water connections?

Are there any other observations and suggestions that you would like to make?

3) Summaries of interviews

Interviews summary, as based on recordings from the interviews

Interview Marc Hooijmans and William Padmos:

Both interviewees fulfill roles of area-managers (gebiedsbeheerders) within Evides. Their tasks are to co-ordinate all events relating to, amongst other, maintenance and new projects within their respective terrains (specify this). This entails working not exclusively on issues of reliability but maintaining overall oversight on the activities on the network and its performance within the area. In that light, issues related to water connections are said to occur commonly and pertain mostly to requests for new water connections or breakdowns of existing connections. Both task-groups can be characterized as data-driven and require using the information-management system available for the company.

Area-managers seldom perform reliability analysis (these are requested from the reliability engineers or technical specialists) but have a defined need for an information portal where data could be enclosed in an easier manner. Oftentimes they receive requests for assessment of a network branch in the light of possible combi-project wherein one of the partner utility-company announces planned excavation work on a given e.g. street and inquires whether Evides would like to benefit from the opportunity to perform any work of their own. On such occasions, area-managers compile available data to analyze whether the distribution network or the connections possess characteristics which, according to the policy, define them as in need of changing. This data right now is relatively fragmented (while still available) and access to uniform display could provide them with faster overview and maximize chance of good assessment.

Both area-managers described their information-demand as encompassing for all information available. This entails the technical specification, ideally together with historical events. Both specialists expressed extra interest in the possibility of connecting the sketches of connections which were available in the former information system at Evides to the portal, further simplifying access to the information.

During the interview it was emphasized that the information system available at the company contains in principle all available information but it is relatively time-consuming to obtain and process all the data. It can therefore be difficult to see the technical composition holistically right away.

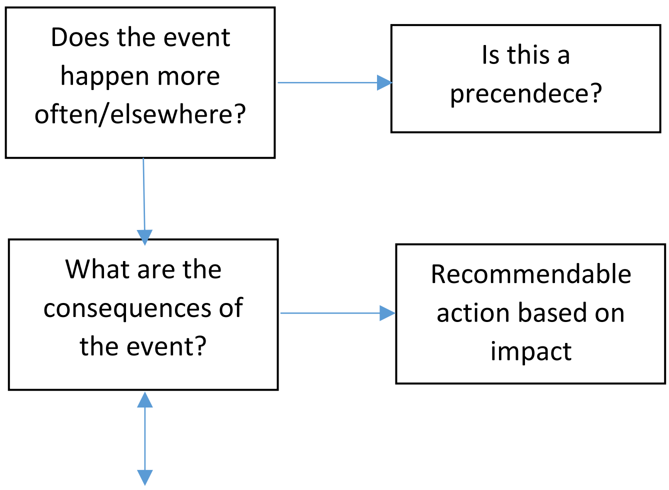
The company goals seldom come in sight in their scope of work, they have however emphasized the importance of the combi-project and the possibility to assess their potential quickly.

Fundamental Objectives	Strategic Objectives	Means Objectives	Process objectives
Sustenance of network performance and customer satisfaction.	Not applicable	Continuous network expansion and replacement management.	Optimize completeness of data and access to it. Improved recognition of network condition.

Interview Bas Dilven

Within Evides water company, Bas Dilven fulfills the role of a technical specialist. He is therefore the contact person for the non-standard issues that occur within the network and pertain to, among others, network composites, reliability and performance. He is further the dedicated company specialist with regard to water connections and water meters. Lastly, he is being consulted with on projects relating to new constructions and network adjustments.

As technical specialist, Bas conducts analysis relatively often with various goals. He described his approach as based on answering the following questions



Do we have to collect more information?

He described the needed information for making an assessment to be as-complete-as-possible, varying with the nature of the request. In that, it was emphasized that at times the end goal of his recommendation is to suggest a systematic change through the management-of-change protocol, rather than an ad-hoc solution. In that, the distance between the steps taken by the company can adhere better to the specifics contained within the risk-matrix, displaying company preferences. This link right now is not always clear and is object of discussion on case-to-case basis.

Because of the not-standardized nature of the requests submitted to Bas, the scope of his recommendation can be addressing as few as 1 and as many as 1 million connections. This was exemplified with the case of analysis of an individual breakdown in contrast to reliability analysis for a particular type of water meter.

Bas has further described ways to parametrize network performance in function of the fault-tree analysis (connection-specific design is present at Evides) and followed by calculation of breakdown rates. With that, both quantitative and qualitative statistics are rendered available. These can then in turn be divided based on the location of the event or the specific type of the connection.

Remarks were made with regard to connection discrimination mechanisms and importance of considering even the less commonly occurring materials and type. Example of copper was made where it was stated that despite of much lower relatively frequency of application, copper connection are often put in place due to the ground pollution. The consequence of pipe breaking in that case can be very severe and should not be overlooked.

Company goals in respect to asset management of water connections were described as evolving and under discussion. There exists a policy in place describing characteristics of the connections which should be replaced in case other works are performed on the adjoined distribution network. This doesn’t however describe the reparation mode (decision on repair vs. replace) in case of individual breakdown, even in case of repeating issues. Improvements in this regard, deepening of the cooperation with the covenant partners (combi-orders) and more data-driven asset management were described as the biggest opportunities for improvement with regards to managing of water connections at Evides.

Fundamental Objectives	Strategic Objectives	Means Objectives	Process objectives
Sustenance of network performance and recognizing technological outliers.	Recognize and convey critical information to management members	Maximize consistency in addressing breakdowns, seek long term results. Data driven asset management.	Ensure multilateral consensus on AM-strategy and reliability goals.

Interview Arno Bindt

Arno Bindt is the manager of the asset management infrastructure department within Evides. This encompasses for the two sub-departments, asset management and area management. He liaisons with the executive board of the company and partakes in policy-making and budgetary planning.

The scope of the interview with Arno Bindt was different from other interviews conducted seeing as Arno himself does not conduct reliability analysis. The results thereof are however pivotal for his insight and recognition of the network´s reliability and the resultant short and long terms goals, therefore only the question 4, relating to the company aspirations and policy were addressed.

Arno described the main current policy-driven activities relating to connections to be the removal of the last of the remaining lead connections in the network and improving quality of the data describing the connection's location and structure. Lead removal is a primary goal given the public-health concern and has been an ongoing activity, vastly accomplished till date. This process is regretfully partially limited due to absence of complete data on some of the connections characteristics. It is however clearly defined in the maintenance framework that in case of any lead connections found in the scope of work, these should be replaced.

Data-quality related issues are common in utility industries where data has been aggregated over long time with different methodologies and throughout company-fusions. In that light, some of the geographical data is missing as well, in solution to which the company needed to assume in the GIS system a simple perpendicular connection at the given address. This does not necessarily have to be far from the truth but in case of excavation works being done around a connection, it cannot be taken as correct and complete. Within the Netherlands, before any excavation work can be done, a "green-light" has to be given by the utility companies in order to avoid damage to any underground assets. Information is conveyed onto the party executing the dig with the precise location of e.g. water or gas conduits. At this point in time, connections are displayed within the said information for the reasons stated above. This likely has influence on the break-rate of connection caused by external parties.

Evides does not incorporate case-to-case decision making regarding reparation mode for connections. All maintenance is currently breakdown-driven with exception for lead removal. This is said to be suboptimal but long term asset planning for water connection is not yet in place and can become the focus for the company in the future. Modelled information regarding remaining life-time of connection batches is desired but the company recognizes time-costs involved in developing operational environment to that end. Reactive maintenance is therefore the most applicable measure with the company keeping tabs on the particularly under-performing cohorts.

Arno described the company goals and objectives regarding water connections to be: keep customer satisfaction high and water supply reliable by attending to breakdown promptly and avoiding to great lengths cases of repeating breakdowns on the same connections.

Fundamental Objectives	Strategic Objectives	Means Objectives	Process objectives
Sustenance of network performance and customer satisfaction within budgetary framework.	Balance stakeholders' interests without decrease in service level. Steps towards LTAP.	Improvement in data quality and transfer to assure best oversight	Maximize data-driven input to substantiate future framework decisions.

Interview Patrick van den Ende

Patrick van den Ende is a reliability engineer within the asset management department at Evides. As such, he is tasked with a variety of analysis relating to reliability and performance. The type of analysis depends on whether it is performed cyclically (reporting breakdown history for conduits annually) or it is an ad-hoc request relating to e.g. increased breakdown rate of any given network subcomponent. Patrick expertise for Evides encompasses for GIS-data processing and scripting, performance analysis and harmonization of data storage within company information systems.

Water connections come to light in the event of elevated breakdown rate as observed by Operation and Maintenance division and in case of updating geographical information within Evides geo-portal. In the scope of an 'standard' analysis he describes taking the following steps:

- Investigation of what happened that substantiates the need for an analysis
- Collection of information from the company information systems (and external if needed/relevant) regarding the technical composition and past events.
    - Delineation on whether this is the first time it happens, if not, how frequently does it happen?
        - Is it structural?
- Risk quantification using available information
    - How many customers are affected by this event and how frequently
    - What is the consequence of said event – no access to water, damage, etc.
        - Can it be expressed in terms of costs, if no, should the costs be estimated.
            - Which type of costs (financial, perception, safety)
    - Are there similar objects in the region of the event that could be susceptible to this type of breakdown
- Application of company risk matrix to quantify the needed scope of action and severity of the event – only applicable if the cast is very vast, this does not happen for connections so far.
    - Is it acceptable for the company to deal with the estimated risks or does it have to be addressed

The scope of the requested recommendation is made based on answering the above-stated questions. Requests can vary from addressing a singular connection of poor reliability to a whole population matched by a common characteristic. In the course of performing analysis, the common element can sometimes be discovered after which the scope of the analysis is expanded or forms foundation to another analysis if requested.

The selection of desired information encompasses for everything available at the moment, also in order to assess data quality and relative certainty with respect to the recommendation made. In the course of performing an analysis, information also from the GIS environment are consulted, describing density of tree coverage or road structures. Breakdowns of underground infrastructure can be related to ground subsidence or variation in the ground water levels. This information are not directly available within Evides data systems but can be attained from external parties.

As reliability engineer, Patrick was enthusiastic about creation of a portal which can automatically produce performance indicators for selected categories. The desired performance indicators should, according to him, remain simple in their nature to be more globally applicable within the system. The conclusion was therefore to carry on with failure frequency and other indicators that relate to time until breakdown occurred and if the case, time between consecutive breakdowns. This was said to allow the possibility for a normalized manner of comparing breakdown events and reliability of whole cohorts or regions.

Primary company goals with respect to asset management of water connections are removal of remaining lead connections, improvement in monitoring and reporting, enabling data driven asset management practices and creating a long term asset planning for connections.

Fundamental Objectives	Strategic Objectives	Means Objectives	Process objectives
Analysis of network performance and influencing factors.	Maximize network's reliability by recognizing outliers.	Optimize data-driven reliability analysis combining diverse data inputs.	Ensure reliability analysis encompass for common factors which could display a broader reliability problem.

4) *Complete thematic analysis*

Phases 1-3 of the Boyatzis model*: generation of open codes and sorting into sub-themes*

The open codes are build based on the summaries of the interview answers which can be found in the following section.

Table 16 Thematic analysis, Phases 1-3

Interview question	**Sub-themes**	**Open code**
1b	• Striking reliability issues • Cyclical studies • Network expansion • Covenant projects • Removal, new connections	• Not all reliability issues are equal • Research and analysis are not continuous • New and old information • Other perspectives and goals to be considered • Overview changes in the systems
1c	• Generating oversight of the situation • Gathering data from available sources • Evaluating extent of the problem • Evaluating cyclicality • Assessing possible consequences • Assessing reliability readings	• Overview not readily available, first view matters • Data collection done manually, sources are defined • Comparing the situation with unaffected units • Accessing historical data (technical and breakdown) • Quantifying number of affected clients/properties • Comparing attained figures with elsewhere in the network
1d	• Cooperation with other utility firms • Removal of lead connections • Analyzing vulnerable material batches • More data drive asset management • Updating company framework • Optimizing client satisfaction • Better reliability oversight	• Other perspectives and goals to be considered • Location of assets based on characteristics • Defining cohorts, group analysis. • Better access to data, more usage of data • Updating company goals and approach • Assessing and improving client satisfaction • Continuous supervision for fast approach
2a	• Network expansion • Removal of old connections • Compliance with norms	• New and old information, feasibility assessment • Decommission, change of status • Company´s framework • Company´s framework

	• Compliance with SLA (not defined for water connections) • Desired reparation mode (repair or replace?)	• Maintenance concepts
2b	• According to the governed area • Large variety, between one and one million • Varies with the size of specific cohort, often is not pre-determined • Discovered in the course of analysis	• Predetermined (arbitrary) areas • Quantity not always predetermined • Quantity not always predetermined • Flexibility in research structure (rephrase)
2c	• Through project scope (e.g. new connections) • Geographically if the study area is predefined • Technologically if elements of the same properties were used • Functionally, with respect to type of building being connected	• Pre-defined groups of objects • Spatial proximity • Technological proximity • Building's type (shift in risk profile)
2d	• As per governed area • Ranges from individual connection to a full municipality • Defined by the extent (gradient) of reliability issues • Depends on the extent of spatial correlation • "Wijk" division	• Predetermined (arbitrary) areas • Flexibility in research structure • Performance indicators + scale adjustments • Spatial proximity • Different mode of area splitting
3a	• Technical configuration • Geographical details • Previous breakdown events • Maintenance history • Compliance with framework • Sustainability of chosen solution (e.g. reparation solution, client contact)	• Display of technical properties • Spatial identification of the object • Historical (breakdown) statistics displayed alongside • Historical (maintenance) statistics displayed alongside • Summary context statistics • Assessment of long-term effect of chosen reparation mode
3b	• Implementation and administrative costs • Other on-going project pertinent to the topic • Cooperation with other companies • Non-compliance, company norms • Choice of reparation mode • Long term asset planning • Asset's life-cycle tenure and costs • Customer satisfaction • Risk avoidance • Social nuisance	• Financial aspects of chosen solutions • Overview of active projects on the given topic • Interest of other parties • Comparison to other internal metrics • Overview data • Forecasts, company policy and risk profile • Assessment of network's and solution performance • Service quality, limiting nuisance • Company risk profile and application of risk matrix • Consequences of performed work
3c	• No singular mode for continuous monitoring • Summary reports • Performance displayed in cyclical reports	• Overview of the available data and metrics • Cyclical checks and report writing • Continuous overview

	• Total of costs and budgeting • Characterized by total amount of yearly breakdowns	• Overview planning and forecasts • Cyclical checks
3d	• Costs of individual repair • Costs per mode of repair • Time used on given repairs • Attaching of available sketches for given connections • Time without water delivery • Ramification of damage • Completeness of data overview • Post-life review •	• Detailed data • Structuring of data to yield best insight • Detailed data • Access to data • Consequences of reliability interruption • Risk management • Data quality and ease of access • Best work practice
4a	• Fulfillment of SLA (indirect, SLA's not defined) • Company goals implicitly stated in the risk matrix • Solution longevity should correlate with the cost of risks of other solutions • Planned reliability should reflect the goals stated in risk matrix • Customer satisfaction should be a critical factor	• Company framework • Company risk profile • Detailed data and data-driven approach • Compliance between company goals and performed actions • Prioritizing of company targets
4b	• Cooperation with other utility companies • Data driven asset management • Structural problems need to be identified as quickly as possible • Improvement of geographical information and recognition • New policies and maintenance practices	• Opportunity cost planned maintenance • Data completeness, oversight and ease of access • Continuous monitoring • Data assessment and revalorization • Maintenance concepts

In this phase, the initial codes have been generated, allowing for distilling a first few observations, as summarized below:

- Attention is often given to "outliers" in terms of reliability performance but there does not exist a formalized definition of 'acceptable' performance
  - Network specialists recognize these levels oftentimes individually. This correlates with the possessed domain knowledge but does not aid harmonizing the standards across the company
- Extent of existing data is very well understood by network specialists, the accessibility and automatization of display is lacking
- Data quality and completeness are known to be deficient at times but with each analysis, a separate quality-assessment needs to be conducted
- Company risk-profile with respect to water connections is not precisely defined

- Company present maintenance strategy with regard to water connections is reactive and breakdown driven.
- Active and formalized projects with regard to water connections pertain to replacing remaining lead connections.
    - A parallel project exists which aims to create a universal Asset Health Index which also addresses the water connections.

Phase 4 and 5: Formulation of sub-themes

In this stage, the open codes are converted into sub-elements and aggregated under provisional themes. Phase 6 is presented in the main body of text under results.

Table 17 Thematic analysis, phases 4-5

Provisional Themes	Sub – elements
Access to data	• New and old information, feasibility study • Data collection done manually, sources are defined • Accessing historical data (technical and breakdown) • Quantifying number of affected clients/properties • Location of assets based on characteristics • Better access to data, more usage of data • Continuous supervision for fast approach • Assessment of long-term effect of chosen reparation mode
Data overview	• Overview changes in the systems • Overview not readily available, assessment of scope • Data collection done manually, sources are defined • Accessing historical data (technical and breakdown) • Location of assets based on characteristics • Continuous supervision for fast approach • Decommission, change of status • Historical (breakdown) statistics displayed alongside • Historical (maintenance) statistics displayed alongside • Overview of active projects on the given topic
Data completeness	• Quantifying number of affected clients/properties • Location of assets based on characteristics • Continuous supervision for fast approach
Reliability checks	• Not all reliability issues are equal • Comparing the situation with unaffected units • Flexibility in research structure • Different mode of area splitting

	• Defining cohorts, group analysis.
Reliability in relation to factors	• Overview not readily available, assessment of scope • Defining cohorts, group analysis. • Compliance with company´s framework • Predetermined (arbitrary) areas • Quantity not always predetermined • Flexibility in research structure • Spatial proximity • Technological proximity • Building's type (shift in risk profile) • Different mode of area splitting • Historical (breakdown) statistics displayed alongside • Historical (maintenance) statistics displayed alongside
Quantitative metrics of reliability	• Quantifying number of affected clients/properties • Compliance with company´s framework • Technological proximity • Building's type (shift in risk profile) • Performance indicators + scale adjustments
Decision review	• Quantifying number of affected clients/properties • Financial aspects of chosen solutions
Decision drivers	• Assessing and improving client satisfaction • Continuous supervision for fast approach • Compliance with company´s framework • Maintenance concepts • Assessment of network's and solution performance • Service quality, limiting nuisance • Company risk profile and application of risk matrix • Consequences of performed work
Cooperation with other companies	• New and old information, feasibility study • Other perspectives and goals to be considered • Other perspectives and goals to be considered
Continuity of monitoring	• Research and analysis are not continuous • Overview not readily available, assessment of scope • Comparing attained figures with elsewhere in the network • Updating company goals and approach • Compliance with company´s framework • Assessment of long-term effect of chosen reparation mode

Company risk profile and reliability targets	• Accessing historical data (technical and breakdown) • Quantifying number of affected clients/properties • Updating company goals and approach • Compliance with company´s framework • Maintenance concepts • Forecasts, company policy and risk profile • Company risk profile and application of risk matrix • Risk management
Data-drive asset management	• Better access to data, more usage of data • Maintenance concepts • Assessment of long-term effect of chosen reparation mode • Detailed data • Detailed data and data-driven approach • Compliance between company goals and performed actions

5) Summaries of the interview answers

Interview Question	Terrain managers 1 & 2	Technical specialist	Reliability engineer	Manager asset mangement	Head of strategy	Manageer operation&maintenance
1a						
1b	Striking, Reliability, Issues	Framework, overview, completeness	Reliability, questionable, cyclical	Lead, budgetary, policy, decisions	Ocasionally, company direction, societally acceptable	Daily, correctedness, client satisfaction
1c	Amount, type, existing connections	Scale, consequences, structural, one-off, longevity, reliability.	Scale, consequences, structural, one-off, completeness, policy	-	-	Outliers (reliability), repeating, re-visits.
1d	Cooperation, utility companies, region, pipe material, vulnerable, company standards	Lead, removal, framework, decision-making, updating, Management of change, customer satisfaction	Network, reudnancy, outliers (reliability), structural, culprit, severity	Cooperation, utility companies, lead, removal, data quality, customer satisfaction, KLIC,	Data driven, societal aspects, nuisance	-
1d i	-	Quantify, attitude, grouping, cohort, factors, common, substantiation, criticality	Grouping, commonality, scope, cohorts	Severity, likelihood	-	-
2a	New projects, reliability, removal, extension, completeness, performance	Individual, complaiance, framework, longevity, reliability, maintenance, scale, consequences	Reliability, questionable, cyclical, completeness, data, structural, one-off	Questionable, cohorts, repeating breakdowns, projects, severity, issue	-	Daily tasks, damaged, broken, connections, lead, company framework, correctedness, reparation mode, client satisfaction, workload, continuity.
2b	Governed, area, large variety.	Large variety, advising, O&B, AMI, framework, structuring, tenders.	Large variety, advising, cyclical reports	-	-	Requesting party, recognition, global, registered, severity, issue, customer satisfaction, network, well being.
2c	New project, reliability, issue, network's capacity, reliability, safety margins, maintenance.	Individual, framework, reliability, maintenance, significance, correlation	Sub-performing, cohorts, oversight, cyclical, siginificane, correlation	-	-	Request, AMI, non-standard, basic, analysis, pattern, spotting.
2d	Governed, area, defined.	Varies, individual, building, municipality, evidence, spatial correlation, cohort analysis.	Reliability, questionable, subperforming, cohorts, cyclical reports, evidence, spatial correlation	-	-	-

Figure 15 Key-words summaries of interview questions 1/2

3a	Type, amount, existing, connections, capacity, extension, completeness, reliability, maintenance, performance	All available information, define, one-off, structural, performance metrics, non-compliance, relative norms, unsustainable solutions	All available information, define, one-off, structural, performance metrics, non-compliance, relative norms, unsustainable solutions	Performance, followed, low performers, quanitfy, scale, importance scaling, completeness, urgency, gain, customer-satisfaction	No specific distinction, attention on customer satisfaction, coherence, substantiation of the metrics	Amount, issues, outliers, structured, analysis, completeness, cause, suboptimal performance
3b	On going projects, other utility companies, replacement, non-compliance, company norms	Costs, reparation modes, different decisions, nuisance costs.	costs vs benefits, LTAP financially, long term, life cycle, costing	SLA, impact, customer-satisfaction, financial monitoring, risk avoidance, non-compliance, cost, optimization	Social, value, quantification, LTAP, data quality, technical acceptability, societal acceptability.	-
3c	Not continiously monitored	Summary reports, communication of outliers, performance based, solutions longevity, planned reliability, overview, severity, consequences	Summary reports, communication of outliers, performance based, solutions longevity, planned reliability, overview, severity, consequences	Yearly summary reports, amount, breakdowns, costs, outliers, completeness, urgency, customer-satisfaction.	General yearly reports, no distinctions, connections,	Yearly summary reports, amount, breakdowns, costs, maintenance, maintaining customer-satisfaction, avoidance repeated visits
3d	Sketches, installation mode, remaining asset lifetime, completeness, performance.	Financial information, distinction between costs of reparation modes, Customer minutes lost, ground subsidience, post-life review, extended assessment, solutions longevity, planned, reliability	External factors, cause of damage, completeness, scale, confidence of assessmnet.	Improvement, information on positioning of assets, avoid damage, third parties, budgetary decisions, complete data-overview, reliability.	Methodology, quantification, societal, environmental, costs, technical, norms.	Customer satisfaction index, custom minutes lost, remaining life-time of asset
4a	Fulfillment of SLA	Frameworks, incomplete, decision guiding, solution longevity, planned reliability, risk matrix	Frameworks, incomplete, decision guiding, solution longevity, planned reliability, risk matrix, completeness of data, positioning, risk matrix, affects.	Risk matrix, limited applicability, connections, ambition, standardization, retaining, network's performance, prioritetization of tasks, cost and performance optimization.	Desirable direction, societal, environmental, awareness.	Maintenance, activities, performed, best, longevity, customer satisfactio reparation choices, workload, technicians.
4b	Cooperation, utility companies, data-driven, management of change	More data use, transition, data-driven, covenant partners, long-term, data oversight, distinction, individual cases, structural, problems, risk scaling	More data use, transition, data-driven, covenant partners, long-term, data oversight, distinction, individual cases, structural, problems, risk scaling	Improvement, geographical, information, covenant partners, limit nuisance, residents, data-driven, optimize, process, management, creation, LTAP, changes, policy, completeness, urgency, customer-satisfaction	Shift, data-driven, data quality, decision, confidence, technical, social, acceptable	Systematic, reactive, maintenance, data-driven, policy, structural, attention, analysis, new, policy, optimization

Figure 16 Key-words summary of interview questions 2/2

6) Definitions of selected performance indicators

Indicators are displayed as averages because the program will average out the result across the entire population which meets the user-selected criteria

$$Failure\ frequency\ (per\ assets\ lifecycle) = \frac{\sum Breakdowns}{\frac{\sum Assets}{Average\ current\ age\ of\ assets}}\ [\%/Year]$$

$$Continous\ Failure\ frequency = \frac{\sum Breakdowns}{\frac{\sum Assets}{Average\ age\ at\ the\ moment\ of\ breakdown}}\ [\%/Year]$$

$$Breakdown\ rate = \frac{\sum Breakdowns}{\sum Connections}\ [\%]$$

$$Mean\ Time\ To\ Failure = \frac{\sum Asset's\ age\ at\ the\ breakdown\ moment}{\sum\ Assets}\ [years]$$

$$Mean\ Time\ Between\ Failure = \frac{Time\ between\ the\ first\ and\ last\ breakdown}{\sum Breakdowns}\ [year]$$

Conformity requirements:

$$PVC\ only\ for\ diameters > 63\ mm$$

$$Diameter > 16\ mm$$

$$If\ ZPE, installation\ year\ \neq 1969 - 1975$$

7) Explanation of portal's windows

Schematic representation of the portal structure

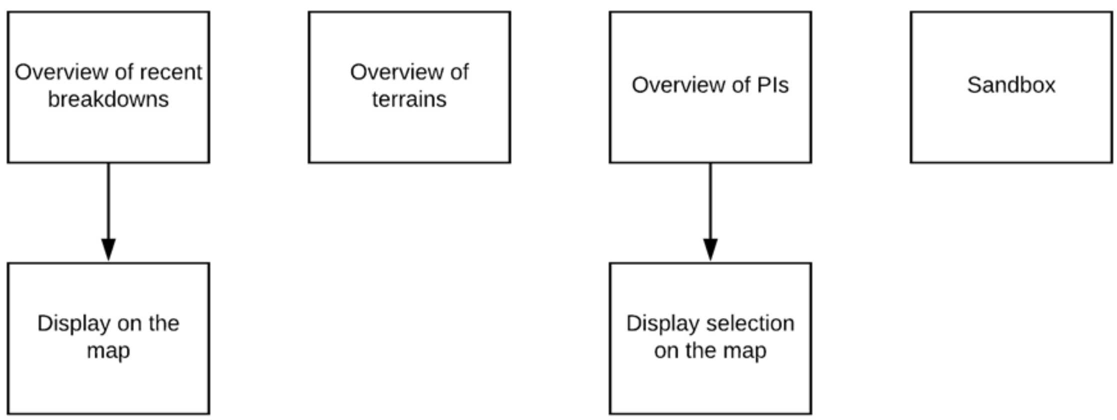


Figure 17 Schematic representation of windows withing the BI tool

Table 18 Association between contextualized questions to be answered in the portal, available display unit and the placement within the portal

Question	Display unit	Placement within the portal
What are the recent breakdowns? What happened, has it happened for the first time, where has it happened?	Comparison charts with different timespans Highlight when not the first instance	Overview of the recent breakdowns + Display on the map
What is the baseline reliability? What is performance of individual technical components?	All performance indicators displayed Filters: specific component, failure mode	Overview of the PI's + Display on the map
What is performance per region, section? How many non-compliers are there in the region?	Filter: geographical, display performance indicators Filter: compliance with the company policy	Overview of terrains
How does it perform compared to (…)? Which are the connections that perform suboptimal? What is the performance of connections on given distribution pipes	Performance indicators comparison Performance indicators comparison Aggregate performance indicators per distribution pipe	Overview of the PI's + Display on the map Overview of terrains Sandbox

Overview of recent breakdowns

This section is designed to allow the user for a global scan of recent events and contextualization of local breakdown rates with each other. It is composed of the following elements:

- List of connections which have recently underwent a breakdown
    - Technical information of the connection, information whether previous breakdowns occurred, who performed reparation and the breakdown rate on the given connection

Object	Melddatum	Werkprioriteit	Gemeente	Wijknummer	Beschrijving	Aangesloten adressen	Aantal WO	Leeftijd storing	MTBF	Aanlegjaar	Materiaal leiding	Service Provider	Continu Faalkans	Schets
ANSL-992836	20-1-20	1 (Hoog)	Rotterdam	5	Lekkage gevel Schieweg 16A Rotterdam(Heijmans)	1	1	130.00		1890	ZPE	FITTERIJ	0.77 %	
ANSL-486591	20-1-20	2 (Midden)	Rotterdam	17	Controle/kl reparatie hoofdkranen	1	1	54.00		1966	CU	FITTERIJ	1.85 %	
ANSL-1759558	20-1-20	1 (Hoog)	Rotterdam	14	Storingen/lekkages aansluiting	1	1	38.00		1982	CU	FITTERIJ	2.63 %	
ANSL-1940619	20-1-20	2 (Midden)	Nissewaard	5	Controle/kl reparatie hoofdkranen	1	1	40.00		1980	ZPE	FITTERIJ	2.50 %	
ANSL-23586214	20-1-20	1 (Hoog)	Maassluis	1	Controle/kl reparatie hoofdkranen	1	1	37.00		1983	HPE	FITTERIJ	2.70 %	

Figure 17 Display of recent breakdowns combined with technical data and maintenance history. In color: amount of previous breakdowns

This information is further coupled up with comments left by technicians after fixing the breakdown. This information is usually not directly connectable to technical data or performance indicators. The user can click on the given connection as seen in the image above (under *Object*) to display the added information for the given connection.

Werkorder	ANSL	Jaar melding	Datum	Status	Beschrijving	Opmerkingen
15253290	ANSL-992836	2020	20-1-20		Lekkage gevel Schieweg 16A Rotterdam(Heijmans)	20/01/2020 16:33:03: Melding alert, waren de klant vergeten. Er zou een monteur tussen 14:00-16: heeft vrij genomen, echter 16:00 nog niemand geweest. klant 06 19 45 20 68 - Ismail koppelt terug lekkage gevel - Heymans had geen lekkage, contact met Richard Hartog 17:00 uur - Bodemdesk geeft aan geen veiligheidsmaatregelen - Prio 3, aannemer beschikbaar, ook maar 1 avondmedewerker(Leo is vrij)

Figure 18 Detailed description of the breakdown type

Basic relative information is included at the bottom of the screen wherein small-scale trends are observable using values for matching periods from a year ago. This is done for both, the last 7 and 30 days. Next to it, a column chart can be found comparing monthly averages between years.

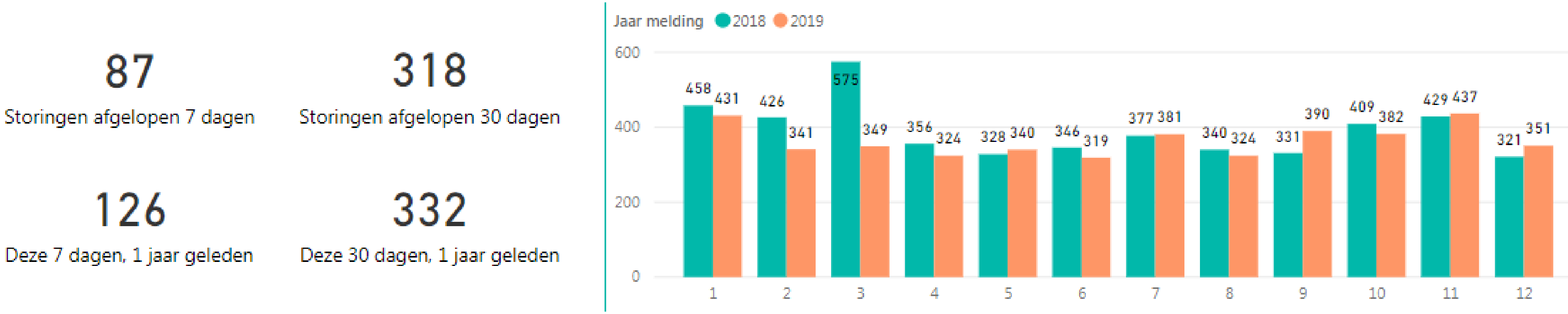
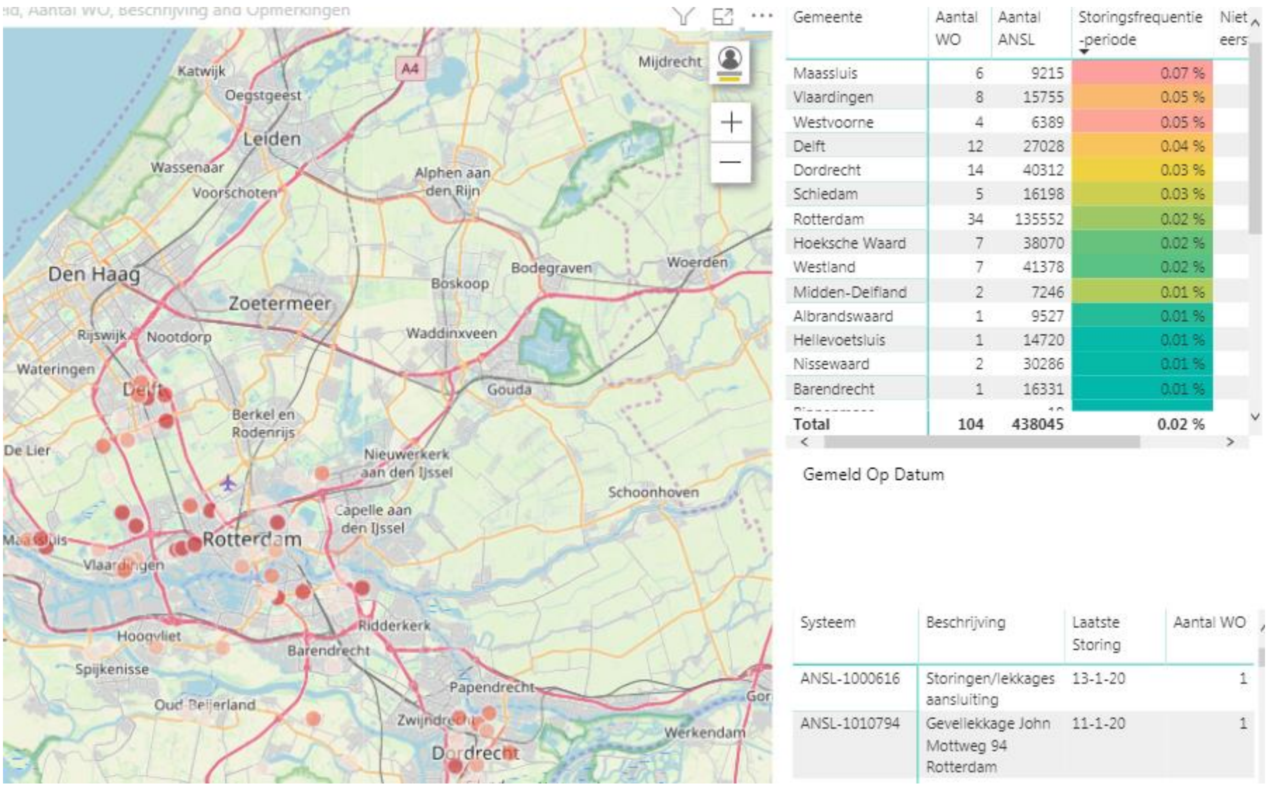


Figure 19 Summary of seasonal data

The user can opt to display the selected breakdowns on a map. Within the map module, dates and regions can be narrowed further and relative statistics are displayed. In the image below, this can be seen for municipalities. A list of selected connections can be exported to a csv file.



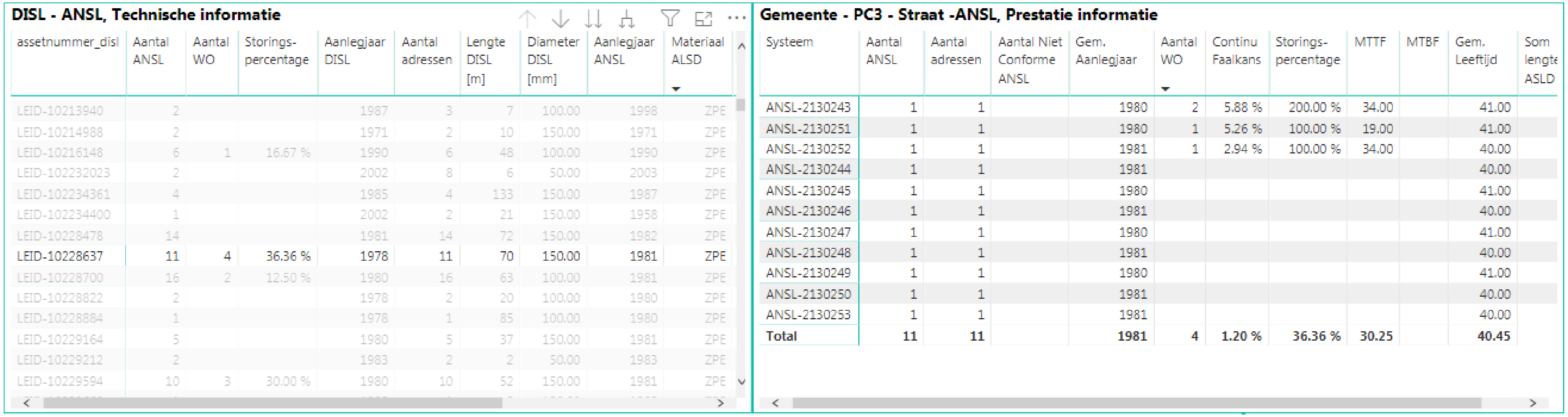
Gemeente	Aantal WO	Aantal ANSL	Storingsfrequentie -periode
Maassluis	6	9215	0.07 %
Vlaardingen	8	15755	0.05 %
Westvoorne	4	6389	0.05 %
Delft	12	27028	0.04 %
Dordrecht	14	40312	0.03 %
Schiedam	5	16198	0.03 %
Rotterdam	34	135552	0.02 %
Hoeksche Waard	7	38070	0.02 %
Westland	7	41378	0.02 %
Midden-Delfland	2	7246	0.01 %
Albrandswaard	1	9527	0.01 %
Hellevoetsluis	1	14720	0.01 %
Nissewaard	2	30286	0.01 %
Barendrecht	1	16331	0.01 %
Total	104	438045	0.02 %

Systeem	Beschrijving	Laatste Storing	Aantal WO
ANSL-1000616	Storingen/lekkages aansluiting	13-1-20	1
ANSL-1010794	Gevellekkage John Mottweg 94 Rotterdam	11-1-20	1

Figure 20 Geographical display of recent breakdowns

Overview of terrains

This section of the portal is designed with the terrain managers in mind. Here, performance indicators can be displayed per distribution pipe or individual connection. This is displayed in the image below:



DISL - ANSL, Technische informatie

assetnummer_disl	Aantal ANSL	Aantal WO	Storings-percentage	Aanlegjaar DISL	Aantal adressen	Lengte DISL [m]	Diameter DISL [mm]	Aanlegjaar ANSL	Materiaal ALSD
LEID-10213940	2			1987	3	7	100.00	1998	ZPE
LEID-10214988	2			1971	2	10	150.00	1971	ZPE
LEID-10216148	6	1	16.67 %	1990	6	48	100.00	1990	ZPE
LEID-102232023	2			2002	8	6	50.00	2003	ZPE
LEID-102234361	4			1985	4	133	150.00	1987	ZPE
LEID-102234400	1			2002	2	21	150.00	1958	ZPE
LEID-10228478	14			1981	14	72	150.00	1982	ZPE
LEID-10228637	11	4	36.36 %	1978	11	70	150.00	1981	ZPE
LEID-10228700	16	2	12.50 %	1980	16	63	100.00	1981	ZPE
LEID-10228822	2			1978	2	20	100.00	1980	ZPE
LEID-10228884	1			1978	1	85	100.00	1980	ZPE
LEID-10229164	5			1980	5	37	150.00	1981	ZPE
LEID-10229212	2			1983	2	2	50.00	1983	ZPE
LEID-10229594	10	3	30.00 %	1980	10	52	150.00	1981	ZPE

Gemeente - PC3 - Straat -ANSL, Prestatie informatie

Systeem	Aantal ANSL	Aantal adressen	Aantal Niet Conforme ANSL	Gem. Aanlegjaar	Aantal WO	Continu Faalkans	Storings-percentage	MTTF	MTBF	Gem. Leeftijd	Som lengte ASLD
ANSL-2130243	1	1		1980	2	5.88 %	200.00 %	34.00		41.00	
ANSL-2130251	1	1		1980	1	5.26 %	100.00 %	19.00		41.00	
ANSL-2130252	1	1		1981	1	2.94 %	100.00 %	34.00		40.00	
ANSL-2130244	1	1		1981						40.00	
ANSL-2130245	1	1		1980						41.00	
ANSL-2130246	1	1		1981						40.00	
ANSL-2130247	1	1		1980						41.00	
ANSL-2130248	1	1		1981						40.00	
ANSL-2130249	1	1		1980						41.00	
ANSL-2130250	1	1		1981						40.00	
ANSL-2130253	1	1		1981						40.00	
Total	**11**	**11**		**1981**	**4**	**1.20 %**	**36.36 %**	**30.25**		**40.45**	

Figure 21 Connectivity of data between distribution pipes (left) and attached connections (right)

On the left-hand side, a list of distribution pipes in the network can be found, together with cumulative information regarding the number of water connections connected onto it and respective breakdowns thereof. On the right-hand side, individual connections from the distribution pipe are displayed and some of the individual performance indicators can be retrieved. The selection made by the user in the left table, simultaneously affects the right table and the bottom part of the window, as shown in the figure below:

In this section, on the left-hand side, a breakdown-rate for the distribution pipe can be retrieved in function of the year of installation. In the central part, the user can select between technical and breakdown characteristics. This allows to locate all connections on which e.g. multiple breakdowns were observed. The *Search* windows allow for manual input, using which, geographical criteria can be altered. On the right-hand side, performance indicators as per can be retrieved. Depending on the user choices, this can be done for the whole network (no distribution pipe chosen) and group of distribution pipes meeting the user selected criteria.

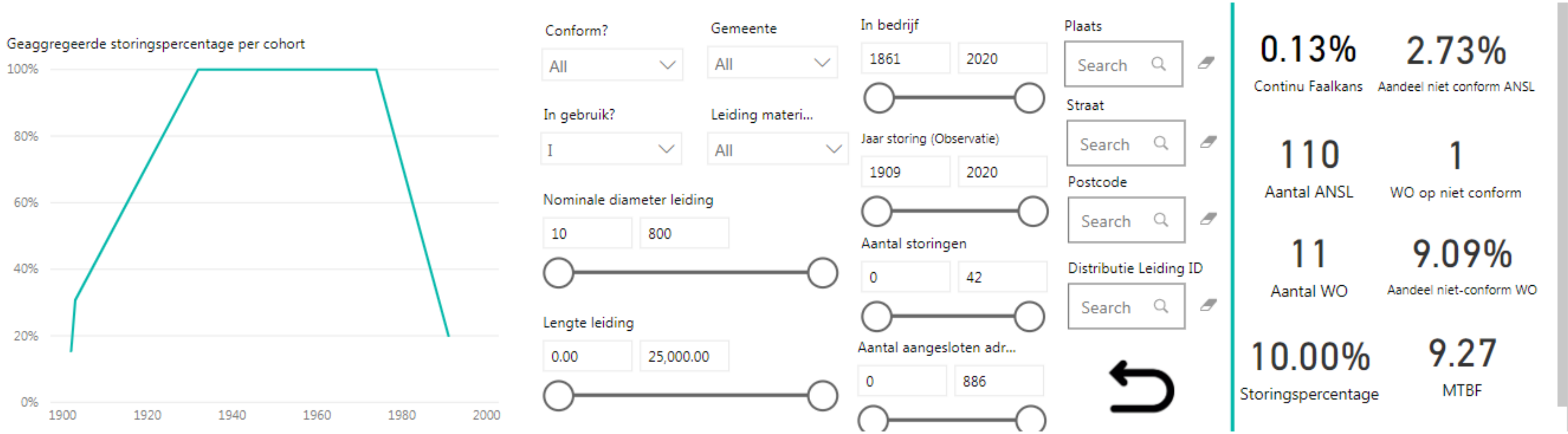


Figure 22 Cohorts breakdown rate (left) in function of installation year, Filtration tools (center), performance indicators for selected cohorts (right)

Overview of PIs

In this window, reliability engineers or other employees can attain the complete list of PIs based on selected filter, encompassing also for failure modes. This window differs from the previous one in having more focus on cohort-creation rather than retrieval of information in pre-existing arrangement (such as: based on the distribution pipe). In that sense the network specialist can analyze in function of which variable (e.g. specific element or specific year of installation) reliability is an issue.

Materiaal - Gemeente - PC3 - PC4 - DISL - ANSL - WO

Gemeente	Gemeente	Aantal ANSL	Aant aangesloten adressen	Aantal WO	Gem. Leeftijd	Continu Faalkans	Gewone faalkans	Storings-percentage	MTBF	MTTF	Meervoudige storingen	Materiaa leiding
Rotterdam	Rotterdam	135552	424083	25934	50.87	0.37 %	0.38 %	19.13 %	6.42	51.64	3785	AC
Hoeksche Waard	Hoeksche Waard	38070	41212	5627	49.74	0.28 %	0.30 %	14.78 %	6.29	53.45	732	ALU-PE
Westland	Westland	41378	52194	4774	40.03	0.30 %	0.29 %	11.54 %	5.00	38.80	527	AC
Schiedam	Schiedam	16198	49944	2595	25.68	0.81 %	0.62 %	16.02 %	2.65	19.86	402	AC
Nissewaard	Nissewaard	30286	43265	3614	39.40	0.37 %	0.30 %	11.93 %	6.31	32.28	357	AC
Delft	Delft	27028	63843	3201	27.50	0.50 %	0.43 %	11.84 %	3.03	23.82	347	AC
Vlaardingen	Vlaardingen	15755	43842	2216	27.50	0.64 %	0.51 %	14.07 %	3.96	22.00	258	AC
Capelle aan den IJssel	Capelle aan	15076	41340	1749	37.96	0.36 %	0.31 %	11.60 %	5.49	31.90	231	ALU-PE

Figure 23 Summarized performance indicators for municipalities in delivery region

At the top of the window, the main selection table is placed. Herein, all performance indicators can be retrieved in function of features as listed in the top left corner of the image above. The user can choose to retrieve results relevant to e.g. particular material, variations of the post-code and individual connection. This selection can be narrowed down using filters placed at the right-hand side, as can be seen in the image below.

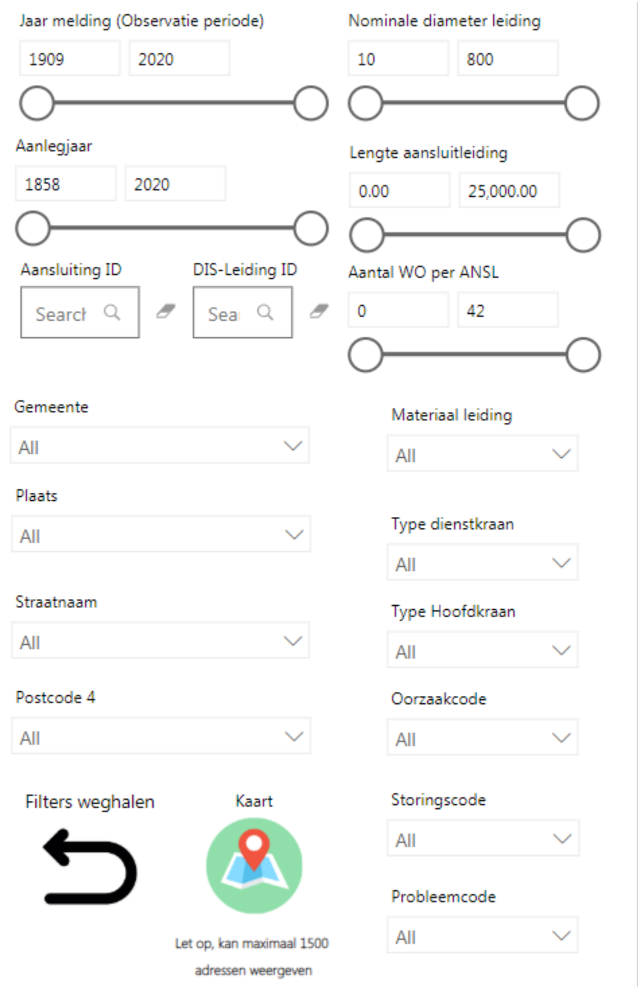


Figure 24 Filter for selecting cohorts using geographical, technical and breakdown data

The combination of the table and the feature selections allows the network specialist to fine tune based on which characteristics the cohort is to be created. Seeing as diverse failure mechanisms occur for every element within a connection, this functionality allows for differentiation according to the failure mode.

As seen with the first table, information for the specific 'row selection' can be readily retrieved. Contextual information can be found below the table and always corresponds to one level higher in the hierarchy. In this example, while the table from figure 23 displays values for each individual municipality, the values shown below describe the whole network. The same applies to the curve which depicts breakdown-rate as function of age for the given cohort (figure 26).

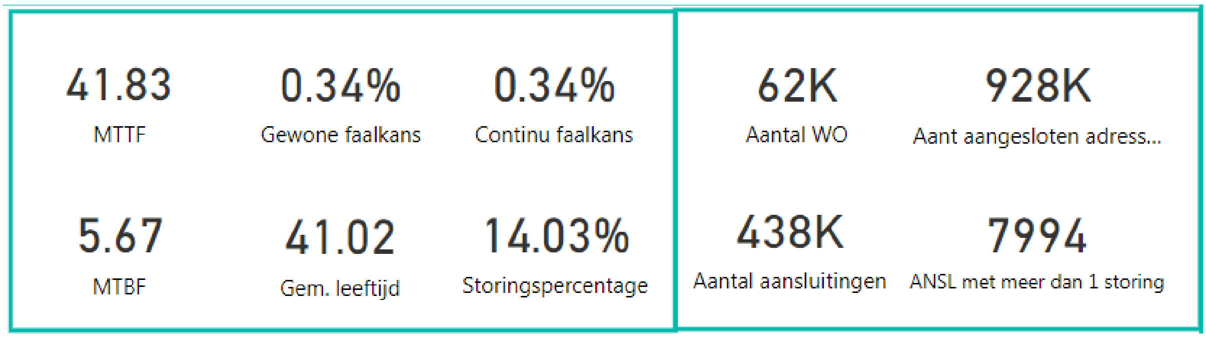


Figure 25 Cumulative performance indicators (left), cohort-defining information (right, complete network)

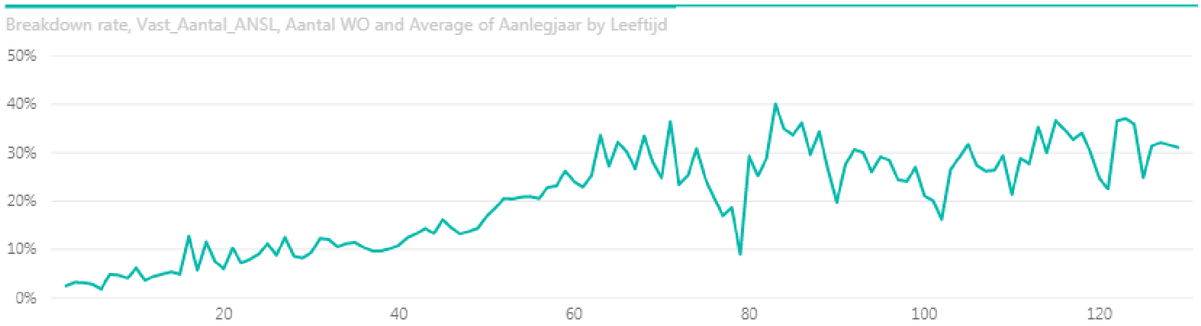
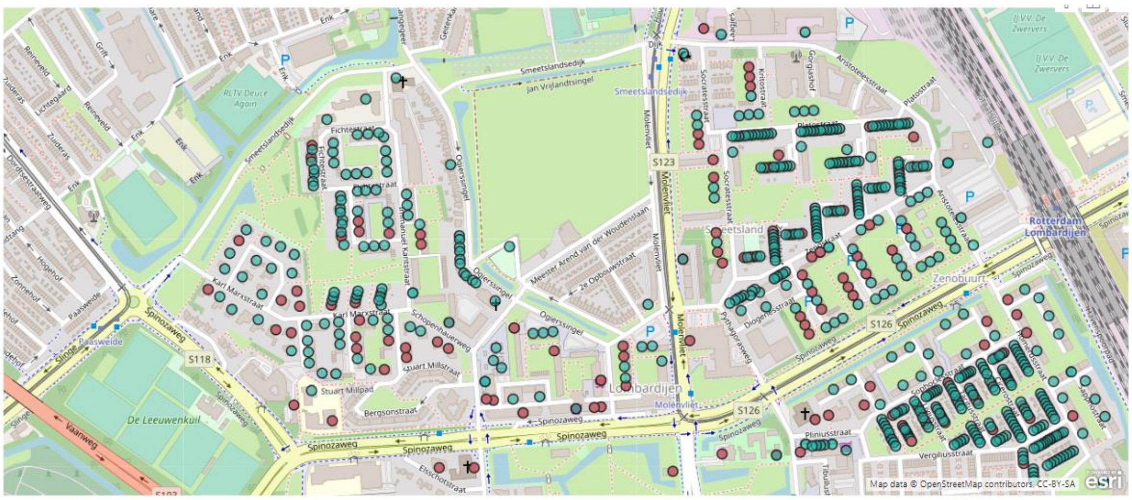


Figure 26 Breakdown curve in respect to asset lifetime

Using this curve, network specialists can quickly display if breakdown events for cohorts are based in known deterioration processes or should be inspected in different light.

Lastly, this window further allows to display the connections belonging to the selected cohort on a map. In the image below, selection was made based on the breakdown frequency for any given postal code (4 digits thereof). From here, the relevant information can be exported further.



Systeem	Aanlegjaar	Gemeente	Postcode 3	Aantal ANSL	Aant aangesloten adressen	DISL	Gem Storingsfrequentie	Aantal WO	Meervoudige storingen	Time-to-failure	Gem. Tijd tot Storing	Storings-percentage	Continu Faalkans	Materiaal ALSD
ANSL-1425463	1964	Rotterdam	307	1	3	LEID-431312130	0 %	6	1	45	47.67	600.00 %	12.59 %	PVC
ANSL-1549421	1974	Rotterdam	307	1	1	LEID-430895035	0 %	5	1	26	32.80	500.00 %	15.24 %	PVC
ANSL-205541	1961	Rotterdam	307	1	1	LEID-433126634	0 %	5	1	34	39.00	500.00 %	12.82 %	ZPE
ANSL-1314513	1961	Rotterdam	307	1	1	LEID-10688013	83 %	4	1	55	55.00	400.00 %	7.27 %	ZPE

PC4
Search
Systeem
Search

Figure 27 Example of graphical representation of connections for given region. Color signifies whether a breakdown occurred

The last window available to the used is called “Sandbox” and contains no content. The purpose thereof is to allow the user to benefit from the data model competencies behind the portal, without being constrained to only windows enclosed in the portal as is.

Example application of created tool and comparison with current methods

To display how the BI tools can aid network specialists in producing asset management recommendations with respect to water connections, examples of tasks named by network specialists are displayed below. First, an explanation is given how the task is currently completed using methods present at Evides. Afterwards, the task is completed using the features of the BI tool. Due to data sensitivity, no print screens of the current systems are offered.

Example 1: Assessment of inclusion of connections in a cooperation project

Terrain managers are asked to decide whether Evides wants to participate in planned projects of other utility companies where excavation takes place. For distribution pipes, there exists a decision support system, for connections that is not the case. The company has defined groups of connections (based on the installation years and material) which need to be included in such projects if the opportunity occurs. In order to assess the situation, terrain managers use the GIS overview of the network to check visually a sample of connections for compliance. There is however no maintenance history included in the data set, and the process is not formalized in terms of ratio of connections to be checked.

If greater use of maintenance and technical data was expected, this would require the specialists to perform each time the actions as seen in the graph below. The information provided to the specialist is the location of the work, usually in terms of street name.

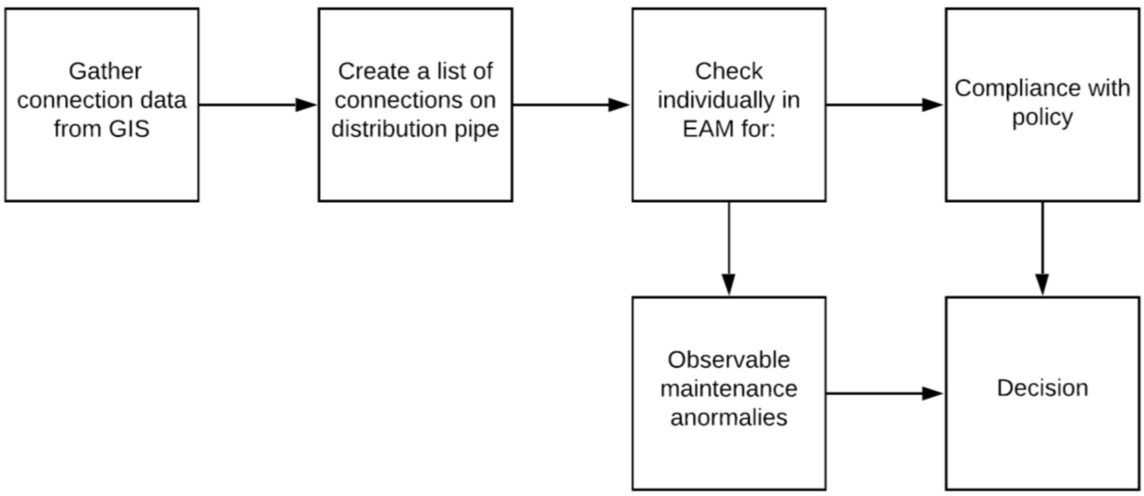
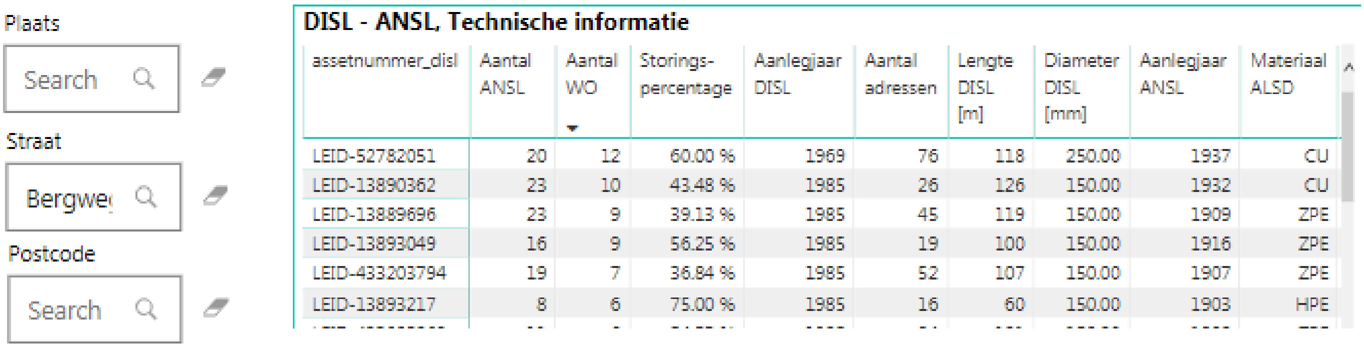


Figure 24 Schematization of the current mode of assessment of co-operation project should reliability be taken into consideration

In the BI tool, the same task would be performed as seen below.

Using search input (figure 28), the user can retrieve the distribution pipes on the given street. The pipes themselves are not labeled with addresses, however, because the water connections are, this information is transferred due to cross-connection of data. In this example, the street Bergweg in Rotterdam is being examined.



assetnummer_disl	Aantal ANSL	Aantal WO	Storings-percentage	Aanlegjaar DISL	Aantal adressen	Lengte DISL [m]	Diameter DISL [mm]	Aanlegjaar ANSL	Materiaal ALSD
LEID-52782051	20	12	60.00 %	1969	76	118	250.00	1937	CU
LEID-13890362	23	10	43.48 %	1985	26	126	150.00	1932	CU
LEID-13889696	23	9	39.13 %	1985	45	119	150.00	1909	ZPE
LEID-13893049	16	9	56.25 %	1985	19	100	150.00	1916	ZPE
LEID-433203794	19	7	36.84 %	1985	52	107	150.00	1907	ZPE
LEID-13893217	8	6	75.00 %	1985	16	60	150.00	1903	HPE

Figure 28 (Left) selection mechanisms for the area, (Right) display of performance per distribution pipe

From here on, the user can choose to display performance indicators for the whole street queried (left side of figure 29). Should the user click in the table from figure 28 on a specific distribution pipe, the performance indicators from figure 29 would be updated for that distribution pipe only. The share of connections not conforming to the company regulations can be seen, together with the amount and share of breakdowns on these connections (respectively: Aandeel niet conform ANSL, WO op niet conform and Aandeel niet-conform WO). In the right section of figure 26, the user can opt for displaying only not-conforming connections or choose other network specifications (Location, status, material, diameter and length).

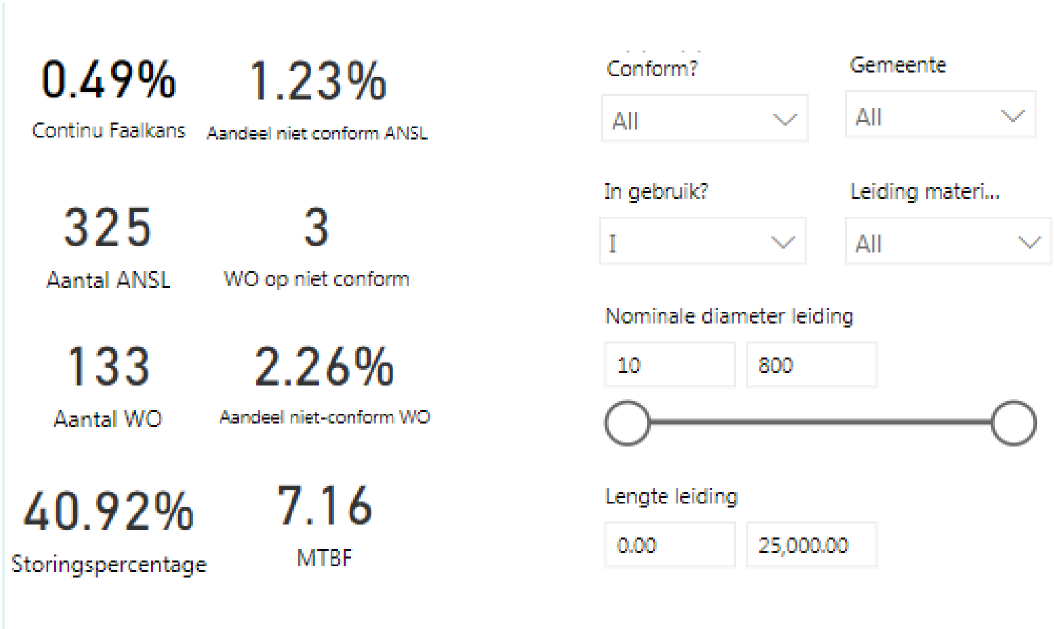


Figure 29 Performance indicators and selection mechanisms

Based on the above, estimated 3-4 hours of time can be saved, should all of the data be analyzed 'manually' with better display of data at hand. In case of this example, all of the connections on distribution pipes from 1985 would be suggested for replacement, due to a high breakdown rate.

Example 2: Reliability of a valve type

For creating company risk profile, maintenance history of specific network component is sought. This is done by reliability engineers on ad-hoc basis when a suspicion is communicated by maintenance department. Should a network engineer be tasked with acquiring this information for a series of valves, the steps from the figure below need to be taken. Note that maintenance information cannot be downloaded from EAM for a selection of connections and instead the whole dataset needs to be downloaded.

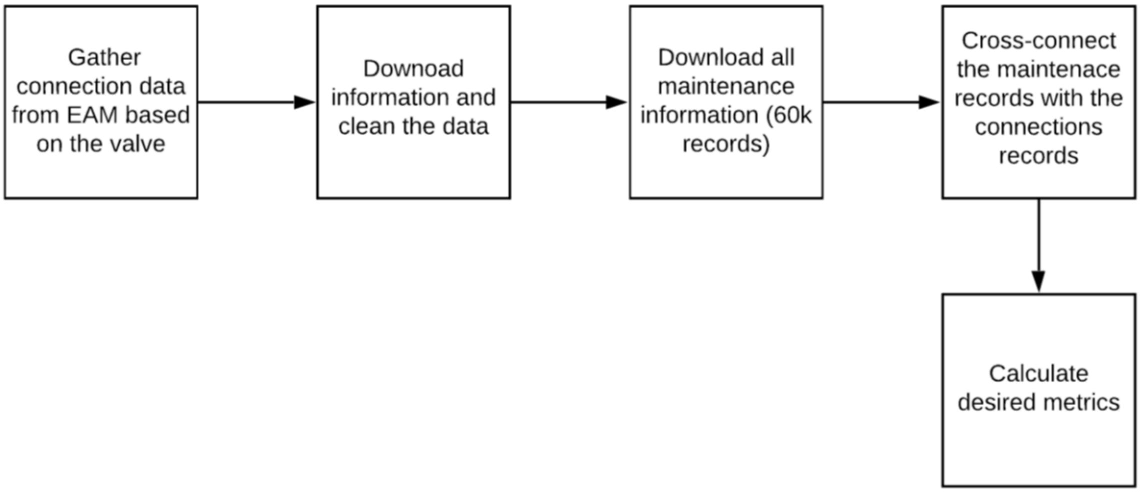


Figure 30 Current process to develop performance overview for a specific element

In the BI tool, the same results can be obtained following the steps below. In this case, the valves of the type xxNK are sought (xx symbolizes different diameters). First, the valves of the NK type are selected (left side of figure 31). Then, the user is shown (right side of figure 31) the performance indicators and amount of connections, breakdowns, connected addresses and units with more than one breakdown for connections with this valve-type. Please note that this information is not filtered for relevant breakdown modes.

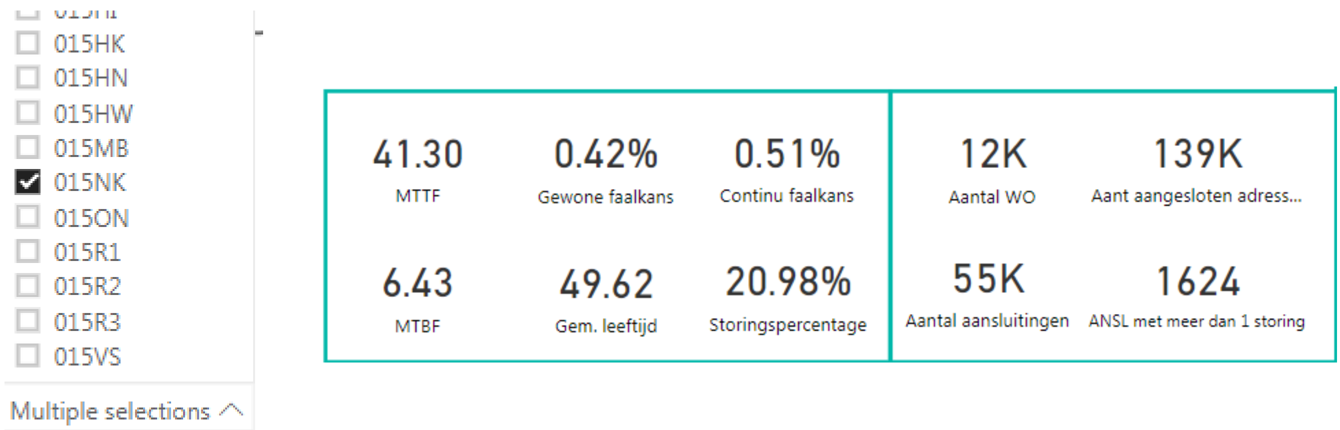


Figure 31 Performance indicators for a selected valve-type for the network

Lastly, the user can also see where the given connections are located. This can be done from different geographical levels, below this can be seen per municipality (gemeente). This allows the user to determine where this valve-type is most common and compare performance in the region with the aggregated statistics from figure 31.

Materiaal - Gemeente - PC3 - PC4 - DISL - ANSL - WO

Gemeente	Gemeente	Aantal ANSL	Aant aangesloten adressen	Aantal WO	Gem. Leeftijd	Continu Faalkans
Rotterdam	Rotterdam	14805	70308	4059	59.12	0.54 %
Westland	Westland	21355	24922	2954	49.26	0.34 %
Midden-Delfland	Midden-Delfland	4268	4743	811	31.55	0.89 %
Schiedam	Schiedam	619	6935	432	28.75	3.86 %
Nissewaard	Nissewaard	3138	4322	717	43.50	0.67 %
Hellevoetsluis	Hellevoetsluis	1867	2383	485	46.06	0.77 %
Westvoorne	Westvoorne	1084	1166	317	54.45	0.70 %
Brielle	Brielle	947	1012	299	64.34	0.60 %
Maassluis	Maassluis	1042	2562	268	40.57	0.84 %
Delft	Delft	597	3549	194	29.75	1.67 %

Figure 32 Presence and performance of the selected valve-type in the network

The steps within the tool take approximately 3 minutes and allow for further gradation in terms of failure mode and other aspects (technical and geographical). Attaining similar overview after importing data into Microsoft Excel and cleaning it, was estimated by the reliability engineer to cost about 1.5 hour to arrive at a functional data set and another 1 hour to arrive at the results This information could also be synthesized using scripting languages but would still require downloading the dataset and clearing data, a step which lends itself well to automatization in the BI environment.

Example 3: Spotting a performance outlier

In case connections with fail multiple failure are spotted, extra attention is required. Should a reliability engineer want to assess where situation of multiple breakdowns occurs, the steps from figure 33 would have to be followed.

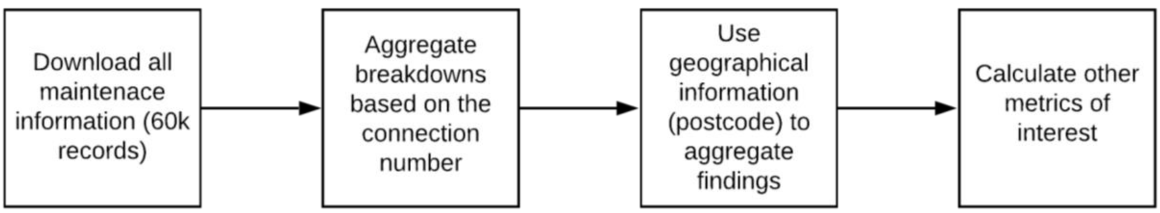


Figure 33 Schematization of current practice

This does not seem like a complicated process, it should be kept in mind however that Excel has a limited linking capacity and the process is slow. Further, because only breakdown data is consulted here, no technical information over individual connections can be retrieved. Also, no relative metrics can be acquired due to not incorporating the database of all connections. This information can be calculated using scripting languages such as Python, however – experience shows that this gets done differently by every person performing the calculation and continuity in reporting is lacking.

In the BI portal, the following steps are taken. First, the header "Multiple breakdowns" (Meervoudige storingen) is clicked on to order the municipalities in descending order of multiple breakdowns as can be seen in Figure 34.

Materiaal - Gemeente - PC3 - PC4 - DISL - ANSL - WO

Gemeente	Gemeente	Aantal ANSL	Aant aangesloten adressen	Aantal WO	Gem. Leeftijd	Continu Faalkans	Gewone faalkans	Storings-percentage	MTBF	MTTF	Meervoudige storingen	Materiaal leiding
Rotterdam	Rotterdam	135552	424083	25934	50.87	0.37 %	0.38 %	19.13 %	6.42	51.64	3785	AC
Hoeksche Waard	Hoeksche Waard	38070	41212	5627	49.74	0.28 %	0.30 %	14.78 %	6.29	53.45	732	ALU-PE
Westland	Westland	41378	52194	4774	40.03	0.30 %	0.29 %	11.54 %	5.00	38.80	527	AC
Schiedam	Schiedam	16198	49944	2595	25.68	0.81 %	0.62 %	16.02 %	2.65	19.86	402	AC
Nissewaard	Nissewaard	30286	43265	3614	39.40	0.37 %	0.30 %	11.93 %	6.31	32.28	357	AC
Delft	Delft	27028	63843	3201	27.50	0.50 %	0.43 %	11.84 %	3.03	23.82	347	AC
Vlaardingen	Vlaardingen	15755	43842	2216	27.50	0.64 %	0.51 %	14.07 %	3.96	22.00	258	AC
Capelle aan den IJssel	Capelle aan den IJssel	15076	41340	1749	37.96	0.36 %	0.31 %	11.60 %	5.49	31.90	231	ALU-PE
Dordrecht	Dordrecht	40312	61605	2568	32.31	0.24 %	0.20 %	6.37 %	3.25	27.05	225	AC

Figure 34 Performance displayed per municipality

Next, geographical information is expanded from municipalities to postcodes (first, postcode with 3 numbers, thereafter with 4 numbers). This renders the following list of postcodes in Rotterdam (figure 35). As can be seen below, postcode 3085 has the most multiple breakdowns.

Materiaal - Gemeente - PC3 - PC4 - DISL - ANSL - WO

PC4	Gemeente	Aantal ANSL	Aant aangesloten adressen	Aantal WO	Gem. Leeftijd	Continu Faalkans	Gewone faalkans	Storings-percentage	MTBF	MTTF	Meervoudige storingen	Materiaal leiding	Laatste melding	Aa jaa
3085	Rotterdam	1433	5090	595	63.55	0.85 %	0.65 %	41.52 %	7.18	49.06	85	ALU-PE	19-1-20	
3086	Rotterdam	1051	4591	426	62.46	0.81 %	0.65 %	40.53 %	6.98	50.13	76	ALU-ZPE	15-1-20	
3083	Rotterdam	695	4946	309	69.27	0.79 %	0.64 %	44.46 %	8.18	56.15	47	CU	20-1-20	
3084	Rotterdam	385	653	98	69.89	0.51 %	0.36 %	25.45 %	7.31	50.23	24	CU	17-12-19	
3082	Rotterdam	293	1609	138	65.54	0.87 %	0.72 %	47.10 %	8.20	54.33	19	CU	28-2-19	
3089	Rotterdam	147	180	61	63.54	0.91 %	0.65 %	41.50 %	8.67	45.62	15	CU	7-1-20	
3081	Rotterdam	98	679	76	64.62	1.52 %	1.20 %	77.55 %	8.25	50.88	14	CU	14-10-19	
3087	Rotterdam	114	244	52	62.83	0.96 %	0.73 %	45.61 %	4.01	47.44	13	CU	29-8-18	
3088	Rotterdam	111	238	55	54.44	1.24 %	0.91 %	49.55 %	4.09	39.85	9	CU	10-11-19	

Figure 35 Performance displayed per post-code area

Hereafter, this postcode is chosen from a drop-down menu to be displayed on the map as can be seen in figure 33.

On the map, green dots symbolize connections which have not undergone a breakdown, red dots mark the ones with at least one breakdown. Different color-coding schemes to display the number of breakdowns. The user can export the list of connections from the created cohort.

Figure 36 Representation of water connections in the given area

The density of breakdowns is visibly high and further analysis of breakdown codes confirms similar failure mode (crack in the pipe due to insufficient flexibility of the material).

This information was gathered and displayed together with the performance indicators in a very short time. This was done to validate the data known from the technicians; however, it shows that more data can be followed to create better oversight of the situation in the network. According to reliability engineers, this type of analysis was not done frequently in the past due to the volume of data and time-cost.

8) Questions used in the evaluation

In red are the themes which the question evaluates

- How many not-conform connections are there in the region? (*Interlinking company goals and reliability readings*)
    - Create a list with these connections, display the amount of occurred breakdowns. (*Accessibility and quality of data*)
- Another utility company is working on a project on the Nieuwe Maas (Schiedam) street (*Monitoring, cooperation with other companies, decision support and drivers*)
    - How many Evides distribution pipes can be found there?
        - On which distribution pipe were there the most breakdowns?
            - Create a sheet with the connections' ID for the distribution pipe with the most breakdowns.
    - What's the average breakdown frequency for the connections on that street?
    - If the distribution pipe is replaced, how many addresses would be affected? (*social nuisance, customer satisfaction*)
    - How does your region perform in terms of breakdown frequency for connections (amount of breakdowns/amount of connections) in 2018? *(monitoring)*
        - And in terms of mean time between failures? (MTBF) (*accessibility and availability of data)*

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    - Which municipalities with more than 100 connections are characterized with the highest breakdown rates *(Monitoring)*
    - How do connections with main valve (hoofdkraan) 025HH compare in performance between municipalities Dordrecht and Capelle aan den Ijssel? (*reliability metrics and dataset fragmentation)*
        - *In the last two years? (accessibility and availability of data)*
    - Compare the mean-time-between-failure for service-valves KK and MK, which municipality appears to have most problems with either of these valves (add problem codes) (*reliability metrics and data fragmentation)*
        - Are repeating breakdowns more common on one of the two?
    - For copper connections: what are the first 2 points in the connections' lifetime when the breakdown rate observes a peak? *(monitoring)*
    - In the period between 2015 and 2019, which municipality experienced the highest failure frequency, limited to problem code S02-ANSL (Lekkage)
        - Between CU, HPE and PVC – which one has:
            - The highest breakdown rate?
            - The earliest breakdown rate peak before age 30?

9) *Post-experiments questions*

Rating scale survey (Linkert scale)

These questions refer exclusively to work-context relating to water connections and the reliability thereof.

Assigning a “1” means that the statement is completely untrue and the application of the portal can lead to deterioration of your work (experience/quality) with relation to water connections. Assigning a “3” means that little added value can be seen, a “5” means that the portal displays a big potential to affect how data is handled and made use of. If you think that insufficient time was given to evaluate given feature, please choose “3”.

- Accessibility and availability of data
    - Within the same time-window, more information can be retrieved using the portal.
    - Overview of assets and performance metrics is improved with the portal
    - The completeness of oversight over the data owned by the company and the contents thereof is improved
    - Data-completeness can be now more easily observed and reported to relevant members of the company.

- Reliability metrics and dataset fragmentation
    - The connections with strikingly low performance/reliability (outliers) are easier to spot now.
    - Creation of cohorts for reliability analysis is more attainable.
    - Suggestions for Management-of-change can in the future be substantiated using the findings from the portal
    - Transparency in decision making can be improved using recognized performance indicators
- Monitoring and summarizing of network performance
    - The data needed for evaluation of the potential for cooperation with covenant partners is now more easily available.
    - The findings from the portal can be easily exported and passed around within the company
    - Repeating breakdowns of the same connections can now be made more quickly visible and the analysis thereof is facilitated by faster access to data.
    - Overview of performance/reliability indicators can allow in the future for normalized (internal) benchmarking and cyclical checks.
- Decision support and decision drivers
    - Data filtering allows for quicker creation of cross-sections and in the future can offer more data-driven decision-support information and metrics.
    - In the future, this type of solution can help us monitor company’s compliance with SLA and point out the regions for improvement
    - Geographic display of the findings on the map simplifies combining technical data with the connection’s positioning information
    - The depth of exploration for systematic/structural issues is improved through the ability to filter data, also based on previous instances of breakdowns