Open Data in Engineering Asset Management

A Case Study into the possibilities and challenges of using Open Data in Engineering Asset Management

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Tim van de Laarschot

Student number: 4344464

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Graduation committee:

Chairperson: Prof.mr.dr. J.A. de Bruijn, Section Organisation and Governance
First supervisor: Dr. A.M.G. Zuiderwijk - van Eijk, Section Information and Communication Technology
Second supervisor: Dr. M.L.C de Bruijne, Section Organisation and Governance
External supervisor: Ben Visser, Oxand

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After six months of dedicated work, I am proud to present this master thesis. Nine months have passed since the first meetings with Ben Visser and Anneke Zuiderwijk where some vague ideas have evolved in an idea for a master thesis. In the months after, I wrote a proposal that, although it has changed over time, was the solid foundation for this thesis.

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Lastly, I want to express my gratitude to all my loved ones. During this interesting, but also challenging period they have always supported me they created the best possible conditions for me to work on this thesis.

Executive Summary

Research context

The use of Open Data (OD) in an Engineering Asset Management (EAM) context is largely unexplored. Even though research into OD is moving forward, this knowledge is not fully usable in EAM because of the complexity and the specific characteristics of EAM.

Research Approach

The research is centred around the case study that has taken place. As input for the case study, a literature review has been conducted to summarize and analyse the existing knowledge of OD and EAM.

This created a starting point for the case study. A case about the traffic situation around the IJsselbruggen and the VIA15 project (A12) has been selected to research the possibilities to use OD with the goal to evaluate the current traffic measures and investigate the possibilities for Data-Driven Decision Making (DDDM).

The combined results of the literature review and the case study have been reviewed by a group of experts in an expert workshop session. Besides there critical opinion about the research, the experts where also asked about their view on the use of OD in the EAM sector.

Findings

The research is divided in three sub-questions. The first sub-question; *What factors in EAM influence data-driven decision making using Open Data?* is answered in the literature review chapter. The conclusion from the literature review is that factors which influence the use of DDDM with the use of OD are according to the literature, mostly concerning the technical capabilities. The complexity of EAM create barriers for the use of open data, but that because of the central role of information management in EAM there are also possible benefits when implemented in the right way. In the literature, mostly technical issues related to the use of OD were found.

The second sub-question; *What factors enable and hinder data driven decision making in a real life case of using open data in an EAM context?"* is answered in the case study chapter of the research. By investigating a real life case the step from the theoretical literature review to a more applied research is made. The case study confirmed that the technical barriers found in the literature review are indeed a problem, but surely not the only problem. The governance problems that came to light were not foreseen but very problematic.

One of the findings is that the way of working during infrastructure projects (like the long-term plannings) makes it difficult to use the potential benefits from Open Data. Thereby a problem is that OD can be free, but for using OD effort has to be done. A good distribution of costs (for the effort) and benefits (from the use of the OD) is necessary and was (in this case) not easy to achieve.

The third sub-question: *What are stakeholder perceptions on enablers, barriers and success factors on using Open Data in Engineering Asset Management?* is answered in the expert review chapter. The conclusion from the review workshop session, conducted with employees from Oxand, is that there are clearly opportunities for the use of OD in EAM, but that the complexity of EAM processes makes it difficult to find a starting point. According to the experts, standardisation of the way in which OD is shared and published can help to make it easier accessible. This could help reducing the efforts or transaction costs of finding and using OD. Besides that they added that it is advisable to start with using the OD for small (side) projects, because using it for the internal processes of an organisation is risky and the lessons learned from these small projects can help to integrate it later on in the whole organisation. A disadvantage of integrating OD with small steps is that the benefits are often not fully reached when OD is only partly integrated.

Scientific contribution

This research contributed to filling the information gap of information about OD in an EAM context. The findings form a starting position for other case studies with OD in an EAM context.

In a broader prospective, this research helped with showing that the barriers that are commonly found (technical boundaries) are not always the main problem. The governance in the EAM-sector is formed in such a way that an other approach to Open Data integration is needed.

Societal contribution

The societal contributions of this research are two-sided; EAM organisations can use the insights from this research when they are thinking about integrating OD in their organisation and governmental organisations can use it to base their OD / information policies on.

Future research

More research to the specific instances of Open Data use in all kind of situations can help to make Open Data more available for organisations to work with. Besides that, research focused on possible interventions from the government to enforce or promote standardisation of ways in which open data is made available would be helpful for the Engineering Asset Management sector in specific.

As for the case study, a pilot study where a traffic model based on the OD is used as a tool for improved estimation of traffic disruption would be interesting as real-world testing is needed to estimate the benefits of such a model. Without real-world testing, contractors will be reluctant to invest money in such innovations.

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Acronyms

Acronyms used in this master thesis:

ASM	Asset Management System
APM	Asset Performance Management
BSM	Backwards Snowballing Method
DDDM	Data-Driven Decision Making
DQ	Data Quality
DQF	Data Quality Framework
DQM	Data Quality Management
EAM	Engineering Asset Management
IAM	Integrated Asset Management
IT	Information Technology
LCC	Life Cycle Costs
MMS	Maintenance Management System
NDW	National Database Road Traffic *(Nationale Databank Wegverkeer)*
OD	Open Data
OGD	Open Government Data
OMS	Operation Maintenance System
OTD	Open Traffic Data
SLR	Systematic Literature Review

1 Introduction

As the amount of generated and stored data is still growing every day (Villars, Olofson, & Eastwood, 2011), the possibilities for using data to enhance better decision making are growing. Governments and organisations are encouraged to share their data with others as a result of the rising awareness of value creation due to Open Data (Janssen, Charalabidis, & Zuiderwijk, 2012).

In some fields, the use of Open Data (OD) is already common practise whereas in other fields, the use of OD is still very limited. One of these seems to be the field of Engineering Asset Management (EAM). Section 1.1 will explain the concept of EAM, section 1.2 focuses on the possibilities and problems of the use of Open Data, section 1.3 describes the system of interest and section 1.4 contains the research gap.

1.1 Engineering Asset Management

Engineering Asset Management (EAM) is *"the process of managing the physical assets within an organization in such a way that their usage can be made cost effective"* (Hastings, 2010, p.12). EAM firms play an important role in society because they manage all the assets that are used on a daily basis in the society. From the roads we use to the electricity grid, asset managers play a key role in creating and maintaining the foundation of societies necessaries.

The main job of EAM companies is to make public infrastructures safe, effective, efficient and environment friendly (El-Akruti & Dwight, 2013). These activities are often a result of collaboration and negotiation between multiple actors, as projects in the field of EAM are often requested by a governmental organisation and executed by a partnership of private organisations (Hastings, 2010).

Nowadays, asset managers are increasingly using computer systems such as an Operation Maintenance System (OMS). These systems are helpful because they provide insights regarding assets as well as inform asset managers. Insights form the OMS's are often estimates based on the wear of similar assets in the past (Bengtsson & Delbecque, 2011). Many factors are considered by an OMS for advising a maintenance plan for assets, such as the aging process of the assets and the availability of workers to conduct maintenance at specific times. An OMS can propose a better maintenance plan by taking more factors into consideration than an asset manager is able to. The underlying assumption is that more information results in better decision making, which is in line with the mainstream decision theory. Mainstream decision theory argues that decisions based on facts are better than decisions based on subjective ideas (Brynjolfsson, Hitt, & Kim, 2011).

Lin, Gao, Koronios, and Chanana (2007) point out that it is crucial for an Engineering Asset Management organization to utilize assets in an efficient way to generate revenue. This revenue is necessary to invest in new assets and to keep current assets in good condition. The problem that is showed by Lin et al. (2007) is that organizations mostly want to make decisions based on data (data driven), as decisions based on data are less disputable than decisions based on personal judgement. Although The Netherlands is one of the leading countries in the area of Big Data and Data-Driven Decision Making (DDDM), the penetration rate of Big Data use and DDDM is quite low (Groenewegen, 2019).

1.2 Open Data

OD initiatives offer the possibility to gather data about all kind of topics, such as traffic data, weather data and spatial planning data. Topics that are all closely related to EAM.

As an example, the amount of traffic data that has become available to the public domain is doubled in the last decade (Chen, Lv, Li, & Wang, 2016). So

EAM organizations that are focused on road infrastructure projects have the possibility to make use of this data in their decision processes.

There are multiple problems with the assumption that asset management companies are willing to add more data to their decision making processes. Data collection and processing takes time, and often decisions have to be made in a specific time window. Therefore, an overload of data can lead to a false belief of certainty. Only data that gives more insights in the problem at hand provides the opportunity to enhance the decision making processes (Eerens, 2003).

Another known problem of the use of Open Data is that the knowledge on how to utilise this data for better decision making is often not present in organisations (Janssen et al., 2012). Without proper knowledge on how to utilise the new data sources, organisations will ignore these new data initiatives.

Another barrier that possibly prevents organisations from using open data in their decision making is that even though Open Data is free, effort has to be done to utilise this data. As organisations have limited resources, the lack of (willingness to make) time to utilise OD can also be a possible explanation for the low penetration rate of OD in EAM.

The last barrier is the quality of the OD. As the quality of external data is more difficult to monitor than internal data (Hodkiewicz, Kelly, Sikorska, & Gouws, 2006), using external data can introduce risk for organisations.

Some other barriers, according to Janssen et al. (2012), are; the lack of capabilities to use data, the lack of time to use data and the unwillingness of open data providers to accept user input in organizations. On the provider side there are also factors that negatively influence the willingness to share valuable data. So are the trade-off between transparency and privacy, the lack of a direct award from opening up data and the risk adverse culture of government institutions reasons for governments to share only the information that is not of direct value.

So even though Open Data can be promising, the use of it not automatically leads to creation of more value, as the assumption that more data leads to better decisions is not always justifiable. To be able to create value more information about Engineering Asset Management and issues with regard to the use of Open Data is needed.

1.3 System of Interest

The field of Engineering Asset Management in combination with Open Data is the System of interest. The data providers (such as (national) governments and open data initiatives) and Engineering Asset Management organizations (such as governments, road authorities and contractors) are important actors in the system. These actors are involved in different activities that altogether can lead to the creation of value through more informed decision making with the use of Open Data. The missing link between the data providers and the EAM organizations is a a well-functioning information system, which forms the bridge between the providers of open data and the EAM organizations that can benefit from this open data. Figure 2 shows a visual representation of this system. As an example, a system with Rijkswaterstaat (Duch road autority) as EAM organisation and KNMI (Dutch meteorologic institute) is displayed, where Rijkswaterstaat uses the weather data from the KNMI to estimate the wear of roads, as the weather can influence the road usage and temperature differences can lead to cracks in asphalt layers.

Currently there is no integration and collaboration between the OD providers and the data using organisations. The actors in the system all have their own interests and act upon these interests. In such a system, the outcome of negotiations between these actors do not always leads to the highest possible social outcome. To refer to the earlier example, when Rijkswaterstaat has influence on the locations and the frequency in which the KNMI gathers and publish weather data the data is probably more useful than the monthly published data that is available right now.

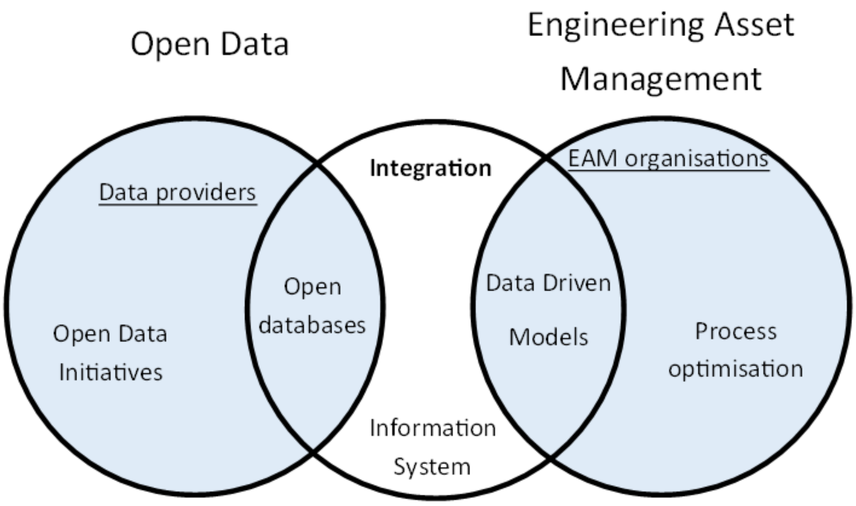


Figure 2: System representation

1.4 Knowledge Gap

Although the use of Open Data in Engineering Asset Management seems promising, its use in EAM is very limited. Because of the possible (societal) benefits it seems to offer, it is interesting to research if the use of Open Data can indeed lead to higher social value and so yes, under which boundary conditions this can be the case.

While there is vast literature about the benefits and the barriers of the use of OD in general and about EAM, there is very limited literature about the potential benefits and the use of OD in an EAM context.

As the use of OD is social relevant as OD can lead to value creation for the community, the goal of this master thesis is to investigate the possibilities to use OD in an EAM context and to find out if and under which boundary conditions the use of OD in EAM can be beneficial.

2 Research Approach

In this chapter the research approach is presented. The research approach will explain what steps are necessary to fill the knowledge gap presented in chapter 1. The main functions of a research approach are; to develop a plan to take the various steps of the research and to ensure validity, reliability, and authenticity in each step of the research (Kirshenblatt-Gimblett & Barbara, 2006). Section 2.1 presents the research questions and section 2.2 shows the research outline.

2.1 Research Questions and Design

2.1.1 Main Research Question

The main goal of this research is to find out if the use of Open Data in EAM can lead to a creation of value and so yes under which boundary conditions that is the case.

Under which boundary conditions is it possible to create value using Open Data in Engineering Asset Management?

2.1.2 Sub-Questions

1. *What factors in Engineering Asset Management influence Data-Driven Decision Making using Open Data?*

Methodology: Systematic Literature Review.
Data Gathering: Desktop research.
Thesis Chapter: Chapter 3: *"What factors influence the use of Open Data in EAM?"*

A literature review will be used to gather all the known information about the core concepts to create a starting point for the research. By conceptualizing the definitions and the relations between the definitions, a conceptual model can be formed.

2. *What factors enable and hinder data driven decision making in a real life case of using open data in an EAM context?*

Methodology: Case Study Research.
Data Gathering: Document Analysis, Interviews.
Thesis Chapter: Chapter 4: *"Case study research into OD in EAM."*

A case study will be conducted in which the effect of the use of Open Data in a specific EAM case will be evaluated. The goal of the case study is to identify case specific barriers and benefits to generate insights in how the process of using Open Data in a real world situation will function. With the insights from the case study, the conceptual model will be updated in a refined and empirically-enhanced model.

3. *What are stakeholder perceptions on enablers, barriers and success factors of using Open Data in Engineering Asset Management?*

Methodology: Expert / stakeholder group review session.
Data Gathering: Workshop session.
Thesis Chapter: Chapter 5: *"The stakeholder perspective on OD in EAM".*

Expert interviews or review groups are a good way to gather "insider knowledge", knowledge that is known by the people working in that specific field but often not made explicit in written format (Bogner, Littig, & Menz, 2009). Using the knowledge from experts is a good way to avoid time consuming data gathering by observation in the field.

The information from the expert group session will be used to update the refined model to the definitive model and it can provide useful insights about the stake-holder perspective.

2.2 Research Outline

As an overview a Research Flow Diagram is included (figure 3). This diagram shows how the questions are related to the research steps and the research methods. In the last column the thesis chapter in which research steps will be reported is shown. Appendix A contains the research planning.

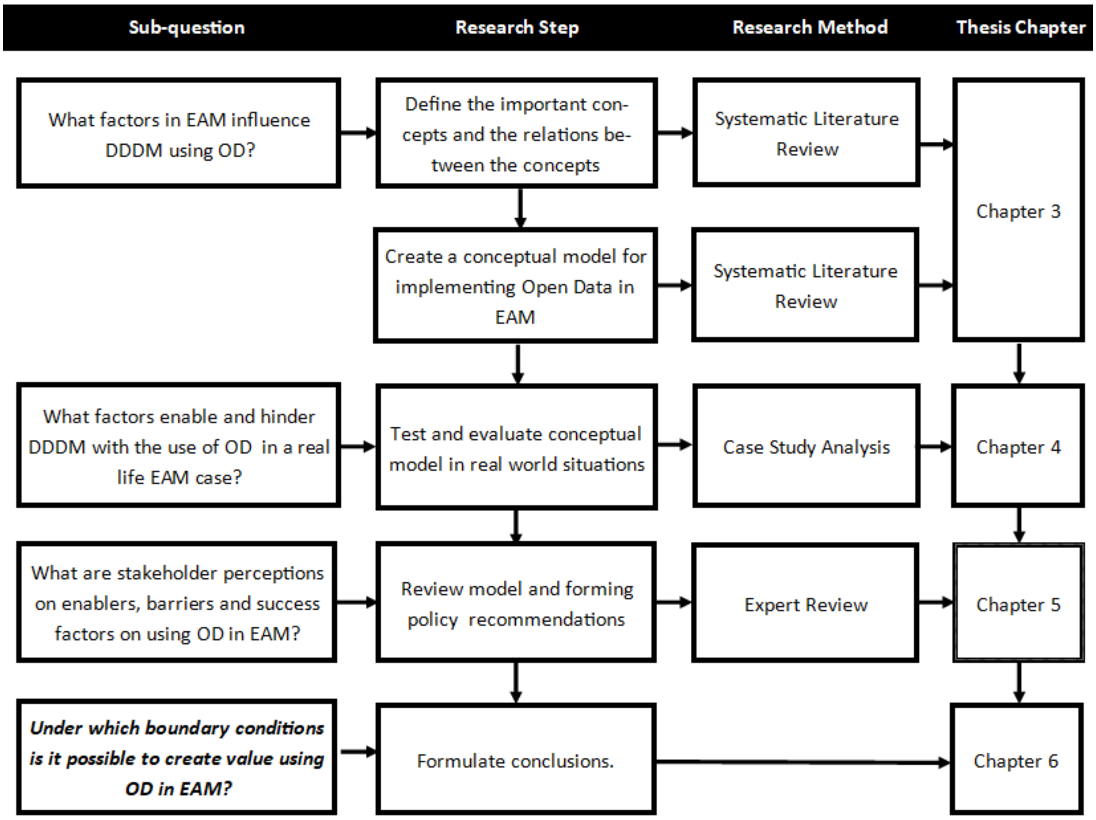


Figure 3: Research Flow Diagram

3 Scientific background on complexity, enablers and barriers of Open Data in Engineering Asset Management

3.1 Introduction

From the Research Approach presented in chapter 2 it is concluded that four sub-questions need to be answered. In this chapter the first sub-question that is; *"What factors in Engineering Asset Management influence Data-Driven Decision Making using Open Data?"* will be answered.

The main goal is to obtain a clear idea of what knowledge about OD in an AEM context is available in the academic literature and how this knowledge can be used for for the rest of the research. To find this academic literature, a Systematic Literature Review (SLR) will be conducted. To answer the sub-question the SLR will start by defining the core concepts such as *Engineering Asset Management*, *Open Data*, *Data Driven Decision Making* and *Data Quality* before diving in to the relations between these concepts.

In section 3.2 the SLR approach is explained. Section 3.3 presents the outcomes of the SLR and section 3.4 concludes the chapter with a conclusion in the format of a conceptual model.

3.2 Systematic Literature Review Approach

As mentioned before, the SLR has a more rigid format than a traditional literature review (in which the author select papers that suits the research interests) (Petticrew & Roberts, 2008). The main difference is that it provides clear understanding of how / why articles are selected and it makes the process of replication of the study easier. Although it still remains difficult because of the search algorithms of the used search engines.

As for every research method, an approach is needed for conducting a Systematic Literature Review. For this SLR, a combination of the methods as described by Kitchenham et al. (2009), Levy and Ellis (2006) and Webster and Watson (2002) is used. The approach mentioned by Kitchenham et al. (2009) is commonly used for conducting SLR's in the academic field, so that the step wise approach serves as basis for the SLR (supplemented with additives from the other approaches).

The first step is to define the literature search questions and keywords that are related with those questions (3.2.1). To make a selection from the articles found with those keywords a quality assessment / selection protocol is needed (described in 3.2.2). From the selected articles the main findings are reported (especially the differences with similar research) (3.2.3). The last step is to formulate answers on the literature review questions, with the use of the reported findings (3.2.4).

3.2.1 Literature Search Questions and Keywords

The creation of search questions is an important part of the SLR because without good questions interesting literature cannot found (Levy & Ellis, 2006). Therefore, questions used in this SLR can be alternated during the process, making the SLR less rigid but still repeaTable afterwards.

The first search for literature related to the research question was found by using the keywords *Asset Management* and *Open Data*; during the process the term *Asset Management* was extended to *Engineering Asset Management* to prevent findings of financial Asset Management literature. The search-term *Data Quality* was added after finding the close link between *Open Data* and *Data Quality*. In the end of the SLR the search term *Data Driven Decision Making* was added to focus on literature about DDDM. The following literature search questions and associated keywords are used:

1. What are useful definitions of the core concepts; *Engineering Asset Management*, *Open Data* and *Data Quality* and *Data Driven Decision Making*?
   Keywords: ("Engineering Asset Management", "Open Data", "Data Quality", "Data Driven Decision Making) AND "definition".

2. How is data currently used in Engineering Asset Management?
   Keywords: "Engineering Asset Management" AND "(Open) Data"

3. How is Data Quality measured in Engineering Asset Management?
   Keywords: "Engineering Asset Management" AND "Data Quality".

4. How is Data-Driven Decision Making (DDDM) related to Engineering Asset Management (EAM) or Integrated Asset Management (IAM)?
   Keywords: "Data-Driven Decision Making" AND "Asset Management".

3.2.2 Quality Assessment

A selection needs to be made from all the articles that are found using the above mentioned questions because the amount of articles found is too large to review. A protocol for selecting articles is created as advised by Kitchenham (2004). When the protocol is too *"strict"*, there is a chance that useful literature will be excluded. On the contrary, when the protocol is too *"lose"*, the literature review will have the same outcomes as a non-systematic approach. To prevent both, the selection rules are to prevent non-scientific articles to be included and some extra rules are there to make sure selected articles are useful in the review with the use of exclusion rules. In this literature review articles are only be selected when:

- The article title and abstract seem to indicate that the article is closely related to the main topic or one of the search questions.
- The article is peer-reviewed.
- The article is published in a scientific journal or in scientific conference proceedings.

Selected articles are excluded from the research when:

- A revised article is available (outdated).
- The article is from an organization that is not independent (the research is clearly sponsored by an organization that gets benefit from a specific outcome of the research).

When articles are selected for the SLR, a second step is taken; The *Backwards Snowballing Method* (BSM) as explained by Streeton, Cooke, and Campbell (2004). The BSM creates the opportunity to find literature that have been referred to in the main selection of articles. By using the BSM, interesting articles from literature lists from the reviewed articles can be added to the literature review. Although this makes the SLR less strict and more difficult to duplicate, it provides the advantage of finding more relevant information for the research (Beauchemin & González-Ferrer, 2011). The selection criteria for articles found with the use of BSM is the same as for articles found with the search questions.

3.2.3 Processing the literature

The goal of the SLR is to give an overview of the existing literature, and the next step is to summarize the main contributions to the topic from all articles. A Table is created that has in each row one article and each column represents a specific concept of that article (Levy & Ellis, 2006). The Table gives an overview of the research field, the research topic and the used research method.

3.2.4 Defining relevant concepts

With the use of information given in the Table, the relevant concepts and the relations between those concepts can be defined in the processing step. This part of the SLR presents in a textual way the findings of the literature study.

3.3 Conducting the Systematic Literature Review

The Systematic Literature Review was conducted from March 10, 2020 to April 10, 2020. Articles published after April 10, 2020, are therefore not included in this SLR. For the SLR, the search engines of *Google Scholar* and *Scopus* are used.

In total 30 articles are selected for the literature review. All articles are either published in scientific journals or they are the proceedings of scientific conferences. Table 1 provides an overview of the academic sources of the literature used in this SLR. As it is shown in Table 1, the sources are very diverse. This explains the fact that this research is multi-disciplinary, but it can also be a sign that there is no common place were research about the topic of open data in EAM is published.

Table 1: Scientific sources of selected studies in the SLR.

Source	**Articles**
Scientific Journals	*18*
ACM computing surveys	1
Automation in Construction	1
Definitions, concepts and scope of engineering asset management	1
Engineering, Construction and Architectural Management	1
Engineering Asset Management Review	2
Government Information Quarterly	1
International Journal of Electronic Business Management	1
International Journal of Information Quality	1
International Journal of Operations and Production Management	1
International Journal of Production Economics	1
International Journal of the Commons	1
Journal of Computing in Civil Engineering	1
Journal of Management Information Systems	1
Journal of Quality in Maintenance Engineering	2
Structure and Infrastructure Engineering	1
Topics in Safety, Risk, Reliability and Quality	1
Scientific Conferences Proceedings	*12*
Annual Industrial Organization Conference	1
Asia-Pacific Vibration Conference	1
Conference on Enterprise Information Systems	1
Construction Research Congress	1
International Conference on Electronic Government	1
International Conference on Vibration Engineering and Technology of Machinery's	1
World Congress on Engineering Asset Management	5
World Congress on Engineering Asset Management and Intelligent Maintenance Systems	1
Total Articles	*30*

Section 3.3.1 covers the processing step, with the academic articles summarized in a Table. The next section, section 3.3.2 provides definitions for the

core concepts of this thesis and section 3.3.3 describes the relations between those concepts.

3.3.1 Processing the Literature

During the process of searching and processing the literature a Table was created with the papers and their field of research, research topic, research approach and relevance to this research (Table 2). As described by Levy and Ellis (2006), this Table provides a good basis for the literature review.

Table 2: SLR Table

Article	Topic	Research Goal	Methodology	EAM	OD	DQ	DDDM
(Amadi-Echendu et al., 2010)	What is EAM?	Characterise the subject matter of EAM more clearly.	Literature review.	X			
(Batini, Cappiello, Francalanci, & Maurino, 2009)	Data Quality Improvement.	Providing a systematic and comparative description of methodologies that help the selection, customization, and application of data quality assessment and improvement techniques.	Literature Review.			X	X
(Brous et al., 2016)	Decision making in data management.	Defining the principles of data governance and advances the knowledge base of data governance.	Systematic literature review.		X	X	X
(Brown et al., 2014)	Strategic Asset Management.	Research on identifying and analysing the elements of Strategic Management for infrastructure and engineering assets and asks: what are the considerations and implications for adopting and implementing an integrated strategic asset management framework?.	Literature Review.	X		X	X
(Brynjolfsson et al., 2011)	Data Driven Decision Making.	Examining whether firms that emphasize decision making based on data and data driven decision making show higher performance.	Case Study Research.				X
(Dahl, Horman, Pohlman, & Pulaski, 2005)	Design Build Operate Maintain Cycle.	Defining the DBOM delivery system and exploring the benefits of DBOM, investigates the ability of DBOM to achieve important sustainable initiatives.	Literature review.	X			
(El-Akruti & Dwight, 2013)	Framework for EAM system.	Including the role of AM in the organizational strategy making and how this is maintained by the AM system activities, relationships and mechanisms over the asset-related activities of an organization.	Review of existing literature and frameworks.	X			

(El-Akruti, Dwight, & Zhang, 2013)	Strategic Role of EAM.	Exploring the AM system′s position within an organizational structure and its role in competitive strategy.	Case study approach to facilitate theory building.	X			
(Frolov, Mengel, Bandara, Sun, & Ma, 2010)	Ontology and Process Architecture for EAM.	Creating an Ontology and as side product a Process Architecture for EAM.	Text analysis, definition and classification of terms and visualisation through an appropriate tool.	X			
(Halfawy, 2008)	Integrated Asset Management.	Discussing the main challenges for implementing integrated municipal infrastructure management environments, and proposes specific solutions to address these challenges.	Design Approach.	X			
(Haider, 2015)	Asset Life-cycle Data Governance Framework.	Sketching out a framework for asset life-cycle management data governance, which highlights the rights and accountability's related to asset data life-cycle management.	Literature review.	X		X	
(Heaton et al., 2019)	Asset Information Requirements.	Defining a top-down methodology that utilises Building Information Modelling to support the development of Asset Information Requirements.	Case study approach and Expert Interviews.	X			
(Hofmokl, 2010)	Internet of Things.	Creating an eclectic theoretical framework.	Empirical analysis.		X		
(Janssen et al., 2012)	Open Government Data.	Deriving the benefits and adoption barriers for open data.	Exploratory, Literature review, Interviews and work-groups.		X	X	
(Khuntia, Rueda, & van der Meijden, 2019)	Big data and Asset Management.	Answering challenges by pathways and guidelines to make the current asset management practices smarter for the future.	Literature review.	X	X		X
(Lin, Gao, & Koronios, 2006)	Data Quality Issues in EAM	Presenting the DQ issues which emerged from a number of asset management processes.	Case studies in real world companies.	X		X	
(Lin et al., 2007)	Data Quality Framework for EAM.	Developing a Data Quality Framework for Asset Management in Engineering organizations.	Nation Wide Data Quality Survey.	X		X	

(Ma, 2007)	Condition Monitoring in EAM.	Discussing new directions of research and application of Condition Monitoring Technology in EAM.	Review of existing literature.	X			X
(Murthy, Atrens, & Eccleston, 2002)	Strategic Maintenance Management.	Outlining the Strategic maintenance management (SMM) approach and it's contrast with current approaches.	Literature Review.	X			
(Nastasie, Koronios, & Haider, 2010).	Integrated Asset Management.	Providing a comprehensive review of standards relevant to the integration of asset management systems.	Review of standards.	X			
(Nikiforova & Bicevskis, 2019)	Data Quality.	Proposing a new data object-driven approach to data quality evaluation (renewed version of the research).	Design Approach.			X	X
(Schuman & Brent, 2005)	Asset Life Cycle Management	Improving physical asset performance in the process industry.	Case Study Approach	X		X	
(Spatari & Aktan, 2013)	Asset Management in Civil Engineering.	Defining the complexity of Civil Engineering Asset Management.	Cymposium and Literature Review.	X			
(Too, 2010)	Strategic Asset Management	Reviewing the goals of infrastructure asset management and identifying the core processes of infrastructure asset management.	Multiple case study design	X			
(Tywoniak, Rosqvist, Mardiasmo, & Kivits, 2009)	Fleet Asset Management as part of EAM.	Investigate how engineering and governance perspectives can be reconciled and integrated to enable optimal asset and organizational performance in the context of asset fleets.	Existing literature review.	X			
(Urmetzer, Parlikad, Pearson, & Neely, 2015)	Asset Management Systems.	Defining key considerations to improve approaches to the design of asset management systems.	Series of interviews with asset managers in companies.	X			
(Vetrò et al., 2016)	Open Government Data Data Quality.	Defining an open data quality measurement framework.	Case Study Approach.		X	X	
(Wang & Strong, 1996)	Data Quality	Developing a framework that captures the aspects of data quality that are important to data consumers.	2-Stage Survey and Sorting Study			X	

(Woodall, Gao, Parlikad, & Koronios, 2015)	Data Quality issues in EAM organizations.	Presenting a classification of the most important DQ problems that need to be tackled by asset management organizations.	Literature review in combination with semi-structured expert interviews.	X	X
(Wu et al., 2006)	Life Cycle Asset Management.	Showing that reliability analysis and its implementation will lead to an improved whole life performance of the building systems, and hence their life cycle costs (LCC).	Questionnaires in the industry.	X	

3.3.2 Core Concepts

This research is covering the core concepts of the field of Engineering Asset Management and the field of (Open) Data. The concepts of Engineering Asset Management, Open Data and Data Quality are defined in sections below. For every concept a Table with an overview of the different definitions mentioned in academic literature is presented.

Table 3: Definitions of Engineering Asset Management

Article	Definitions
(Amadi-Echendu et al., 2010).	I) EAM is the total management of physical assets [p. 4]. II) Engineering Asset Management is the management of the economic value of engineering assets. [p. 4] III) Engineering objects, the things that are managed by engineering asset managers exist independently of any contract [p. 8].
(Dahl et al., 2005).	EAM exists in the whole lifetime of an asset, which consists of the following lifecycle steps: Design, Build, Maintain, Operate and Demolish [p. 2].
(Spatari & Aktan, 2013).	I) EAM is focused on the management of physical assets such as large infrastructures and other buildings [p. 2]. II) Effective Asset Performance Management (APM) tries to optimize reliability and availability of physical assets while minimizing risk and operating cost [p. 3].
(Tywoniak et al., 2009)	I) Classical Engineering Asset Management only focuses on the operational performance of assets [p. 1553]. II) (Engineering) Asset management (should) focus on the sustainability and improvement of the profitability and the asset value [p. 1555].
(Wu et al., 2006).	EAM is the management process concerned with lowering the Life Cycle Cost of Engineering Objects [p. 144].

Engineering Asset Management: As for many complex terms, there is no single definition of Engineering Asset Management. An overview of the definitions found in academic literature is shown in Table 3. The reason for using the term Engineering Asset Management instead of solely Asset Management is that Asset Management is often related with financial assets where Engineering Asset Management is focused on the management of physical assets such as large infrastructures and other buildings (Spatari & Aktan, 2013).

Amadi-Echendu et al. (2010) define Engineering Asset Management in their paper as: *"the total management of physical, as opposed to financial, assets."* (Amadi-Echendu et al., 2010, p. 4). An important note to their definition is that although EAM is not about the management of financial assets, it does not imply that the financial component of physical assets is not part of EAM.

According to Spatari and Aktan (2013)), Effective Asset Performance Management (APM) tries to optimize reliability and availability of physical assets while minimizing risk and operating costs (Spatari & Aktan, 2013). Engineering Asset Management exists in the whole lifetime of an asset, which consists of the following lifecycle steps: Design, Build, Maintain, Operate and Demolish (Dahl et al., 2005).

As research conducted by Wu et al. (2006) shows, reliability management during the whole life cycle leads to better performance of Engineering Asset Management. With the right information available it is possible to get the lowest Life Cycle Costs (LCC). As Figure 4 shows, there is an optimum (lowest LCC) somewhere between assets with low acquisition costs, but high maintenance costs and assets with high acquisition costs but low maintenance costs. The aim of asset managers is to design and maintain assets in such a way that the LCC are kept as low as possible, while still keeping the asset in a condition that it performs at the required level.

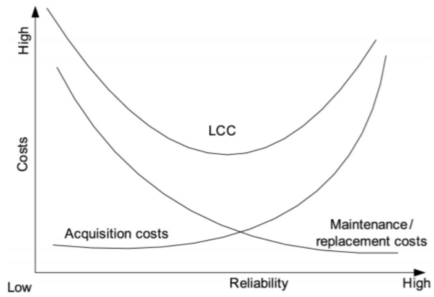


Figure 4: Relationship between reliability and costs in EAM (Wu et al., 2006).

According to Tywoniak et al. (2009) all the definitions of EAM presented so far are too restricted, because they do not take the governance (or business) aspect into account. EAM often focuses on optimizing life cycle costs but not on the business function of the assets. As they state: *"Asset fleets provide a relevant and important context to investigate the interaction between engineering and governance views on asset management..."* (Tywoniak et al., 2009, p.1). Therefore, Asset Management should not only focus on the operational performance but also on the sustainability and profitability of the value of the assets. For engineering assets this means that not only the condition of the asset has to be managed but also the function of the asset has to be monitored closely.

The definition that is used in this research is a combination of all the definitions found during the literature review. In this research, Engineering Asset Management (EAM) is: *The management of physical assets during their whole life-cycle, with the focus on optimizing reliability and availability when minimizing costs and optimizing the sustainability and profitability of the assets.*

EAM places emphases on making the engineering assets cost effective and maintain those assets through governance of EAM. The definition selected for this research is already a bit broader, including the functionality of the asset. Asset managers have specific interests in managing assets that are not fully in line with how society would make decisions (Brown et al., 2014). As payment structures are often rigid, decisions that would benefit society (such as inventions that lead to less traffic disruption on highways), but that not lead to higher payments from the road owner (Rijkswaterstaat) to the road contractor will not be taken even if the benefits from society are larger than the costs for the road contractor. The complicated governance structure which involves different organizations with different stakes does not leave room for new prospects.

Open Data: It is noTable that a clear definition of Open Data is difficult to find in academic literature. That is why, other research work such as Vetrò et al. (2016) refers to the web definition of (Open Knowledge Group, n.d.) as basis for defining their Open Data Quality Framework. In this framework they presented guidelines on how to measure the quality of Open Data.

Definition from Open Knowledge Group (n.d.) is the following: *"Open Data is data and content that can be freely used, modified, and shared by anyone for any purpose"*. This definition is in line with other web references, such as the definition of The European Data Portal that describes Open Data as:

"Data that anyone can access, use and share. Governments, businesses and individuals can use open data to bring about social, economic and environmental benefits." (European Data Portal, n.d.).

All of these definitions cover the open part of open data, and a definition of data is still missing. A common used definition that covers the term quite extensive is given by The Royal Society, p. 12 (2012), which states that data is: *"qualitative or quantitative statements or numbers that are (or assumed tot be) factual. Data may be raw or primary data (i.e. direct from measurement), or derivative of primary data, but are not yet the product of analysis or interpretation other than calculation".*

Open data is characterized both by a legal and a technical point of view and by lower restrictions applied to their circulation and reuse (Vetrò et al., 2016). According to Hofmokl (2010), this characteristic allows open data to initiate collaboration, creativity and innovation.

The definition of open data used in this research is the definition of the Open Knowledge Group (n.d.): *Open data is data and content that can be freely used, modified, and shared by anyone for any purpose* as this definition covers all aspects of *"opines"* and is therefore a useful definition for this research.

Table 4: Definitions of (Open) Data

Article	Definitions
(Hofmokl, 2010).	Open data is data that is widely available with the goal of initiating collaboration, creativity and innovation [p. 241].
(Open Knowledge Group, n.d.).	Open data is data and content that can be freely used, modified, and shared by anyone for any purpose [Internet page].
(Vetrò et al., 2016).	Open data is characterized by lower restrictions applied to their circulation and reuse [p. 325].

Data Driven Decision Making: The most commonly accepted definition of "Data Driven Decision Making" (DDDM) is that with DDDM, decisions are automatically made by a (self-learning) machine (Brynjolfsson et al., 2011). As DDDM is purely based on data, and not on the subjective thoughts of humans, decisions are always objective. This can be very beneficial when the decisions are based on the right data, but also risky when the data is faulty or the quality of the data is not high enough. Decisions with high complexity are often made by humans because it is difficult to include all parameters of the decision in a model when the complexity of the decision is to high. DDDM is therefore most effective when decisions are not straight foreword but not too complex to describe the decision parameters clearly (Brynjolfsson et al., 2011).

Brynjolfsson et al. (2011) have concluded in their case study that DDDM leads to higher productivity and in most cases also to higher profitably. That is in line with the mainstream decision theory, which argues that decisions based on objective measurable facts are better than decisions that are based on subjective ideas. Although DDDM can lead to better results, this is only the case when the decisions are based on accurate, high quality data (Nikiforova & Bicevskis, 2019).

Table 5: Definitions of Data Quality

Article	Definitions
(Lin et al., 2007).	I) The four most frequently mentioned Data Quality dimensions in the literature are accuracy, completeness, timeliness and consistency [p. 103]. II) Maintaining data quality in EAM requires good data management [p. 104].
(Wang & Strong, 1996).	Quality data are data that are fit for use by the data consumer [p. 6].

Data Quality: Through the past decades several researchers have tried to define Data Quality, where most of the research is focused on dimensions from an accuracy point of view (Lin et al., 2007). Although accuracy is the most obvious dimension of data, high accurate data does not always make the data useful for its purpose. Wang and Strong, who also have tried to define the dimensions of data quality, came in 1996 with a broader definition that is still used nowadays: *"Quality data are data that are fit for use by the data consumer"* (Wang & Strong, 1996). An overview of those definitions is presented in Table 5.

To be able to evaluate the quality of a certain data set, the quality requirements have to be specified. This is often difficult and problematic because it is hard to define what minimal quality is required. Having a clear definition of "Data Quality" is therefore important starting point. There are dozens of researchers that have tried to capture the term "data quality" in different dimensions to quantify what data quality actually means. The literature review by (Batini et al., 2009) shows that the chosen dimensions by different researchers share some common grounds. In this thesis the dimensions of data quality that will be use are presented in Table 6, as these dimensions are the most commonly used dimensions of data quality (Batini et al., 2009).

Table 6: Dimensions of Data Quality

Dimension	Definition	Subdivisions / explanation
Accuracy	"the extent to which data are correct, reliable and certified" (Wang & Strong, 1996).	I) Semantic accuracy: How close is the stored value to the real word value? II) Syntactic accuracy: How close is the data to an expecTable value in the data set (for example the value 1.87m is not syntactic accurate for the data point address of a person).
Completeness	"The degree to which a given data collection includes data describing the corresponding set of real-world objects" (Batini et al., 2009).	The amount of "missing values" in a data set.
Consistency	"The violation of semantic rules defined over a set of data items" (Batini et al., 2009).	I) Inter-relation constrains: The range of possible values for a data point. II) Intra-relation constrains: The range of possible values because of the value of another data point of the same object.
Time-related Dimensions: Currency, Volatility, and Timeliness.	All related to the update time of data.	Currency: Currency is the degree to which data is up-to date (Redman, 1996). Volatility: A measure of information instability, the frequency of change of the value for an entity attribute. (Bovee, Srivastava, & Mak, 2003). Timeliness: The average age of the data in a source. (Naumann, 2003).

3.3.3 Towards a Conceptual Model

After defining the important concept for the study, a more refined analysis of the selected papers is undertaken to develop the conceptual model.

Integrated Asset Management: Asset management in general is a complex task as the lack of complete knowledge about the assets and the long lasting impacts that decisions about those assets have. Especially the asset management of large physical infrastructures is difficult and therefore often poorly executed (Spatari & Aktan, 2013). Instead of viewing parts of asset management as non-connected parts, EAM needs A *"whole-systems approach"* - an approach in which the different aspects of EAM and there relations are closely watched - to the currently piece wise manner in which we plan, finance, construct, operate and maintain our infrastructures according to (Spatari & Aktan, 2013, p. 2).

These findings are in line with the findings of Halfawy (2008), who concluded that there is a need for an integrated asset management approach. Although there are differences in the exact formulations, in the past decade it became clear that there is a need for an integrated process for physical asset management (Halfawy, 2008; Too, 2010; Spatari & Aktan, 2013).

Murthy et al. (2002) were one of the first to mention the importance of a maintenance management system (MMS). Since the performance of an asset largely depends on the quality of the asset, it is important to know when to perform maintenance on the asset. In recent years, more often the breakdown of crucial assets such as bridges appear in the news (Spatari & Aktan, 2013). In such situations, it is clear that maintenance has not been conducted on time.

As for Schuman and Brent (2005), Integrated Asset Management (IAM) is concerned with making the right choices at the right moments to generate the highest possible value from Engineering Assets. To make the right decisions for the creation of value, not only the long-term life cycle costs need to be taken into consideration but the short term governance perspective, focusing on how well an asset performs during a specific time (normally a book-year), need to be taken into account as circumstances change over time and short-term tuning can create the right adjustments to these changes. A combination of a good short-term management and a solid long-term vision is important to generate the higher value with Engineering Assets (Tywoniak et al., 2009).

The challenges that come with implementing IAM are: processes have to be coordinated, data and software has to be integrated in the processes (Halfawy, 2008), different business activities have to be linked (Murthy et al., 2002) and there has to be a continuing process of asset management (Too, 2010). These challenges make the adoption and advancement of asset management in organizations normally a slow process.

To make IAM successful in EAM organizations, it is important to view IAM strategically. There is a clear understanding of steps that are required for EAM (Too, 2010). This four steps are: I) To create alignment of assets and operations with corporate objectives, asset management is about managing the trade-offs between the functional and the financial performance in such a way that value is created for the stakeholders. II) To create a link between decision making and information, as asset information is crucial to be able to make these trade-offs. III) To keep asset life cycle costs as low as possible in the process. IV) To have understanding about the processes and activities that are related to the assets because these are the creators of value for stakeholders.

Data is a crucial part of these four steps and it is therefore important that data is collected and managed in a systematic way, so that the data is available and well-structured when needed to make EAM decisions (Murthy et al., 2002). In Table 7, an overview of the reviewed articles and their notions about the importance, challenges and guidelines about IAM are presented.

EAM System: Since 2014, the ISO 55000:2014 standard for asset management defines an asset management system (AMS) as: *"...a set of interrelated or interacting elements to establish asset management policy, asset management objectives and processes to achieve those objectives"* (Urmetzer et al., 2015).

El-Akruti et al. (2013) argued that the link between physical assets and the organizational strategy has not been thoroughly studied. In another paper published later in the same year El-Akruti and Dwight (2013) presented a framework for an Engineering Asset Management System. This framework visualized the main tasks of a good functioning integrated asset management system, linking the physical and the strategical aspects of the Engineering Asset. The framework consists of six main processes (I) Decision Making, II) Coordination planning, III) Work Task Control, IV) Measurement Monitoring, V) Control Reporting and Analysis and Evaluation), in which each process delivers input for the next process. In a well-functioning EAM system, all those processes are (somehow) linked and a more integrated approach will be most beneficial.

Steps towards standardization of standards in EAM could help to integrate such processes (Koronios, Nastasie, Chanana, & Haider, 2007). In their review

Table 7: Integrated Asset Management

Article	Importance	Challenges	Guidelines
(Halfawy, 2008).	"adopting integrated multidisciplinary approaches is a key requirement for implementing efficient, sustainable, and proactive asset management programs"	I) the process systematization and coordination challenge; II) the data integration challenge; and III) the software integration challenge.	
(Murthy et al., 2002).	I) Maintenance Management is a vital core business activity vital for survival and success of the business. II) Maintenance decisions should be integrated with other strategic decision making.	Linking the different business activities closely together.	Good data collection and data management system.
(Spatari & Aktan, 2013).	A whole-systems approach to the currently piece wise manner in which we plan, finance, construct, operate and maintain our infrastructures, would be highly beneficial to the long-term performance of civil engineering assets.		
(Too, 2010).		I) The adoption and advancement of asset management is found in the 'step child' status that is often bestowed upon asset management groups within organizations. II) The contentious state of what constitutes asset management.	I) Asset management needs to be viewed from a strategic approach in order to create value to the organization. II) There is a need for a clear understanding of what asset management is.
(Tywoniak et al., 2009).	Viewing EAM as a combination of the operational performance of an asset over its lifetime (long-term) and the short term governance problem of optimizing the usability of the asset is essential for optimizing the profitability of an engineering asset.	Integrating two different visions on EAM that normally take each other for granted.	Showing the importance of taking both visions into consideration by engaging stakeholders in the process.

of international and national standards used in the industry, Koronios et al. (2007) show an increasing use of the same international standards over the years.

Data and Information in EAM: As noted in the Integrated Asset Management paragraph and visible in the EAM Framework of El-Akruti and Dwight (2013), data is crucial in the engineering asset management process. There is consensus in the academic literature that because of the complexity and the versatility of EAM processes, this integration of data is not easy to accomplish (El-Akruti & Dwight, 2013; Haider, 2015; Woodall et al., 2015).

In the paper *"Smart Asset Management for Electric Utilities: Big Data and Future"* written by Khuntia et al. (2019), the function of data-driven decision making in predictive maintenance is explained. With the rise of "smart" tools for condition monitoring of assets, the amount of data that is available about the condition of assets is growing exponentially, and with data-driven decision making this can help in decision making about maintenance plans. According to Khuntia et al. (2019) there are four major challenges that Big (and Open) Data can play an important role in: I) the quantity issue, II) the data flow issue, III) the accuracy issue and IV) the diversity issue. The rise of Big Data and Open Data can increase the quantity of available data and thereby help to overcome the problem of having not enough data (quantity issue). The second challenge is the data flow. Most models require a constant stream of input so it is important that data is delivered with constant time intervals. Open Data sources can be used to deliver this data, but when the Open Data source is suddenly not working anymore, it can deliver problems as the data flow will be interrupted. The accuracy issue is about the quality of the data. As measurements can be deviate from there real world values or even be totally wrong, data is not always reliable. For modelling purposes, it is important that the data is trustworthy so that the model will not use wrong inputs. The last issue is the diversity issue. As more and more "things" are interconnected (known as the Internet-of-Things), more diversity in sources of data, more kind of data sources are becoming available. To be able to use these different types of data, the model has to be able to deal with all the kind of data inputs.

The main data issue in EAM - according to Heaton et al. (2019) - is: *"The fundamental lack of understanding of what information should be collected to support the efficient management of assets throughout their life."* (Heaton et al., 2019, p. 1). In the paper they proposed an information management relationship framework (Figure 5).

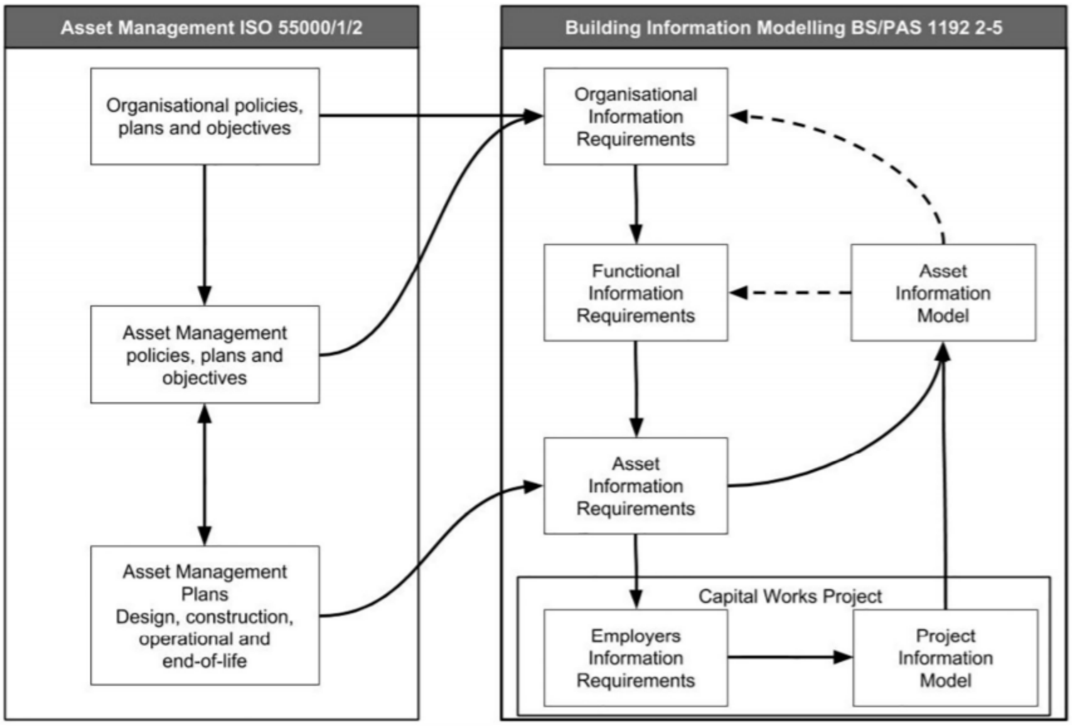


Figure 5: Information Management Relationships in EAM (Heaton et al., 2019).

In this framework (Figure 5) the relations between Asset Management (AM) and Building Information Modeling (BIM) are visualised. On the left side the AM goals of the organisation, the policies and plans that are the result of this goals and the plans for design construction operation and end-of-life phases of assets are shown. On the BIM side there are three types of information requirements: organisational information requirements (the result of the organisational policies, plans and objectives at the AM side), functional information requirements (the result of the organisational requirements), asset information requirements (the result of the functional information requirements and the AM plans, design, construction and end-of-life phases of assets at the AM side). The asset information requirements are the input for the asset information model, in combination with specific project information (coming from the project information model). All in all it shows that the way the asset information is modelled has to be a result of the objectives of the organisation. An asset management model therefore has to be seen as an integral part of an EAM organisation.

Open Data Governance Many public organizations store and analyze large amounts of data, and this data can have societal benefits as it can enable organizations to improve their decision making (Brous et al., 2016). "With data governance, companies implement corporate-wide accountabilities for Data Quality Management (DQM) that encompass professionals from both business and IT" (Wende, 2007, p417). From a public point of view, there are four important formal goals according to Brous et al. (2016); I) to enable better decision making, II) to ensure compliance, III) to increase business efficiency and effectiveness, IV) to support business integration. There are four essential principles that need to get enough attention to make data governance work; Organization, alignment, compliance and common understanding. These four principles are further divided into smaller data governance goals (see Figure 6).

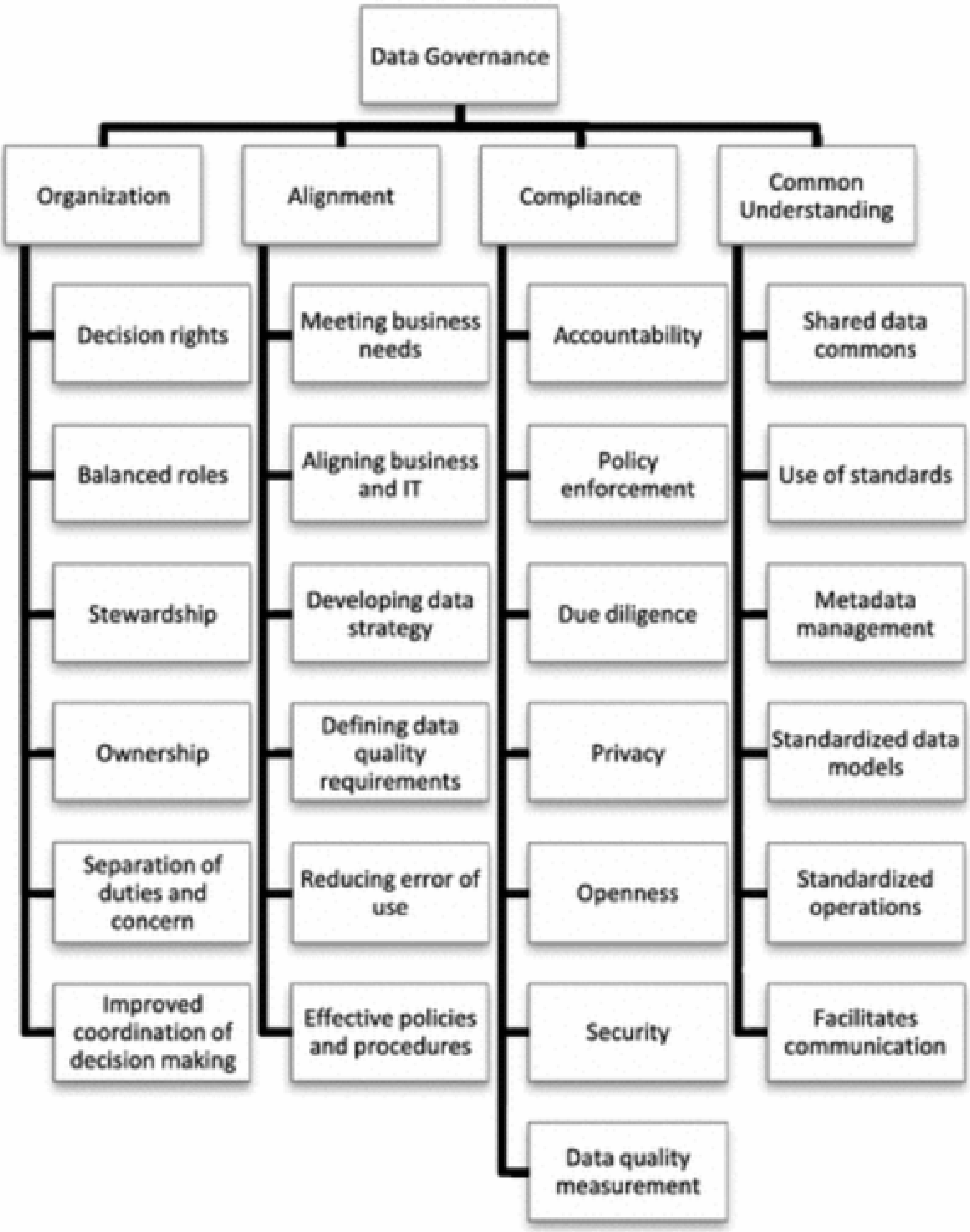


Figure 6: Data Governance Principles (Brous et al., 2016).

Open Data and EAM The barriers that are often related with open data are that data is not available, difficult to find or not manageable for potential users (Zuiderwijk & Janssen, 2014). In combination with the complexity of integrated / data-driven asset management as showed by (Lin et al., 2007), it is not common to practice open data in EAM.

But with the rise of awareness for the benefits of sharing data (Janssen et al., 2012) and the advancement of management information systems (Heaton et al., 2019) there are possibilities to reap the benefits of using OD in EAM.

In (2012), Braunschweig et al. studied over 50 open data platforms to create an overview of possibilities and limitations on the use of data from such platforms. Their main conclusion is that most of the platforms do have an API and that most of the data is not standardized, which makes this data not usable for automated tools to process the data.

Therefore, it is expected that finding open data will be useful for EAM decision making. Direct integration of open data in EAM information systems will probably not possible to fulfill. Table 8 shows the main possible benefits and Table 9 shows the barriers of the use of open data.

Table 8: Benefits of Open Data (focused on EAM).

Article	**Benefits**
(Braunschweig et al., 2012).	Opening up data would lead to transparency, participation and innovation throughout society.
(Janssen et al., 2012).	I) Easier access to data and discovery of data. II) External quality checks of data. III) The ability to merge, integrate and mesh public and private data. IV) Stimulation of innovation. V) Sustainability of data (no data loss).

Table 9: Barriers of Open Data (focused on EAM).

Article	**Barriers**
(Braunschweig et al., 2012).	I) Aligning open data can be challenging and time consuming. II) The Majority of the (Open Data) platforms lack of proper standards and APIs, and have a lot of data published that is not machine-readable or in a proprietary format. III) The open data community acts very uncoordinated at the moment and needs to be aligned in the future.
(Janssen et al., 2012).	I) No process for dealing with user input (for data Providers) II) Lack of ability to discover the appropriate data. III) No access to the original data (only processed data). IV) Data formats and data sets are too complex to handle and use easily. V) No standard software for processing open data. VI) Lack of accuracy of the information for the user. VII) Unclear value: information may appear to be irrelevant or benign when viewed in isolation, but when linked and analyzed collectively it can result in new insights.
(Zuiderwijk & Janssen, 2014)	I) No publication standards for Open Data. II) The data that are published are usually not published in a format that makes it easy to reuse the data, such as a format that enables machine readability. III) Data are not published continuously or not updated.

Together with the information about integrated EAM and the processes of Open Data this will be the input for the development of the conceptual model.

3.4 The Conceptual Model

A conceptual model is created following all the information gathered from literature review. The conceptual model is double sided, where both parts are integrated to one model. The top part of chart shows how Open Data is integrated in an EAM organization and the bottom part explains the possible beneficial influence of the processes, and the possible barriers which cause the difficulty of creating a good working Open Data information system.

The conceptual model is presented in Figure 7 (see next page). The model is divided in three main parts; the Data Providers part, the Open Data Information System part and the EAM organization part.

3.4.1 Data Providers

The Data Providers cover the part inside organizations that make data easily available. After data collection, the organization can save the "raw" data, or first progress the data (change the data in such a way that it is serving the organizations interests) and then save it. As Zuiderwijk and Janssen (2014) showed, this processing step can be a positive step as the data can be more valuable when it is processed, but often this processing of data makes that the data is afterwards only useful for one specific purposes and if that is not the purpose the data receiver has the data becomes useless. A combination of providing the "raw" data and the processed data is therefore preferred but that is normally not the case. There are a lot of reasons why this is not happening such as sensitivity of the organizational information, not seeing the possible benefits for others, extra work that has to be done to make the data available and so on.

When data owners decide to open up their data they can also benefit from that as opening up data can lead to more collaboration (Braunschweig et al., 2012). Normally, not all internal data will be shared with other organisations because this could harm the organisations interests or the data can contain private information (Janssen et al., 2012). That is the reason why there is a distinction between the internal data base and the public data base in the model.

3.4.2 Engineering Asset Management organisations

The right part shows the EAM / IAM processes. An EAM organization has a business strategy based on the business goals of that organization (Spatari & Aktan, 2013). Decisions made with this strategy are often helped by decision support models (Halfawy, 2008). These decision support models are quantified models that try to make use of available knowledge to reach best possible decisions that serve the organization's interests. These decision support models can use information from inside the organisation or information from outside the organisation (Janssen et al., 2012). The implied benefit is that more information, coming from OD sources, *could* lead to better decision making (Braunschweig et al., 2012).

3.4.3 Open Data Information system

In the middle column, the missing link; an Open Data information system for an EAM organisation is presented. It depends on the situation how this system behaves. Some data providers have their own platform where they publish their open data while others publish their data to an third party owned data base / website. The EAM organisations can search for this data, then progress it according to their needs and after evaluating the final product use the data in their decision support models.

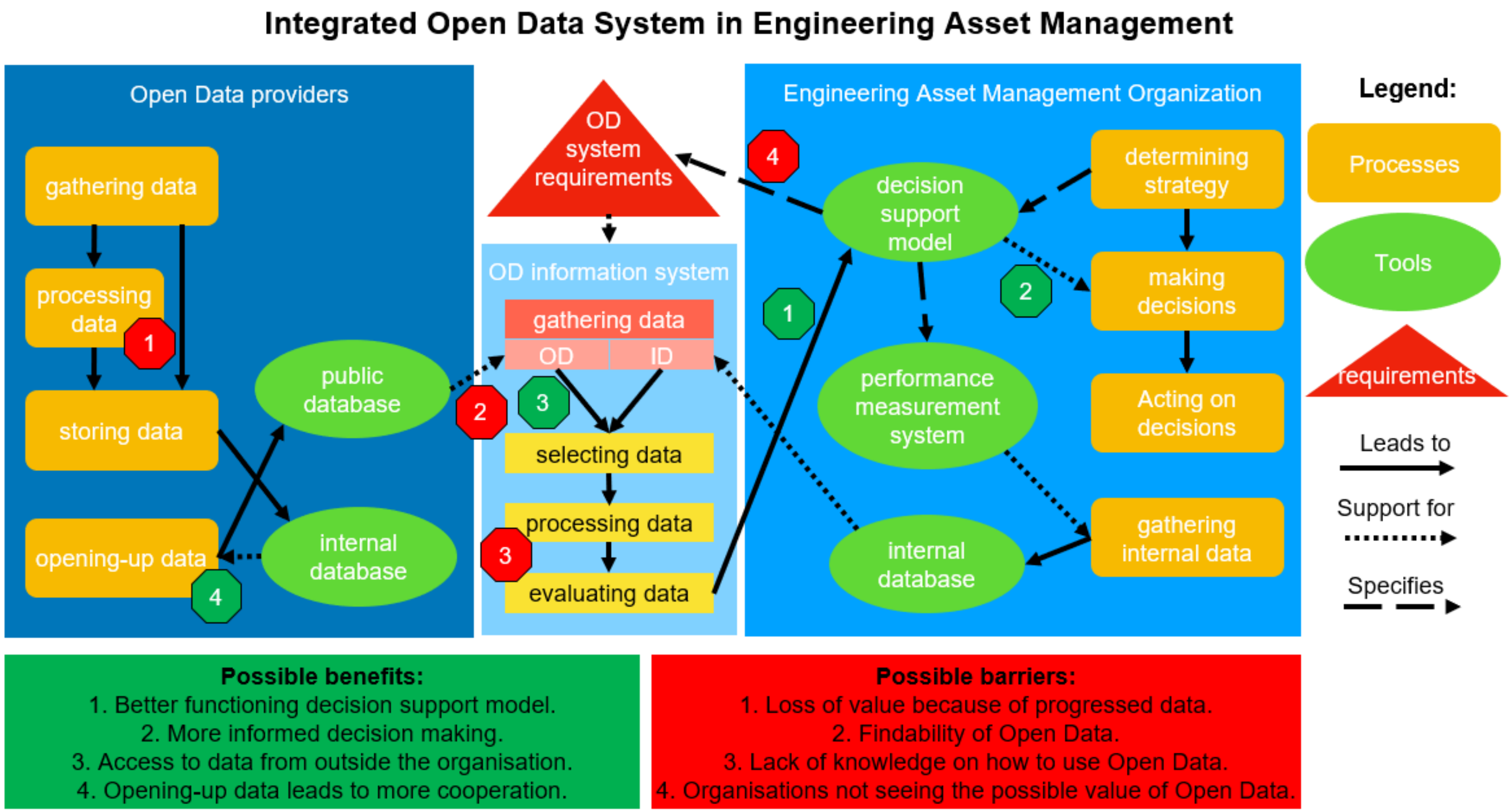


Figure 7: Conceptual model I; information flows in EAM *(created by author)*.

4 The IJsselbruggen and ViA15 case study

4.1 Introduction

In this chapter, the focus will be on second sub-question that is; *"What factors enable and hinder data driven decision making in a real-life case of using open data in an EAM context?"* The goal is to evaluate the conceptual model with the use of a case study approach. This can be a valuable addition to the research because it can provide case specific information that can be used to improve the conceptual model. The outcomes are used in two ways, to improve the conceptual model to a refined model and to reflect on the findings of the literature review.

The book "Case Study research and applications: Design and methods written by Yin (2018) provides guidelines for conducting case study research.

The first consideration is if the case study approach is the best choice as research method. According to Yin (2018), there are three aspects that need to be taken into consideration: (I) the form of the research question, (II) the control over behavioral events, (III) the (lack of) focus on contemporary events. As the research question is in line with case study research questions and the focus is on contemporary events, the first and the third condition are met. As the case study research is conducted by the author there is some control over the behavioral events. But because of the large influence of other actors, this is not a research that can be conducted with an experimental design. An experiment requires *"an investigator to manipulate behavior directly, precisely, and systematically"* (Yin, 2018, p.43). Therefore, a case study approach is more appropriate.

4.2 Case Study Selection

As the literature review shows, there is no fixed routine for implementing open data in EAM. The literature is normally focused on one of the topics (EAM, OD or DQ), that is why the information on how these topics interact with each other is still ambiguous. With this knowledge from the literature review (chapter 3) the following selection criteria are composed:

- The case study is related to the use of Open Data in an Engineering Asset Management context.
- In the case study, the use of Open Data would potentially lead to more informed (data-driven) decision making about a EAM question by an EAM organisation.
- The case is relevant for the society / in the public domain.
- The case is a specific situation of a commonly experienced EAM research question.

4.2.1 Selection of a case

Because of the exploratory nature of the research question, the selection of the case study is an iterative process. In collaboration with *Oxand Nederland* two possible case studies were designed; Using open traffic data to evaluate the effects on the traffic flow of the relief measures on the IJsselbruggen and using precipitation data for evaluating the efficacy of a watertight geomembrane construction.

The IJsselbruggen case fulfilled all the selection criteria. The IJsselbruggen are assets that need to be managed on the engineering perspective (maintenance) as on the traffic management perspective.

Rijkswaterstaat can be identified as problem owner in this case, as they have the responsibility to conduct the maintenance on the bridge and doing that in such a way that the traffic flows are disturbed as minimal as possible.

However, from the documentation of Rijkswaterstaat it appears that there is more traffic disruption than expected and the reason for the extra traffic delays is unclear (Rijkswaterstaat, 2020c). On January 21, OmroepGelderland (2020) wrote a news article about the frequent traffic disruptions on the IJsselbruggen, naming it "A large problem for the society as the large traffic delays won't be over before 2022".

By using open data to gather more information about the traffic flows on and around the IJsselbruggen, it could be possible to identify the reasons for the excessive traffic disruption.

The case is in the public domain and socially relevant, as the IJsselbruggen form a important connection between the east and the west side of the IJsselriver. Traffic hinder is societal undesirable as it leads to loss of travel time which has a negative impact on the economy (Small, 2012). Creating a situation in which the maintenance on the bridges can be done while minimizing traffic hinder, societal benefits are achieved.

4.3 Case Study Design

The ASM-approach of Yin (2018) is adopted for the case study design. This approach has a formal protocol, as described in the following section.

4.3.1 Case Study Protocol

To be able to conduct the case study in a reliable and accurate way, using a case study protocol is advised (Yin, 2018). This protocol consists of five components: case study questions, case study propositions, the unit of analysis, the logic linking the data and the propositions criteria to interpret findings.

Case study questions Case study questions help to formulate the goal of the case study research. When the case study questions are well formulated, the answers on the case study questions are aligned with the goal of the case study research. The goal of the case study is to investigate the possibilities around this case to implement OD and what effects are expected from the implementation of this OD. The process itself is interesting as well, as it can provide insights in the barriers and drivers of the OD implementation in this specific case. To be able to investigate the case, some case study questions are formulated with regard to these topics. The first set of questions focuses on how the case studies are conducted where the second set of questions is related to the connection between the case studies and the conceptual framework from the literature study.

- 1. What is the current traffic situation at the IJsselbruggen?
  - 1.1. Why is this solution selected?
  - 1.2. On what data is this solution based?
  - 1.3. Is the current situation as expected?
- 2. Are there possibilities to improve the current situation with the use of open data?
  - 2.1. Which insights can be created with the use of the open data? What data is needed to be able to make better decisions?
  - 2.2. What data would be needed to get those insights?
  - 2.3. What decisions can be influenced by this new insight?
  - 2.4. What would be the expected positive influence?

        * 2.4.1. Which stakeholder(s) would benefit from these possible effects?
        * 2.4.2. Which stakeholder(s) contribute to the creation of these possible effects?

- 3. What gaps / barriers are there between the current situation and the "to-be" situation?
    - 3.1. Which steps should be taken to make the open data ready to implement?
    - 3.2 Are these gaps in line with the expected gaps from the literature review?
    - 3.3 Which of these gaps are passable and which gaps are not?
    - 3.4. Are there possibilities to have influence on the way the open data is gathered / published?

Case study propositions From the conclusions of the literature review a, list with possible benefits and barriers is derived. Although one of the goals is to find out how well the conceptual model describes the reality, it is not a proposition as it is expected that the reality will differ from the findings in the literature study.

Propositions:

- The use of properly progressed open data - data that has been carefully selected and processed to the needs of the decision maker - could lead to more informed decision making and better decisions.

- Open data is not always published in a user friendly way, leading to lower use of this data.

- Although it would be desirable for the receiving organisation to have influence in the data gathering process, in practice this does not happen. The only choice is to use the open data provided or to not use it at all.

- The costs and benefits of implementing the OD in the decision making are not automatically fairly divided between the stakeholders (Rijkswaterstaat, road-authorities and road users).

Unit of Analysis Unit of Analysis The unit of analysis should be clear because it is important to know what is being analyzed during the case studies. The unit of analysis can be anything from relations between actors to the occurrence of specific situations (Yin, 2018).

For the case studies in this research, the main focus is on the process of implementing open data in an EAM related situation. With the use of the case study questions, the case will be analysing on the drivers and barriers and on the steps that would be needed to implement OD in the decision making process. This means that the end result of the case study is not the main unit of analysis, but the process towards this end result is the unit of analysis.

The unit of analysis in the case study are the "gaps" or the "barriers" between the current situation and the best possible situation. By analyzing these gaps more insight in the possible use of open data in EAM can be created. After these "gaps" are presented, these gaps and the gaps found in the literature review can be compared.

Linking the Data to propositions To be able to link the collected evaluation data of the implementation processes to the propositions regarding the conceptual model, it is important that there is a one to one relation between the questions answered in the analysis and the propositions regarding the conceptual model.

In table 10 the link between the propositions and the case study questions is visualised.

Table 10: Propositions and data collection questions *(created by author)*.

Proposition	**Questions**
1. The use of properly progressed open data - data that has been carefully selected and processed to the needs of the decision maker - could lead to more informed decision making and better decisions.	Question 2.
2. Open data is not always published in a user friendly way, leading to lower use of this data.	Question 3.
3. Although it would be desirable for the receiving organisation to have influence in the data gathering process, in practice this does not happen. The only choice is to use the open data provided or to not use it at all.	Question 3.
4. The costs and benefits of implementing the OD in the decision making are not automatically fairly divided between the stakeholders (Rijkswaterstaat, road-authorities and road users).	Question 2.

4.3.2 Data Sources

To be able to conduct the case study data is needed. In table 11, it is visible what data is used for the case study.

Table 11: Data sources for case study.

Data needed	Source	Content
Project information IJsselbruggen	(Rijkswaterstaat, 2020c)	Article with project information about IJsselbruggen
	(OmroepGelderland, 2020)	Article about traffic disruption around IJsselbrugggen
	Interview Operational Traffic Expert	Question 2 and 3 (Appendix C)
Project information ViA15	(Rijkswaterstaat, 2020b)	Article about ViA15 project.
	Interview Operational Traffic Expert	Question 5 (Appendix C)
General information work processes	(Ministerie van IenW, 2017)	Countrywide Transport Model
	(Abrantes & Wardman, 2011)	Value of Travel Time
	(Yang, Iida, & Sasaki, 1994)	Origin-Destination Matrix
	(Rijkswaterstaat, 2020a)	Data Information System Infrastructure Objects
	(Rijkswaterstaat, 2020e)	Design, Build, Finance and Maintain (DBFM)
	(Rijkswaterstaat, 2020d)	Accessibility
	Interview Operational Traffic Expert	Question 3 and 6 (Appendix C)
Open Data	(NDW, 2020)	National Data-bank Traffic (NDW)

4.4 Analysis

The case analysis is conducted in five parts. The first part (section 4.4.1) is the background analysis, in which the important information about the case is gathered to get an idea about the overall problem in the case study. After that, the As-is analysis is presented in section 4.4.2, in which the current situation is analysed. Section 4.4.3 describes the preferred situation, which is the result of the To-be analysis. The difference between the As-is situation and the To-be situation can be seen as the "gap". The Gap analysis (section 4.4.4) describes the different gaps between the As-is and the To-be situation. In section 4.4.5, a limited implementation is performed to experience the process of implementation.

4.4.1 Background Information

Currently the road situation on the IJsselbruggen is changed to relieve the pressure of one of the bridges. Therefore the lane layout on the bridges is changed and the effective capacity is decreased. On the north-west side of the bridge, the "Velperbroek" junction is located, connecting the north south directed "A12" that will pass the IJsselbruggen and the west-east orientated "A38" which is running parallel to the north side of the IJsselriver. The subfigures in figure 8 show the traffic lane situation on the north river bank (left sub-figure), on the bridges (middle sub-figure) and on the south river bank (right side). The traffic situation is quite complex, because on both sides of the river multiple roads are connected to each other.

As the situation on the bridges is very important for the analysis, figure 9 shows a more detailed picture of the bridges that cross the IJssel River. The two

Figure 8: The northside (L), the bridges (M) and the south side (R).

main bridges in the north east are the continuous parts of the highway "A12" and the extra bridge in the south west is an extra bridge that connects the traffic from the highway "A348" and the national road "N352" to the A12 on the south side of the river. This road layout is developed to prevent extensive lane switching while cars are passing the bridge (Rijkswaterstaat, 2020c). The main bridges have both three lanes and the extra bridge in the south-west has two available lanes.

Figure 9: Closer view on the bridges over the IJssel-river.

In the current situation, the South-West Bridge is not in use anymore because of its bad physical condition. So the traffic is only making use of the two main bridges. The total available amount of lanes is thus decreased from eighth to six.

4.4.2 As-is Analysis

As an important start to analyze the possibilities of the use of open data and the barriers preventing its use, a thorough analysis of the current situation is needed.

According to Rijkswaterstaat, at the start of the renovation project an analysis is been done to get an idea about the expected delays that can occur when the situation on the bridge would change (Rijkswaterstaat, 2020c). Later in the article they admit that the traffic disruption experienced by road users is heavier than on forehand expected.

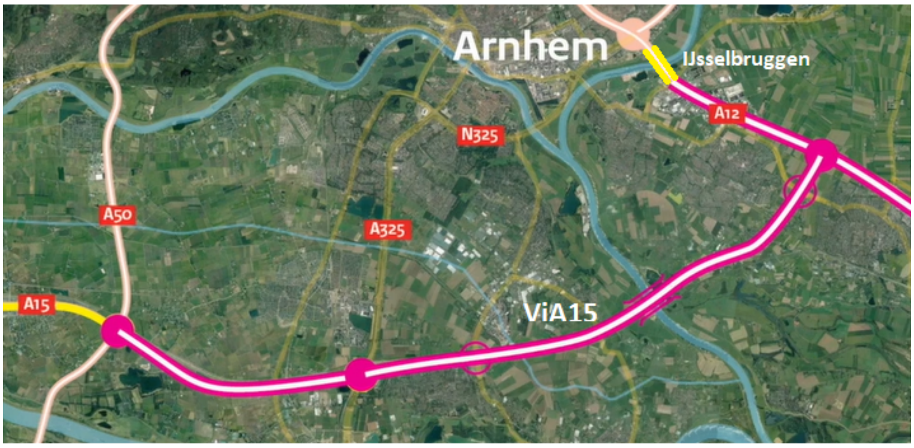


Figure 10: Situation overview ViA15 and IJsselbruggen (Rijkswaterstaat, 2020b).

Estimation of traffic disruption: Rijkswaterstaat uses the *"Landelijke Model Systeem"* (ENG: Countrywide Model System) and the *"Nederlands Regionale Model Systeem"* (ENG: Dutch Regional Model System) for analysing changes in traffic situations. These models are used to predict traffic volumes based on travel behavior of the Dutch population (Ministerie van IenW, 2017).

Based on the perceived trips of people in the Netherlands, an origin- destination matrix is created. This matrix is used in both models to generate trips over time. For every trip the best route (normally a consideration of the fastest or the shortest route) is selected. When this is done for all trips combined with the available capacities of the road network, this can give insight about traffic patterns (Yang et al., 1994; Ma, 2007). By comparing the traffic capacity in parts of the network with the requested capacity (the sum of all trips that need to use that part of the network at a specific time) traffic disruptions can be predicted.

Rijkswaterstaat has the ambition to create a long term vision on monitoring and maintaining "Kunstwerken" (the Dutch technical name for all special infrastructure objects such as bridges and tunnels) in a good functioning condition (Rijkswaterstaat, 2020a). However, the condition of the IJsselbruggen turned out to be worse than expected and the planned maintenance work had to be advanced.

According to the strategic traffic planner that works for Rijkswaterstaat I spoke with, these models are used to predict the impact of the partial closure of the IJsselbruggen on the traffic flows. Rijkswaterstaat concludes that the traffic hinder is *"Heavier than expected"* (Rijkswaterstaat, 2020c).

The IJsselbruggen and the ViA15 project: The IJsselbruggen and the ViA15 project: The project *"ViA15"* is geographically nearby the IJsselbruggen. The goal of the project is to extend the A15 to the east and create a link between the A12 and the A15 (Rijkswaterstaat, 2020b). The construction phase of the project will start in 2020 and according to the planning the project, should finish in 2024.

As visible in figure 10 the scope of the ViA15 project does not only cover the future construction part of the A15 but it also covers a significant part of the current A12. In the north, the ViA15 project continues all the way up to the IJsselbruggen.

Because the projects are nearby each other, it is plausible that traffic disruption on one of the projects can create problems on the other project. Because of that, it could be wise to investigate the impacts of both projects on each other and plan the work activities according to the outcomes of this impact analysis to minimize the combined traffic impact of the projects in the coming years.

However, this "combined impact analysis" is no common practice in projects. In the interview with the Operational Traffic Expert (appendix C), it turned out that the projects are evaluated separately with the focus on the outcomes, not on the temporal impact the construction phase of the project has. It is logical to focus on the long-term outcomes (when the project is finished), but more attention to the short-term impacts (during the construction phase) could benefit the road users in the coming years. At this point the use of OD can be beneficial.

Vehicle loss hours: The lack of focus on the effects of (multiple) construction sites in all probability leads to a sub-optimum outcome for society during the construction or maintenance phase of roads as traffic disruption at one place can lead to traffic disruptions on other places. The combination of projects that will have impact on the traffic flows close to each other could lead to accumulative traffic disruptions. As time is worth money, this could lead to increased negative social welfare (Abrantes & Wardman, 2011).

4.4.3 To-Be Analysis

In the ideal situation, travel time losses as result from road construction would be minimized, without increasing the project costs or project time. Measurements are effective when their (societal) benefits are larger than the (societal) costs. Taking measurements that can prevent traffic distortion without leading to more costs related to the construction or planning of the project would be desirable.

To predict which measurements can be implemented in the situation of the IJsselbruggen / ViA15 case, insights like how the projects are related and how they impact each other is crucial. In the current situation, the impacts of the maintenance works were estimated with the use of traffic models and historic data in advance.

The research of De Fabritiis, Ragona, and Valenti (2008) showed, that real-time traffic data can be used to make short-term predictions on the utilisation of a road network. This information could be used to make adjustments in the project planning when possible to relieve the pressure on the road network. As road data is collected and shared in real-time in open databases, this offers the possibility to use this data as input for a traffic model (Leduc et al., 2008).

In 2009, Rijkswaterstaat launched in a coalition together with 19 Dutch provinces and municipalities, An initiative called *Nationale Databank Wegverkeersgegevens (NDW), https://www.ndw.nu/nl/ (ENG: National Database Road traffic data)*. This database is updated every minute with 150.000 data points. This information can be used freely and the goal of sharing this information is to *"make better use of the current infrastructure by providing better and more information"* and to *"create better cooperation between road authorities with regard to data collection, exchange and data quality"* (NDW, 2020).

Currently there are 16 OD initiatives mentioned on the NDW website that are using the NDW data to create all kind of smart tools, most of them focused on providing traffic information to consumers (NDW, 2020).

This real-time information could be valuable for an EAM organization because it gives insight in road utilization. When the model is able to create predictions for the traffic volumes based on historic data to incorporate the effect of long term trends and the real-time data to take into account the current situation, it is likely that estimations of traffic densities will be improved.

In the case study, Gelregroen (the consortium resposible for the construction of the ViA15 project (Rijkswaterstaat, 2020b)) could benefit from this information for planning the construction and maintenance activities of the ViA15 project. Figure 11 shows an applied version of the conceptual model of the IJsselbruggen Case. On the left side the processes inside the NDW are visible and on the right hand side the (possible) processes in GelreGroen to use this data. In the middle the Open Data information system is shown which forms the bridge between the internal processes of GelreGroen and the Open Data base of the NDW.

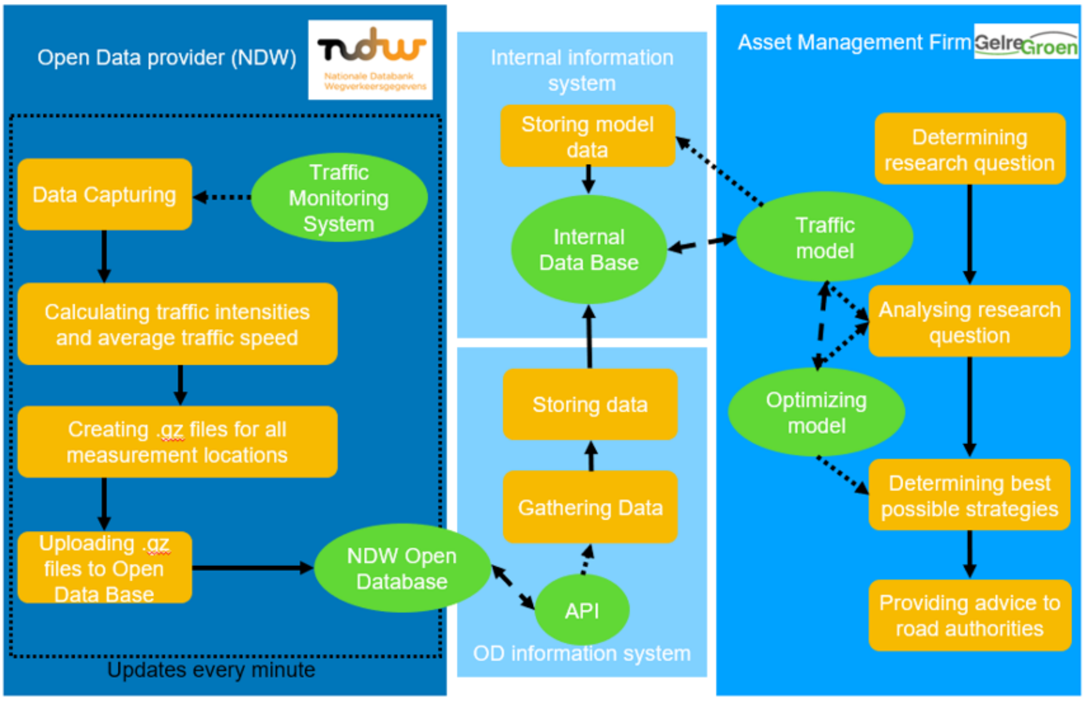


Figure 11: Possible implementation of a Open Data Information System at the IJsselbruggen Case.

4.4.4 Gap Analysis

Now that the current-situation is mapped-out, and the to-be situation is clear. A gap analysis is performed to analyse which issues play a role in preventing the to-be situation to happen. There are different aspects that influence the feasibility. In the next paragraphs these "gaps" and their influence on the outcomes will be explained.

Technical difficulties: The main difficulty is the technical implementation, when it is really easy to create a model that provides better inside in the traffic disruption than it would be used already. The costs for creating such a model are high, although the use of the open-data is free. As an integrated traffic-flow model that is specifically designed to use open data as input does not exist yet, it has to be created and therefore organisations will be reluctant to the idea of using such a model. This means that for those organisations the perceived costs are higher than the perceived benefits.

Creating a good functioning model means that the .gz data from the NDW-databank has to be collected every minute and than transformed in such a way that it can be the input for the traffic model. As traffic models are flow models, meaning that the over time traffic "moves" through the model from point to point and the data that is collected is static (how many cars passed a specific point at which average speed, this connection is not straight forward.

Besides that, an internal database that saves the data that comes in every minute is required to be able to analyze the data from the last hour, week or month (whatever is needed in a specific situation). As the data that can be downloaded from the NDW-database is updated every minute to the newest data, the database should save the data every minute to create an historical data track.

An Application Programming Interface (API) is a set of commands, functions, protocols, and objects that programmers can use to create software or interact with an external system (TechTerms, 2016). Such an API is needed for the communication between the NDW website and an internal database / the traffic-flow model.

Another option is to use the "Data as a service" option from the NDW website. Although this is not free, NDW offers this service as an option for organizations that want to use this free data, but in such a way that the data is already modified in such a way that the client's needs are accommodated.

Data Quality: Besides the technical difficulties to create a model that uses the Open Traffic Data from the NDW, a valid question to ask is if the quality of the data is guaranteed?

In a small pilot study with historic NDW data (section 4.4.5 and appendix D), two out of seventeen traffic measurement points did not give correct data. For one traffic measurement point (RSW01 MONIBAS 3251hrr0276ra) no data was given, and for the other point (RWS01 MONIBAS 0120vwd1359ra) the measured speeds were zero kilometer per hour at all times. In the first situation the sensor is probably not connected anymore, where in the second situation the sensor is probably not measuring correctly anymore but still providing (false) data.

These data quality problems are related to the dimentions of data quality mentioned in the literature review (paragraph 3.3.2). The problem of missing data points are related to the quality dimension *"completeness"* and the problem of incorrect data is an *"accuracy"* issue.

Both quality issues can be problematic. When no data is provided anymore from one of the traffic measurement points, the model would normally give an error. When false data is provided to the model, the model would probably still function but it would give wrong information. For the traffic model to run smoothly, a check for the completeness and correctness of the data has to be done occasionally.

As the NDW is only the authority that passes on the provided data from the sensors (the NDW is not responsible for the sensors) they have no influence in preventing these problems from happening.

Robustness of data providing: In the selection process of traffic measurement points in the NDW database, the service time of all the traffic measurement points are provided. In figure 12 the information provided by every traffic measurement point in the NDW data base is shown. As visible in the picture, the valid from (NLD: Geldig vanaf) and the valid to ((NLD: Geldig tot) dates are provided as well.

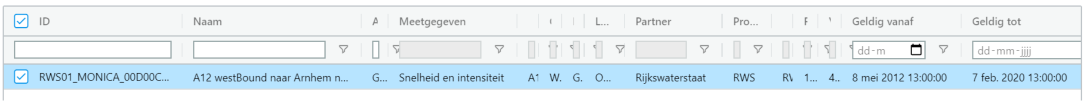


Figure 12: Information provided by traffic measurement points in NDW database.

As the road layout changes, the measurement points also change and because of that new traffic measurement points are added and old points are deleted. When creating a real-time traffic model that should be able to run for a long time, changes in the data providing for the model should be taken into account.

This creates the difficulty that situations are hard to compare. As new traffic measurement points do not exactly measure the same as the old points (for example the amount of lanes changed what influences the traffic density). Although this leads to more labor on the model, the model also has to change without this problem, as a new road layout also requires an updated version of the model.

Distribution of costs and benefits: Integrating more information in the decision process is costly for the organization that decides to do so. In this case Rijkswaterstaat as project owner of the IJsselbruggen renovation project or Gelregroen as project owner of the ViA15 project could invest in a way to integrate this OD in their decision making (Rijkswaterstaat, 2020a, 2020b). A problem that arises is that this increase the costs for those projects while the road users will profit from the results.

Added to that is that the benefits are uncertain and later in time and that the investments have to be made in advance. Especially the fact that it is not sure if the investments will be recouped, is a problem.

Table 12 shows the main actors that are involved in the case and which interests this actors have. As Rijkswaterstaat is directly involved in both projects (as executive party at the renovation of the IJsselbruggen and as outsourcing party at the ViA15 project), Rijkswaterstaat could take a leading role in organising a way in which it is interesting for Gelregroen to invest in the OD model.

Table 12: Actors involved and their interests

Actors	**Main Interests**
Rijkswaterstaat	Increase the accessibility and mobility of Dutch road users.
Consortium Gelregroen	Create the new road connection within the limits of the contract for the lowest possible costs.
Road users	Safe and fast transportation from origin to destination.

When travel traffic disruption decreases Rijkswaterstaat will be satisfied as increases in travel time decreases the mobility (Rijkswaterstaat, 2020d). Without a financial incentive, it is unlikely that Gelregroen would like to cooperate.

Contractual agreements about this kind of payment structures are difficult, but common practice. Rijkswaterstaat works with DBFM contracts (DBFM stands for Design, Build, Finance and Maintain) in which bonuses and fines are normally included to make sure that the executive consortium lives up to the agreements (Rijkswaterstaat, 2020e). In these type of contracts it is normal to provide boundaries for the amount of Traffic Loss Hours that the work activities may produce.

However, the calculations of those rewards and fines are often based on model estimates instead of measurements on location. When Gelregroen thinks that the traffic disruption (traffic loss hours) are overestimated they are likely to be happy with a new model that gives a better estimate, but when they have the feeling that the new model will estimate more traffic loss hours they have no incentive at all to create such a model.

Change is difficult to achieve: From the interview, it appears that road construction projects have a rigid form and that changes are difficult because of the long-term plannings that are followed during the project.

Gelregroen is a consortium of large infrastructure contractors and before the project starts this consortium agrees on the project planning and on the distribution of tasks between the contractors. The payments a contractor is awarded is depending on the result of the projects and on the agreements that are made in advance.

Based on the project planning, Rijkswaterstaat releases time slots for construction or maintenance work on specific locations. These time slots are released well in advance so that the contractors can prepare the work activities.

When the real-time traffic model shows that the released time slots are not the best time slots anymore, changing the time slots is difficult. Short-term tuning will require other ways of working; Construction teams that are standing standby that are send to a location where the road capacity is not exceeded in the next hours so construction of maintenance work would not increase the experienced traffic disruption.

Towards a Open Data Traffic Model. With these conflicting interests it is difficult, but not impossible to create a situation in which all actors could benefit from implementing the open traffic data in the project planning. When Rijkswaterstaat offers compensation for less traffic disruption this can make up for extra costs or work that Gelregroen has to carry out.

An idea that could also work is to use the data in a slightly different way than in the ideal situation, but still create better insights than that are now available. A model that runs on the more precise data from the NDW database, but that is not real-time connected to the NDW database is more likely to be feasible because such "weak" links do not require direct connection between the NDW-database and the model.

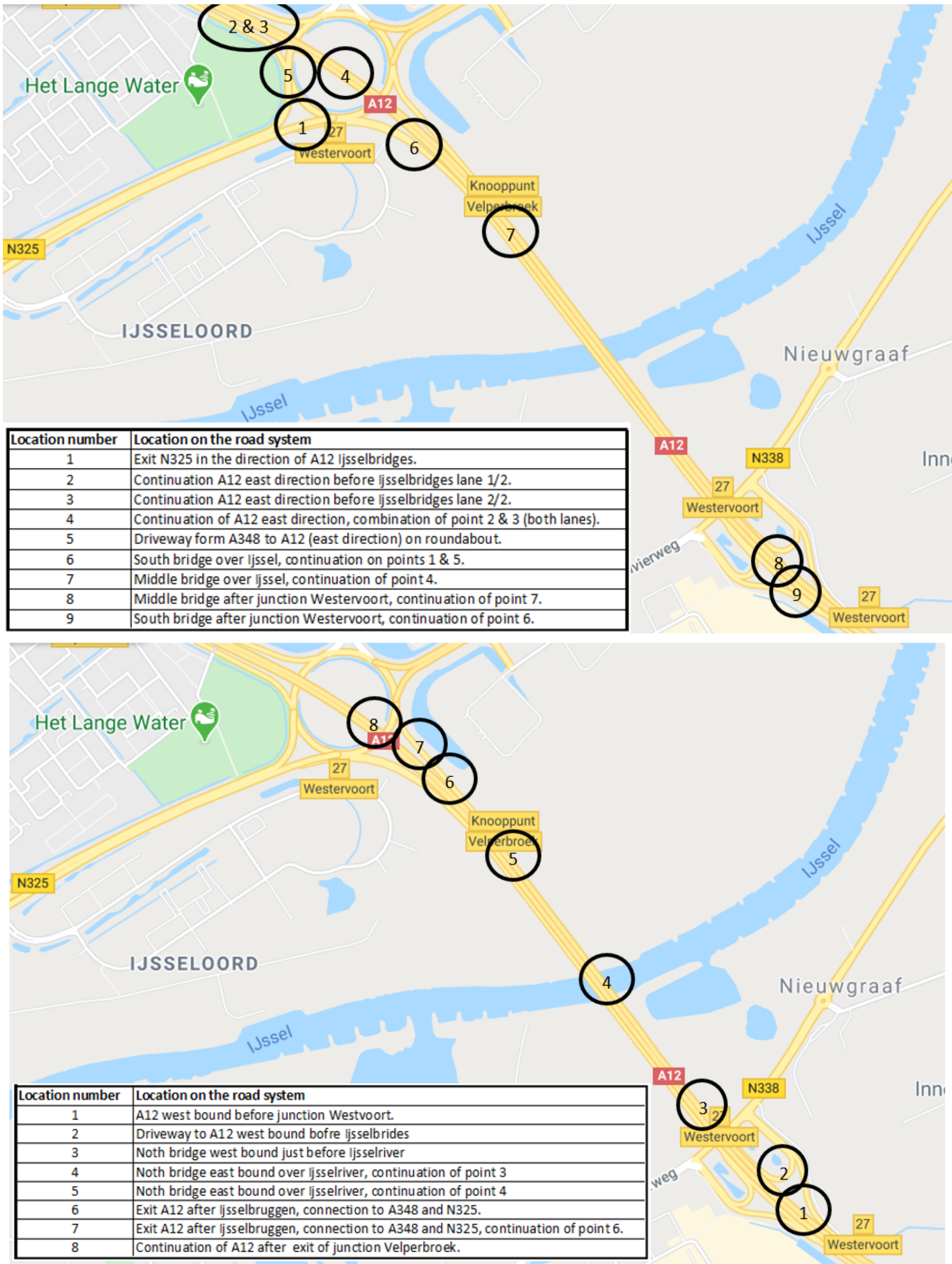
To test how suitable the data from the NDW-database is for such a model, a (very) small pilot study is conducted in the next paragraph in which the historic data from the NDW is used to give some more insight in where on the IJsselbruggen the most traffic disruptions are experienced.

4.4.5 Limited implementation with historic data

To be able to check the quality of the data and to argue about how difficult it will be to implement a working real-time Open Data information system, I did some small research into the possibilities to use the NDW historic open data base because creating a working real-time model is costly and falls out of the scope of this research.

Selecting time-frames: The starting point was to select two time-frames one before the road layout changed and one after the road layout changed. Both are comparable. Because of the corona virus the second time-frame is chosen to be from February 15 (2020) to March 15 (2020), just between the new road layout is in use and the start of the impact on the traffic intensities because of the Corona Virus. To be able to have a good comparison, the same time-frame a year earlier is selected as the first time-frame.

Selecting traffic measurement points: For the selection of traffic measurement points, only points that where active in both time-frames are selected. To be able to analyse the traffic on the IJsselbuggen, around 8 to 10 points are selected on the A12 and on connection roads for both directions (see figure 13).



Location number	Location on the road system
1	Exit N325 in the direction of A12 Ijsselbridges.
2	Continuation A12 east direction before Ijsselbridges lane 1/2.
3	Continuation A12 east direction before Ijsselbridges lane 2/2.
4	Continuation of A12 east direction, combination of point 2 & 3 (both lanes).
5	Driveway form A348 to A12 (east direction) on roundabout.
6	South bridge over Ijssel, continuation on points 1 & 5.
7	Middle bridge over Ijssel, continuation of point 4.
8	Middle bridge after junction Westervoort, continuation of point 7.
9	South bridge after junction Westervoort, continuation of point 6.

Location number	Location on the road system
1	A12 west bound before junction Westvoort.
2	Driveway to A12 west bound bofre Ijsselbrides
3	Noth bridge west bound just before Ijsselriver
4	Noth bridge east bound over Ijsselriver, continuation of point 3
5	Noth bridge east bound over Ijsselriver, continuation of point 4
6	Exit A12 after Ijsselbruggen, connection to A348 and N325.
7	Exit A12 after Ijsselbruggen, connection to A348 and N325, continuation of point 6.
8	Continuation of A12 after exit of junction Velperbroek.

Figure 13: The selected points east-bound (top) and west-bound (bottom).

Analysis For all these traffic measurement locations the data is gathered and processed. In Appendix D, all the tables with averages traffic speeds and intensities per hour of the day for both periods (2019 / 2020) are shown including a comparison between the 2019 and 2020 data.

Results: The data shows that the average speeds decreased since the new traffic situation. It is notable that during the peak-hours (7am. to 10am. and 4pm. to 7pm.) the average speeds decreased less than during the other hours of the day. This could probably be the result of lower speed limits on the bridge that slows down the traffic when the traffic density is low, while during rush-hour the speeds are already below the maximum speed. On the whole trajectory the traffic densities are lower in the new situation so people are probably avoiding the IJsselbruggen currently.

Figure 14: Impact on traffic speeds visualised.

As visualised in figure 14 the traffic speeds decreased the most for west-bound traffic (from Germany in the direction of Arnhem). It is also noticeable that the impact of the maintanance works on the IJsselbruggen itself is larger than on the direct connected roads, meaning that the low capacity on the IJsselbruggen itself is probably the main problem.

A redesign of the lane-layout is in which the west-bound traffic capacity gets increased and the east-bound capacity gets decreased could probably lead to less overall traffic disruption. When comparing the speeds of the west- and east-bound traffic, this could improve the average speed of the west-bound traffic by five to ten percent.

On an average day, around 150.000 cars* cross the IJsselbruggen. Lets assume that the average occupation in a car is 1,5 persons, the value of time for the average person in the Netherlands is 10 per hour and all cars can save 1 minute per trip over the IJsselbruggen because of the new traffic measurements. The daily worth of travel time earnings would than be 37.500 euro per day (or around 1 million per month).

As theses possible earnings / savings are substantially, it would be worth the analysis to investigate with the use of a OD traffic model the effects of possible interventions.

4.5 Case study conclusions

This chapter tried to answer the question: *"What factors enable and hinder data driven decision making in a real life case of using open data in an EAM context?"*. From the analyses it has become clear that there are quite a few factors that enable (such as the potential social gains from preventing travel time losses) and hinder (such as technical difficulties, data quality aspects and governance aspects) the use of open data.

To be able to reflect on the propositions, the list with the propositions is shown again:

- The use of properly progressed open data - data that has been carefully selected and processed to the needs of the decision maker - could lead to more informed decision making and better decisions.

- Open data is not always published in a user friendly way, leading to lower use of this data.
- Although it would be desirable for the receiving organisation to have influence in the data gathering process, in practice this does not happen. The only choice is to use the open data provided or to not use it at all.
- The costs and benefits of implementing the OD in the decision making are not automatically fairly divided between the stakeholders (Rijkswaterstaat, road-authorities and road users).

As for proposition one, it is plausible that the new insights of the OD would actually enable better decision making. From the analysis and the small implementation study can be concluded that with more (detailed) information, traffic disruptions can be prevented or minimized. That OD is not always published in a user friendly way is confirmed by the NDW database as the available files are .gz files, which are not commonly used outside the own organisation. The third proposition is partly true in this case, as there is a possibility to have influence on the data that is made available by the NDW. This is called Data as a Service, in which the customer pays the NDW to adjust the data to their needs. As this is still the same data, but the customer pays for the adjustments it is disputable if this still counts as "Open Data". The last proposition is very recognisable in the case study. The problem that one party has to put effort in using the OD in their decision making and that other parties benefit from this action, is clearly the case in the IJsselbruggen / ViA15 case.

The case study showed that there is potential for the use of Open Traffic Data in (some) Engineering Asset Management cases. The use of this data outside the organizations that monitor this data, can lead to better decision making inside other organizations. However, it is situation dependent if the benefits will outweigh the costs. It is difficult to make estimations about the possible benefits and the costs related to implementing OD in such cases, which presents another barrier.

Thereby it is also clear that the way road construction and maintenance management has developed over the years leading to increased efficiency, which is useful but this path dependency also makes it difficult to be able to use new insights from (Open) Data. The long-term planning that is central in road construction and maintenance management offers little to no room for ad-hoc changes such as changing the order of tasks in order to prevent traffic disruption at certain locations.

In addition, the use of Open Data in this case leads to higher social welfare in the form of shorter travel times for road passengers, but without incentives (rewards) for the contractor when traffic disruption is minimised, it does not offer direct returns for the organizations which need to put extra effort in integrating the Open Data into the decision making process. Testing should prove whether this kind of OD integration could be successful, are the improvements enough to make up for the extra transaction costs?

4.6 Refined Model

The Refined Model is an enhanced version of the conceptual model, focused on the potential use of Open Traffic Data instead of all Open Data with the use of the information gathered from the case study. The model shows the processes, tools, requirements and the relations between them. Figure 15 shows this defined model.

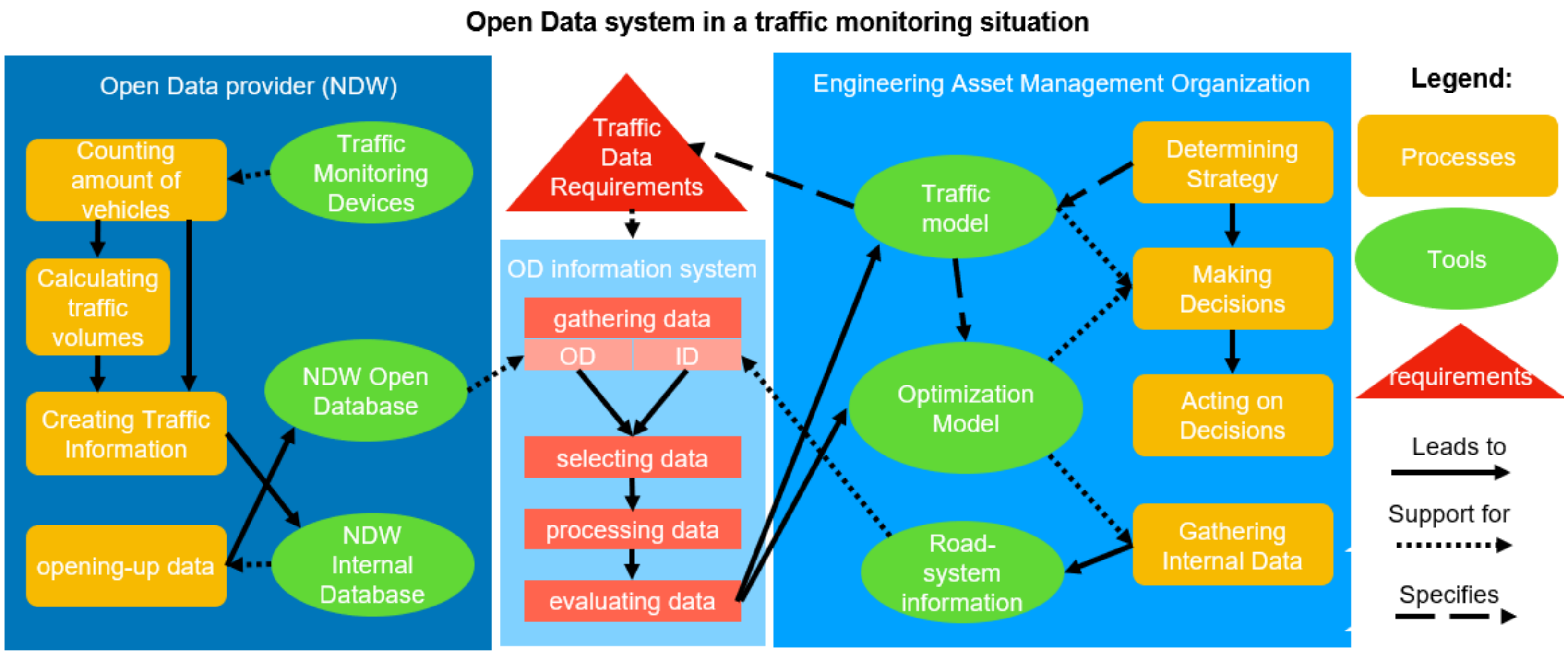


Figure 15: Refined model adjusted for a possible Open Data infrastructure in a traffic monitoring / modelling case.

5 The Stakeholder perspective on Open Data in Engineering Asset Management

To answer the third research question that is *"What are stakeholder perceptions on enablers, barriers and success factors on using Open Data in Engineering Asset Management?"* An expert workshop session is conducted.

5.1 Setup of the Expert Workshop Session

5.1.1 Selection of experts

It is practically (especially in the current times of Corona measures) difficult to gather multiple stakeholders from different organizations. Therefore, I make the choice to only invite employees from Oxand Nederland to participate in the workshop session. Oxand is a consulting firm that works closely together with all kind of organizations (Rijkswaterstaat, project teams, local governments and construction firms). Its employees are able to place themselves in the shoes of different type of stakeholders. Although the optimal situation is to invite stakeholders from all kind of organizations, this is the best possible solutions given the limited time and scope of the research.

5.2 Setup of the review session

The review session took place online at Friday 10th of July, 2020. In total, 18 persons joined the session. All attendees were employed at Oxand NL and most of them were working as business consultants. All business consultants at Oxand have a master degree that is related to engineering. After a 20 minute presentation in which I presented the refined model and the findings of the case study, they were asked to give their opinions about the refined model and the outcomes of the case study. Besides that their opinions about Open Data in Asset Management in a wider context was asked.

Kimball has introduced the idea of "liberating structures" (Kimball, 2012). The idea is that specific group session formats can help to create innovative ideas and to brainstorm about all kind of topics. From the book Liberating Structures by the Creators Company I selected the structure *"What? So What? What now?"* as basis for the review session as this structure encourage involvement of the attendees. I adjusted it a bit because of the limitations that an online meeting has over a normal meeting. Figure 16 shows the different parts of the workshop session. Figure 17 shows the brainstorm part in more detail.

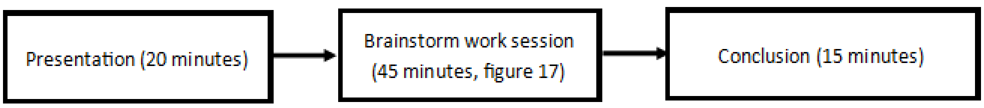


Figure 16: Flow diagram expert workshop session.

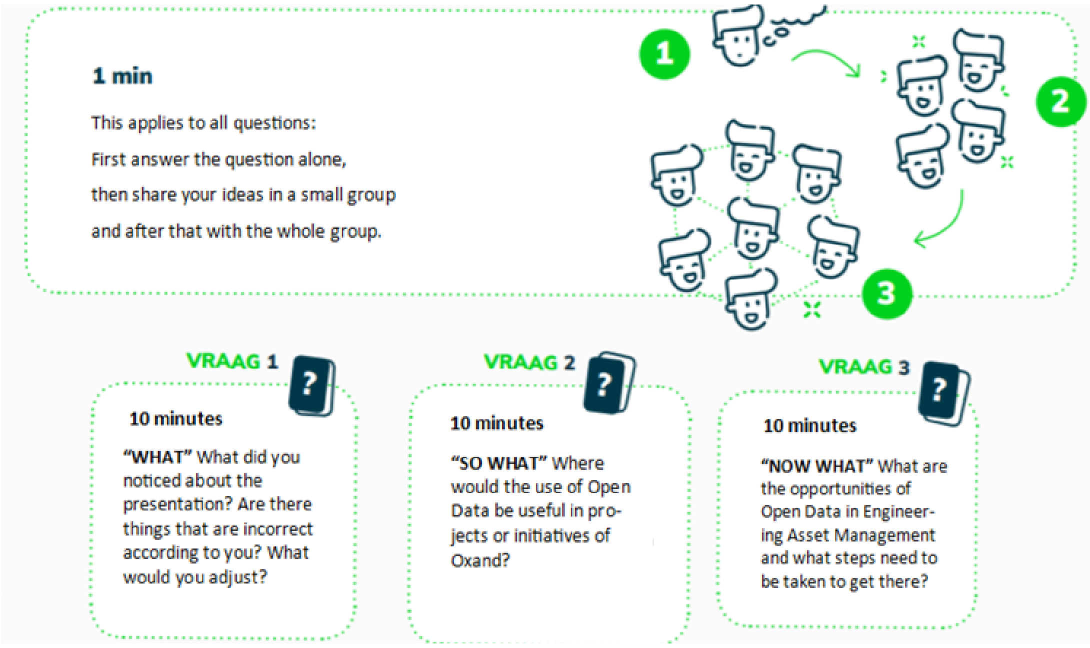


Figure 17: The adjusted Liberating Structure "What, So What, Now What?".

After the central presentation, groups of 4-5 people were formed. They were asked to join separate meeting room so every group is able to have their own conversation. In three rounds of 10 minutes, the participants were asked to first think about a question on their own and then to share their thoughts with other people in their group. In this way the thoughts of the 17 participants was bundled to conclusions per group on every question.

The online tool Miro was used where the participants shared their thoughts with their group members. Each participant had their own "place" in the Miro board in a specific group. They were able to post answers on the questions. Between the group place and the central place in the middle, boxes were created where every group was able to bundle their thoughts (a box for every round / question). The benefits of Miro are that all participants were able to see the board develop at the same time. This imitates a normal (pre-corona) setup in which every group would make their own poster and than share all the ideas together on a whiteboard.

In the last 15 minutes, the session was concluded with everyone back in the central meeting room. Where one member from every group was asked to share their ideas / conclusions on the questions (this part of the session is recorded). Those conclusions were captured in the central area and the conclusions form all the groups were combined together. Figure 18 shows a screenshot of the (end result of the) Miro workplace that was used during the session.

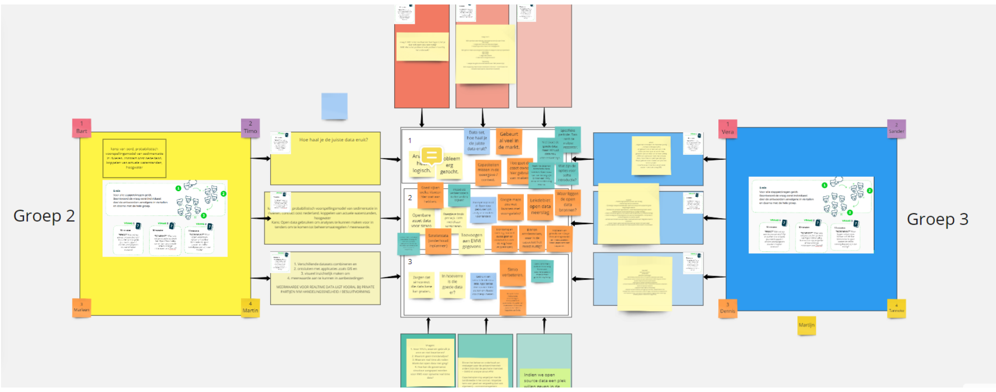


Figure 18: The online workplace in Miro.

5.3 Results

The results of the workshop session are dividable in different parts. The first part is the feedback on the refined model, the second part is substantive feedback about the research and Open Data in EAM as a whole and the last part is ideas for the future.

5.3.1 Towards a Definitive Model

The experts were mostly positive about the refined model and they were able to relate to the ideas behind it. One of the aspects in the model that was not clear enough is the how the open data is selected, processed and evaluated.

> *"What I do not see in the refined model, is the complexity of how the Open Data is selected? Isn't that a iterative process that continues until the evaluation of the data shows that the data satisfies the requirements "*

This process of selecting, processing and evaluating the OD is iterative and more complex than presented in the defined model. It is focusing more on the improvement of the model. Besides that an arrow between "Acting on decisions" and "Gathering Internal Data" became a topic of conversation, so that is added as well. The feedback of the experts is included in the definitive model (figure 19).

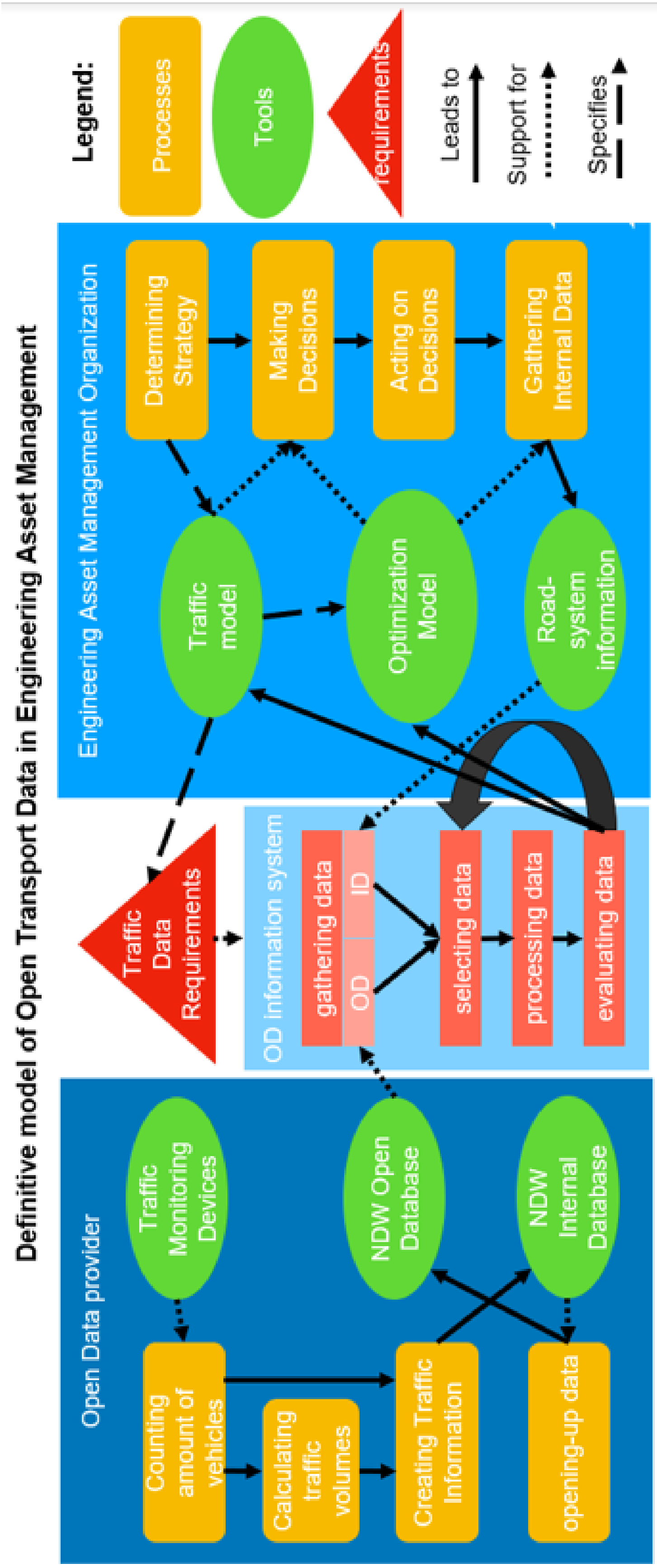


Figure 19: Information system for Open Data in Engineering Asset Management.

5.3.2 The expert views on Open Data in EAM

One of the expert-groups noticed that the IJsselbruggen case feels as a solution for a non-existing problem:

> *"We (group 2) had the feeling that the problem of the case study is that you have searched for a problem that connect to a solution (Open Data, red.). The problem with searching for problems for a solution is that they never connect as well as the other way around".*

One of the conclusions from this is that intensive search for a problem that can be linked to whatever Open Data is found is not wise. This notion will come back in the reflection of the thesis. Another remarkable quote is about the standardization issues of Open Data:

> *"For an organisation as Oxand, it is important that when we would use Open Data, this data can be directly linked with our own software. As our software is based on all EAM-standards (ISO & NEN), standardisation of the format of Open Data and the way this data is shared would be very helpful".*

Standardization would be helpful in all sectors, but because of the habituation of employees to work with (international) asset management standards, this can be extra valuable for employees of an EAM organisation. When standards are met, integration would be easier and therefor less time consuming and less costly. The last interesting topic that is discussed is about change-management in organizations:

> *"As a consultant, on a daily basis I am trying to make organisations move forwards and from my experience it is not likely that proposals with large changes from the day-to-day way of working will not be welcomed with open arms"*

It is clear that changes that have a large influence on the organization are often not easily welcomed. When the OD implementation involves multiple actors (such as in the IJsselbruggen / ViA15 case) this will be even more the case as multiple organisations have to change to make it work.

Because of the uncertainty around Open Data it is therefore wise to start with implementing Open Data in small parts. A counterargument to this statement is that there is need for a total system change to make use of the potential benefits of OD and that phased integration would probably not be beneficial at all.

5.3.3 Ideas for Open Data implementation

In the brainstorm part of the session, participants were asked to come up with ideas in which Open Data is used in an EAM situation. The following ideas are worth to mention:

> *"When there is openly available data about Assets available, that would be very interesting to see where that data can be used instead of visual inspections. Maybe that can be done with the use of smart combination between different data sources as well."*

> *"Satellite data can be used to observe assets visually form above. Deviations in constructions that need visual inspection on the ground could be selected based on those observations. It can also be used to inspect an area before a project starts."*

> *"An idea is to use participation data to estimate the amount of water that falls in a certain area. This data can be compared with the data from pumps in a foil construction. In this way we can proof that the foil construction works as it should be (no leakage, red.). "*

> *"Using a combination of traffic data and weather data to estimate the wear of highways. As frost, rain and traffic are the main things that lead to issues in the concrete, this data can help to estimate when and where repair work has to be done."*

> *"Using traffic data instead of estimates to calculate the compensation the road administrator has to get from the road owner (Rijkswaterstaat, red.)."*

These ideas show that the experts think that there are opportunities for Open Data in various processes related to EAM. It is also clear that traffic data is the most obvious, but not the only kind of data that offer possibilities, so to the experts conclude.

5.4 Conclusion

With the use of the expert workshop session this chapter tried to answer the question *"What are stakeholder perceptions on enablers, barriers and success factors on using Open Data in Engineering Asset Management?"*. From the session can be concluded that the experts - who are (even though not all kind of) stakeholders in the EAM sector are positive about the use of Open Data. According to them, it offers possibilities although currently the technical difficulties and the hard to change governance structures are affecting sector wide implementation of Open Data. The experts agree with most of the conclusions from the case study, but they added the notion that standardization of how open data is published and the format of the data may be an essential step to decrease the technical barrier of implementing OD.

6 Conclusion and discussion

In this chapter the conclusions of the research will be presented. In the second part, a discussion section will present the main deficiencies of the research and which steps could be taken in the future to continue the research in this field.

6.1 Conclusion

The goal of this thesis was to answer the main research question: "In what way can value be created by using Open Data in an Engineering Asset Management context?" With the help of a literature review, a case study and an expert review the information to answer this research question is gathered.

The literature review argued that there is complexity in Engineering Asset Management processes. Besides that, it presented the main opportunities and barriers of Open Data in a general context and later on in a EAM specific context. The conclusion of this literature review is that there is not written a lot about the use of Open Data in EAM. The barriers found in the literature study are mostly related to the quality and the findability. The complexity of decision making in EAM needs a deeper understanding of the relations on how OD could be used in a EAM context but this is missing in the literature.

To be able to examine the possibilities to integrate Open Data in real-world EAM situations, a case study research is conducted. The case study concluded that there are a few prerequisites have to be met before OD can successfully be implemented in a EAM organisation or EAM case. The technical difficulties that have to be overcome such as creating a working connection between the NDW database and a well-functioning transport model is one of the barriers. The benefits should out weight this effort and it has to be possible to divide the benefits in such a way that all actors involved are willing to invest their time or money. Remarkable is that in the case study the main barrier is the governance structure between EAM organisations that makes it difficult to create interest from organisations to use OD. This is contrasting with the findings from the literature review, where the focus is on the technical difficulties and the quality of the OD.

As the benefits of adding OD to existing processes in road maintenance or construction are often uncertain, the willingness to invest in new initiatives is low. The problem is that it is difficult to estimate the benefits so some kind of pilot study has to be performed. The problem is that a valid business case has to be found to find an organisation that wants to invest in such a pilot and that is currently not the case.

The integration of more precise OD in the traffic models without using the real-time component can also be interesting, as it is difficult to create a functioning real-time information system and the more detailed (precise) data can already be helpful to create more insight in the traffic disruption problems.

The expert review session showed that not only open traffic data (as used in the case study) has the potential to add value to EAM. During the brainstorm part of the session, multiple other ideas of how to use Open Data in an EAM context were proposed.

Another problem for further integration of OD in EAM is that there are no standards for sharing and using OD. This makes it difficult to find and use Open Data for EAM organizations and it makes it difficult for organizations that have data to offer to publish it in a user friendly way. In a sector that is used to work with all kind of standards (such as the ISO and NEN standards), it would be very helpful when there are similar protocols for the use of Open Data in EAM. The Institute of Asset Management could maybe also play a role in this transition as they are the leading actor in creating and maintaining industry standards.

Right now it is difficult for organizations to bundle different sources of Open Data together, and that is one of the ways to create more value. One of the barriers that prevent this from happening is that data sources are so divers that it is difficult and labor intensive to combine data from different sources. Standardising the format in which OD is published increases the possibilities to combine information from different data sources as the data from those sources would be easier to compare.

Another important aspect that is blocking further integration of Open Data in EAM is the path dependency of a lot of EAM related processes. The case study showed that the Open Data could contribute to real-time data driven decision making but that is only possible when real-time decision making is an option. In a lot of cases, decisions are made weeks or months in advance as a result of working routines and contracts between administrator and contractor. As a result, real time adjustments in the planning are not optional, even though more social value could be created when doing so.

One of the lessons learned from the case study and the expert review is that small steps towards the goal of more Open Data integration in EAM are wise, because total integration is difficult and can be risky because the provision of an Open Data source that is currently available is often not guaranteed for the future.

6.1.1 Societal contribution

The outcomes of the research are relevant for organisations in the EAM business which want to use Open Data in their operations. The definitive model can help policy makers to understand the complexity of integration of OD in EAM.

As Open Data creates social value, leads to innovation and promotes collaboration, it is important that there is sufficient attention to continue research in the field of Open Data and as the combination with Engineering Asset Management is not sufficiently studied yet this master thesis tried to make a start with that.

The societal contributions are two sided, on hand companies and organisations can benefit from the lessons learned in this thesis, and on the other hand the government can use the information to prioritize their actions towards more open data integration in a good way.

Business Recommendations: Not only the government can improve the positive societal impact of Open Data, companies can practice this as well. For the government, societal welfare is one of the main goals, and for a company maximizing profit is important. As returns on investment are crucial for a company, investments in OD initiatives will only happen when the company thinks that the benefits out weight the costs for their organisation. This costs include investments, labor costs and risks related to the integration of OD.

With the current trend of digitization, information management gets a more central role in organizations (Chen et al., 2016). Because of this importance, internal data is normally preferred over third-party data, as having control over the data can be important for the company. All of these barriers - prevents organizations to make a change from using internal data to using Open Data.

On the other hand, using (and sharing) Open Data can also have huge potential. Gathering and processing internal data can be very costly, where Open Data is (normally) free to use. In addition, there is data about topics that can be interesting for organizations that is outside their direct field of interest.

The search for a case study resulted in finding OD and searching for a way to implement this OD in an EAM related problem. The problem with this is that the need for a solution is low in such cases and therefore the urge for a solution is low as well. Therefore a forced search for a way to implement OD in an organisation is not recommended.

Searching for a way to implement OD for a not yet existing problem is therefore not advisable. There is still a chance that it would work to search for a way to integrate OD that is found by someone in the organisation, but as the experts noted there is a chance of ending up with searching for a problem that is not worth solving.

Important for organizations is to start with small initiatives and not to make the Open Data too soon part of the core operations of the company. Depending on Open Data yield risks because of the uncertainty that is connected to the Open Data provision. Open Data can be helpful, but it should not be a goal in itself to use open data in an organization.

As found in the case study and in the expert review, the costs and benefits of the use of Open Data are often not inside one single organization. In such situations, smart collaboration initiatives are needed to create social welfare without increased cost for organizations that are not compensated for that.

The differences between the findings form the literature review and the case study (and expert review) are presented in Table 13 shows the findings from the literature on the left side compared to the findings during the case study and expert review on the right side. As visible, there is certainly overlap between the literature and the case study and expert review. However, the extra findings from the case study about the barriers related to the governance aspects and related to the path dependency in the way of working are not existing in the literature overview.

Table 13: Findings from Literature Review compared with Case Study and Expert Review

Literature study	**Case study and Expert review**
Benefits	
Opening up data would lead to transparency, participation and innovation.	Open Data can be use full for organisations but is mostly used by OD initiatives (such as traffic information apps).
External quality check on the data.	When the data is also in-house available this will be the point, in reality the data quality is often unknown to the receiving organisation.
Barriers	
Aligning OD can be challenging and time consuming	The "Technical Barriers found in the case study.
Most platforms lack of proper standards	Use of gz. files in case study shows that in the case study.
Unclear value: information may appear to be irrelevant or benign when viewed in isolation,but when linked and analyzed collectively it can result in new insights.	Problem found in case study that it is difficult to estimate how large the benefits are.

In conclusion, it is wise as an organization that is active in Engineering Asset Management to search for possibilities to use Open Data, but start small and be aware of the barriers that are currently preventing a steep rise in the use of Open Data in EAM.

Government advice: As presented in the introduction, Open Data is a vague concept. Although the amount of Open Data is growing exponentially, people and companies are often struggling with implementing this open data in their business structures. In Engineering Asset Management, information about assets is crucial for the decision making process. As a result of this, the correctness and the robustness of the data provided are very important for the Asset Managers.

As the sector would benefit from standardisation in OD it would be useful when the government takes an advising role in proposing such standards. It is in the governments interests that companies create value for the society and this step could increase the total values that organisations and companies are able to create.

An EAM expert stated in the expert review, a standard such as a NEN or an ISO are really helpful because with a standard format, it is easier to compare data with other data and select the best data in a given situation.

An Open Data platform provided by the government could be a later step, as this can be beneficial in many ways; It makes the findability of the Open Data published their better, it makes it easier to combine data from different sources and it can creates the possibility to easily compare data from different sources because it is published in the same database.

As OD can lead to increased social welfare, the government can promote Open Data initiatives by creating an environment in which it is easier for organizations to share and use OD.

6.1.2 Scientific Contribution

The field of Open Data research is starting to expand and that is important because the knowledge of Open Data is can have an positive impact on the scientific society. As there was no research into the integration of Open Data in Engineering Asset Management, this research tried to filled that scientific gap.

The literature review provides a overview from the known information about EAM and OD, an overview that did not exist until now (see Table 13). The case study provide insights in the deeper complexity of EAM and why OD can be useful but also very difficult to implement in such an environment. This information can be used to develop further insights and can serve as starting point for other case studies about (other forms of) OD in EAM. The lack of focus on the governance perspective propose also possibilities for further research.

The expert review session is scientifically relevant as the experts were able to validate the model and to argue about the findings of the thesis.

The particularities of Engineering Asset Management make that there are differences between the use of Open Data in EAM and in other areas. In a broader prospective, this research helped with showing that the barriers that are commonly found (technical boundaries) are in an EAM context not always the main problem. The complexity of EAM and the governance structures in and between EAM organisations make the integration of OD more complicated than the technical boundaries that are commonly mentioned. This means that the current theory is not directly applicable in the field of EAM.

6.2 Discussion

As with all research, choices have been made that have influenced the outcomes of the research. These choices were necessary to be able to complete the thesis within the possibilities and in the given time period.

The most important choices:

1. Conducting a semi-structured literature review.

2. Conducting only one case study.

3. Being partly involved in the case study as a researcher.

4. Conducting the expert review with only people from Oxand NL.

6.2.1 Limitations

These choices let to some limitations that are connected to results of this master thesis, despite the efforts to conduct the study as thorough as possible.

At first the literature study covers 30 academic sources, which are gathered in a semi-structured way (based on the literature search questions). Literature that slightly relates with the topic but that does not consists of terms from this search queries can be left out. As a result of a combination of selection by rules and the use of a snowball-strategy, the literature review can be a bit biased by the authors view on the topic. The choice for this method is that it offers the possibility to find most relevant literature without increasing the search time for literature extremely.

The lessons learned from the case study are interesting, but it is possible that other aspects come to light when case studies with other Open Data (then Traffic data, red.) are conducted. Because of that it would be interesting to see other case studies into the possibilities to use Open Data in Engineering Asset Management. As traffic data has the closed link to EAM compared to other OD sources, I chose to use traffic data for the case study in this thesis.

Because of the nature of the case study, I was directly involved as a researcher in the case study. That is the reason for splitting the research in a analysis part (non-influenced) and the implementation part (conducted by the researcher). In this way the findings from the case study are influenced as minimal as possible.

At last, the choice to use only Oxand employees for the expert review could have influenced the outcomes of the expert review. As Oxand is focused on specific processes in the EAM-business, it is assumable that the opinions from the experts are centered around this perspective and not from the whole EAM sector. As the Covid19 virus made it difficult to reach out to other experts I made the choice for conducting the review with the collegues form Oxand.

6.2.2 Further research

More research to the specific instances of Open Data use in all kind of situations can help to make Open Data more available for organisations to work with. Besides that, research focused on possible interventions from the government to enforce or promote standardisation of ways in which open data is made available would be helpful for the Engineering Asset Management sector in specific.

As for the case study, a pilot study where a traffic model based on the OD is used as a tool for improved estimation of traffic disruption would be interesting as real-world testing is needed to estimate the benefits of such a model. Without real-world testing, contractors will be reluctant to invest money in such innovations.

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A Research Planning

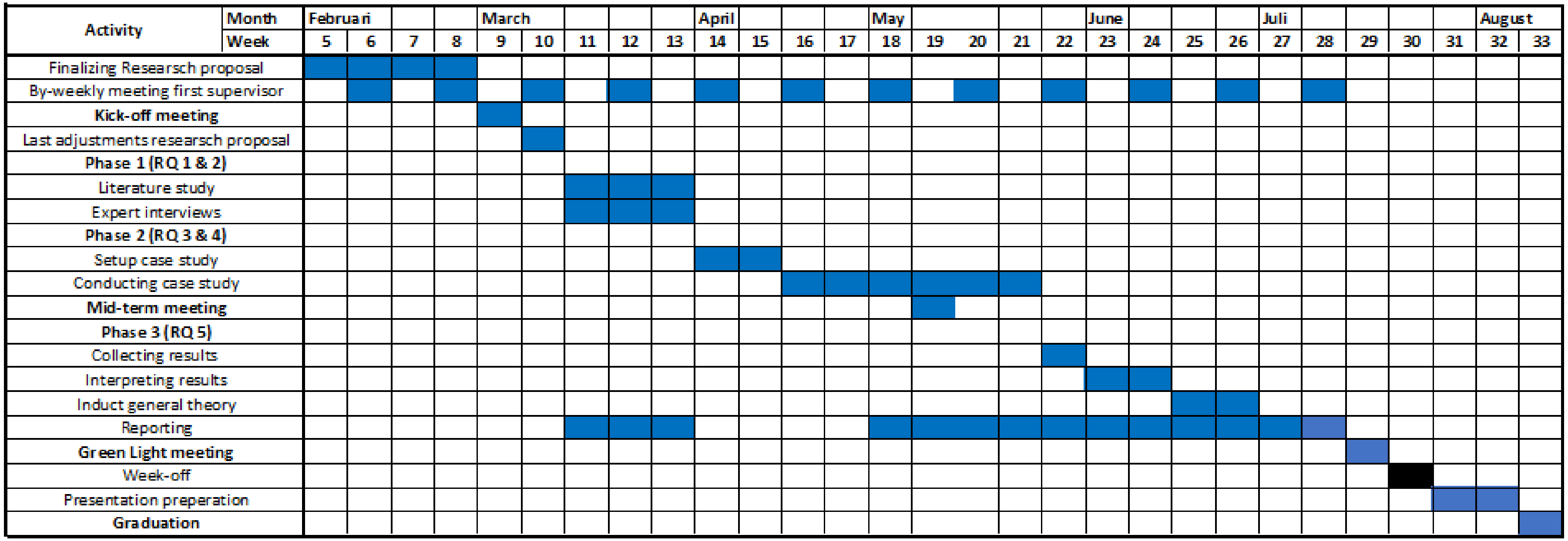


Figure 20: Research Planning

B Interview Protocol

Interview Questions (NL) for interview with stakeholders of the IJsselbruggen / ViA15 case:

Question sequence 1:

- Welke stappen zijn er genomen om te bepalen op welke manier de ontlasting van de IJsselbruggen / het doortrekken van de A15 zo goed mogelijk plaats kon vinden?
- Welke data / modellen zijn hiervoor gebruikt?
- Waarom is hiervoor voor gekozen / waren er andere opties?
- Welke inzichten zijn daarmee verkregen?
- Hoe hebben deze inzichten bijgedragen aan de uiteindelijke beslissingen?

Question sequence 2 (RWS Only);

- Is er na de afsluiting enige evaluatie geweest op hoe het daadwerkelijke effect was?
- Volgens de Rijkswaterstaat website is er "meer hinder dan vooraf verwacht", waar zat de inschatting er naast?
- Op welke manier wordt er omgegaan met het feit dat er nu al meer hinder is dan verwacht?

Question sequence 3:

- In hoeverre is er rekening gehouden met het project ViA15 waarbij er gelijktijdig werkzaamheden zullen zijn op de IJsselbruggen en vlak daarbij op de A12 om een aansluiting van de A15 op de A12 te realiseren?

Question sequence 4:

- Zou een model dat gebruik maakt van real-time verkeersdata, dat zowel een voorspellende component (wat gebeurt er als ik deze weg afsluit op de andere wegen) als een evaluatieve component (wat is het effect van de wegafsluiting enkele minuten / uren / dagen / weken later) heeft een nuttige toevoeging zijn?

C Interview Transcript

The interview was held in Dutch. This transcription is not a literal translation of the interview but somewhere between a literal translation of the Dutch transcript and a summary.

C.1 Interview with a traffic management consultant

Question 1: What is your job description and what are you work activities on a normal working day?

Back in the days "we" (my colleagues and I red.) where called operational traffic experts. Nowadays, our job is called "consultant in traffic management". That is a position on a traffic control center. The job description is not for all consultants in traffic management the same, a clear job description is missing. I've around 4 to 5 colleagues working at the traffic control center Wolfheze (Traffic control center Rijkswaterstaat Oost-Nederland District Zuid red.) and those colleagues are all responsible for a specific region and they try to "perform" traffic management in their region. This is in all kind of situations, such as large events and road construction projects. For those situations that can lead to traffic disruption, scenarios are developed to find an adequate solution for problems that can occur. I am not in direct contact with such region (like his other colleagues, red.) but I'm mostly busy with traffic numbers. For example this morning a colleague called with the question if I could check with traffic data some claims about a specific traffic situation from a few days ago. They wanted to know at what time the traffic jam started and how long the traffic jam lasted to check if the contractor indeed started and finished the road construction activities insight the allowed time-frame. I've helped him with a time path diagram to show how the traffic jam developed over time. Evaluating traffic choices and giving inside in why and how things happened is the main part of my job.

Question 2: Where you directly involved in the IJsselbruggen case?

I have when the new system was installed on the bridge (the new lane layout red.) I was asked to think about the possibilities to set up some monitoring program to be able to see the impact of the new lane setup on the traffic flows. Therefore I have - only for a short period of time, because the hinder quickly diminished as a result of the Corona Crises - monitored a bunch of travel time trajectories on the different roads. This trajectories included the A12 (from before junction Velperbroek to the boarder of Germany) and the surrounding roads A348 and N325 (both the last few KM before the connection at the Velperbroek junction with the A12).

Question 3: What was the goal of this monitoring, mostly to optimize or mostly to evaluate?

It's main goal was to provide some evidence for the "feeling" that arises in meetings, where I'am not a part of, that have the function to evaluate the developments, that there is more hinder than expected because of the new measures on the IJsselbruggen. For example, the province states: "the traffic is stuck a large part of the time, so something needs to change". And then the question arises; Is the traffic indeed stuck for a large part of the time? How is the traffic disruption in comparison with the old situation? Thereafter I did some research into the old situation and traffic disruptions on the IJsselbruggen is not a new phenomena. It is not only because of the new lane layout as consequence of the relieve measures that there are traffic disruptions.

So for my research I started with the old situation (null-situation) and when you look at the old situation it is clear that the IJsselbruggen already was a bottleneck. So it is important to compare that with the new situation to find out how much the traffic disruptions are increased.

Question 4: So afterwards there is some analysis on to evaluate the impact of the measurements, is there also in advance some analysis to create the plan?

There certainly is in some way. There is the possibility - when road construction is needed - to use a road-construction planner (the one we use is Transpute) that uses historic data to see what moment would historically be the best time to do the construction work. This kind of tools can give insight in the possible effects on the capacity of the road of - for example - lane narrowing or lane blocking. How much traffic can still go trough and with what speeds? In this way it is possible to make an estimation for the possible effects of road construction on the traffic flows.

Question 5: The reason I asked this question is because in the nearby future the ViA15 project (construction) will start and it is possible that the combination of both projects will lead to even more traffic disruption. Is there already taken some action to get insight in the possible negative impacts?

What I know is that in the near future they will start with adding an extra lane on both directions on the A12 between the IJsselbruggen and the new - still to be realized - junction between the A12 and A15. Furthermore the project details - mostly the time-path - is currently in development and not know yet so currently that is not researched yet.

The planning is to start with the widening of the A12 because that will relieve the pressure on the traffic flows from the IJsselbruggen. So the whole project would then be split-up in two parts; The widening of the A12 and the construction of the missing part of the A15 and the junction A12 / A15.

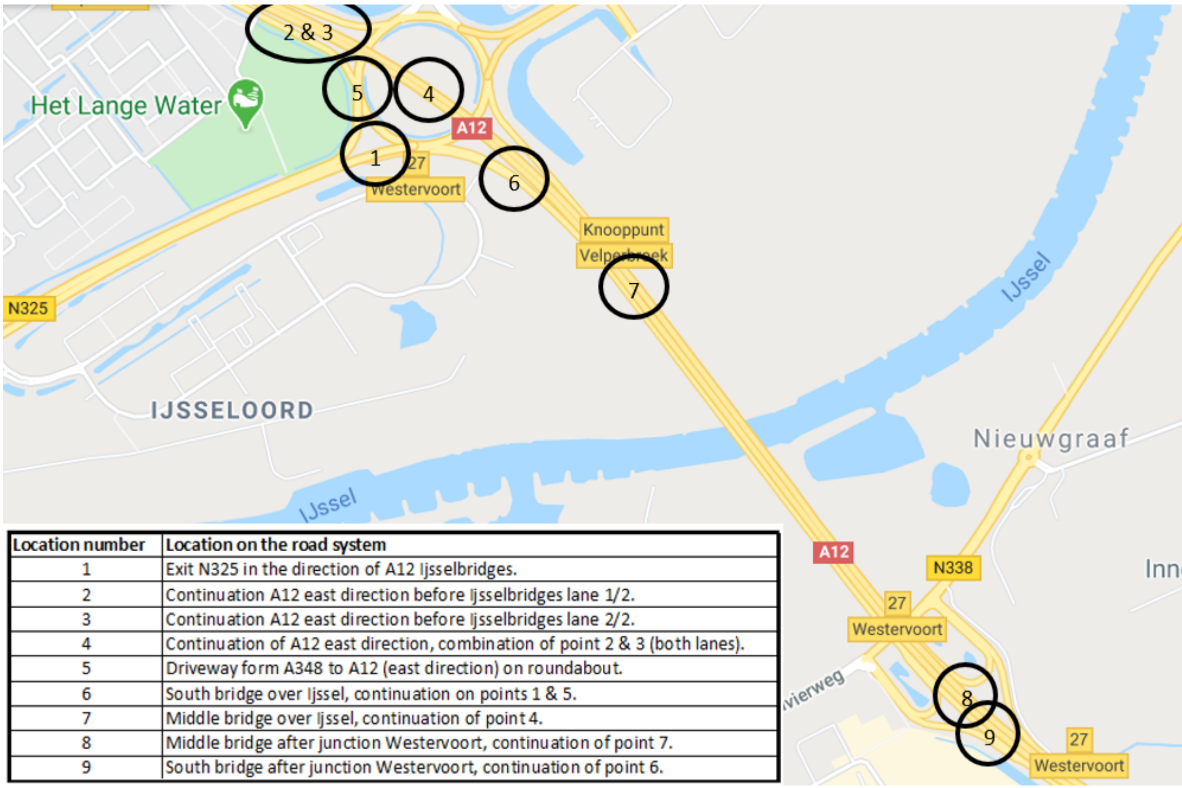
Question 6: Now is there openly available data that is updated every minute about the intensities and average speeds on these roads. Currently, is there any real-time monitoring system that can helps decision making for choosing the right time to start / finish road construction?

In principle, the road authorities decide when "slots" are given to contractors to conduct road construction. This is based on the historic data we spoke earlier about. Although real-time monitoring can be interesting, I don't think that there is any tuning between the road authorities and the contractors about the fine-tuning of the start- or end-time of the construction work.

In the current line of work, such last minute changes are not standard practise and therefore real-time monitoring is not very useful. The contractors need to make their planning in advance so last minute changes will not be a improvement from their viewing point. It cloud be helpful, but then the system shoud be changed.

D Case Analysis Results

D.1 East direction



Location number	Location on the road system
1	Exit N325 in the direction of A12 Ijsselbridges.
2	Continuation A12 east direction before Ijsselbridges lane 1/2.
3	Continuation A12 east direction before Ijsselbridges lane 2/2.
4	Continuation of A12 east direction, combination of point 2 & 3 (both lanes).
5	Driveway form A348 to A12 (east direction) on roundabout.
6	South bridge over Ijssel, continuation on points 1 & 5.
7	Middle bridge over Ijssel, continuation of point 4.
8	Middle bridge after junction Westervoort, continuation of point 7.
9	South bridge after junction Westervoort, continuation of point 6.

Figure 21: East-bound traffic measure locations used in analysis.

Data for location 1 is missing.

Location 2
(RWS01_MONICA_00D00C14E440D0070007)

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	116	117	1	25	24,8	-0,2
01:00 - 01:59	117	113	-4	9,3	9,3	0
02:00 - 02:59	117	112	-5	6,7	7,7	1
03:00 - 03:59	117	118	1	11,5	8,6	-2,9
04:00 - 04:59	117	117	0	34,4	23,2	-11,2
05:00 - 05:59	116	115	-1	92	71,8	-20,2
06:00 - 06:59	113	113	0	452	397,8	-54,2
07:00 - 07:59	94	110	16	974,5	900	-74,5
08:00 - 08:59	110	110	0	954,9	905,4	-49,5
09:00 - 09:59	109	103	-6	791,7	719,3	-72,4
10:00 - 10:59	102	105	3	832,7	745,1	-87,6
11:00 - 11:59	93	107	14	837,3	745,5	-91,8
12:00 - 12:59	108	107	-1	860,9	824,5	-36,4
13:00 - 13:59	105	102	-3	933,5	925,2	-8,3
14:00 - 14:59	91	93	2	1042,2	1055,3	13,1
15:00 - 15:59	61	80	19	1331,4	1308,4	-23
16:00 - 16:59	22	30	8	1197,7	1198,4	0,7
17:00 - 17:59	19	27	8	1087,7	1042,5	-45,2
18:00 - 18:59	53	65	12	931,2	844,2	-87
19:00 - 19:59	111	110	-1	537	456,7	-80,3
20:00 - 20:59	112	112	0	291,7	245,6	-46,1
21:00 - 21:59	113	113	0	208,9	161,9	-47
22:00 - 22:59	114	114	0	169,8	144,6	-25,2
23:00 - 23:59	116	117	1	117,1	84,8	-32,3

Location 3
(RWS01_MONICA_00D00C14E440D007000B)

	Speed			**Intensity**		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	102	102	0	189,5	180,2	-9,3
01:00 - 01:59	100	99	-1	104,4	106,1	1,7
02:00 - 02:59	98	99	1	86,5	80,8	-5,7
03:00 - 03:59	98	99	1	114,9	104,4	-10,5
04:00 - 04:59	99	98	-1	197,1	166	-31,1
05:00 - 05:59	98	98	0	321,3	309,4	-11,9
06:00 - 06:59	97	97	0	701,3	687,9	-13,4
07:00 - 07:59	85	97	12	967,3	972,6	5,3
08:00 - 08:59	98	98	0	1015	1010,6	-4,4
09:00 - 09:59	97	91	-6	975,6	958	-17,6
10:00 - 10:59	92	95	3	1000,3	985,7	-14,6
11:00 - 11:59	84	96	12	991,9	1002,8	10,9
12:00 - 12:59	96	96	0	1021,7	1018,6	-3,1
13:00 - 13:59	94	92	-2	1027,7	1034,8	7,1
14:00 - 14:59	81	86	5	1032	1057,4	25,4
15:00 - 15:59	52	74	22	1055,8	1100,2	44,4
16:00 - 16:59	23	30	7	886,5	932,4	45,9
17:00 - 17:59	18	28	10	829,8	878,1	48,3
18:00 - 18:59	50	58	8	910,4	897,2	-13,2
19:00 - 19:59	98	98	0	801,7	767,8	-33,9
20:00 - 20:59	100	99	-1	654	620,9	-33,1
21:00 - 21:59	100	100	0	565,6	541,4	-24,2
22:00 - 22:59	101	101	0	522,9	491,3	-31,6
23:00 - 23:59	103	103	0	432,5	384,6	-47,9

Location 4

RWS01_MONIBAS_0121hrr1342ra

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	99	97	-2	219	209,7	-9,3
01:00 - 01:59	97	94	-3	118,6	119,3	0,7
02:00 - 02:59	95	94	-1	95,7	91,7	-4
03:00 - 03:59	96	96	0	127,8	115,9	-11,9
04:00 - 04:59	97	95	-2	234,9	192,2	-42,7
05:00 - 05:59	97	96	-1	418,7	387,9	-30,8
06:00 - 06:59	97	96	-1	1162,2	1091	-71,2
07:00 - 07:59	88	95	7	1948,5	1873	-75,5
08:00 - 08:59	97	95	-2	1971,3	1920,6	-50,7
09:00 - 09:59	96	91	-5	1772,8	1690,2	-82,6
10:00 - 10:59	89	92	3	1836	1732,4	-103,6
11:00 - 11:59	83	93	10	1833,3	1751,6	-81,7
12:00 - 12:59	95	93	-2	1877,2	1855,3	-21,9
13:00 - 13:59	92	87	-5	1963,6	1967,4	3,8
14:00 - 14:59	71	83	12	2070,8	2118,5	47,7
15:00 - 15:59	52	68	16	2365,5	2401,5	36
16:00 - 16:59	21	26	5	2076,7	2135,7	59
17:00 - 17:59	18	25	7	1953	1946,6	-6,4
18:00 - 18:59	51	57	6	1871	1773,4	-97,6
19:00 - 19:59	97	95	-2	1345,2	1239	-106,2
20:00 - 20:59	98	97	-1	952,5	875,2	-77,3
21:00 - 21:59	99	97	-2	785	710,8	-74,2
22:00 - 22:59	100	98	-2	704,6	645,5	-59,1
23:00 - 23:59	101	99	-2	557,3	475,6	-81,7

Location 5
(GEO0K_K_RWSTI362205)

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	93	90	-3	44,3	28,8	-15,5
01:00 - 01:59	91	87	-4	18	9,7	-8,3
02:00 - 02:59	91	88	-3	11,5	6	-5,5
03:00 - 03:59	90	87	-3	16,3	7,2	-9,1
04:00 - 04:59	91	89	-2	33,4	25,1	-8,3
05:00 - 05:59	90	89	-1	118,8	77,5	-41,3
06:00 - 06:59	90	88	-2	394,1	345,5	-48,6
07:00 - 07:59	90	86	-4	941,3	899	-42,3
08:00 - 08:59	89	86	-3	883,5	791,7	-91,8
09:00 - 09:59	88	83	-5	684,1	600,2	-83,9
10:00 - 10:59	62	82	20	679,3	581,2	-98,1
11:00 - 11:59	86	83	-3	756,1	581,4	-174,7
12:00 - 12:59	87	83	-4	821,9	680,5	-141,4
13:00 - 13:59	87	82	-5	903,5	769,8	-133,7
14:00 - 14:59	85	81	-4	970,5	832,2	-138,3
15:00 - 15:59	73	78	5	1220	1106,4	-113,6
16:00 - 16:59	52	62	10	1654,7	1637,7	-17
17:00 - 17:59	42	61	19	1590	1565,2	-24,8
18:00 - 18:59	80	79	-1	1012,9	808,4	-204,5
19:00 - 19:59	91	85	-6	552,5	432,7	-119,8
20:00 - 20:59	93	87	-6	348,4	261,6	-86,8
21:00 - 21:59	93	88	-5	280,7	205,1	-75,6
22:00 - 22:59	94	89	-5	240,9	176	-64,9
23:00 - 23:59	93	89	-4	151,8	95,8	-56

Location 6
(RWS01_MONIBAS_0120vwy1347ra)

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	93	81	-12	176,2	163,5	-12,7
01:00 - 01:59	91	81	-10	79,9	79,2	-0,7
02:00 - 02:59	89	80	-9	51,3	47,5	-3,8
03:00 - 03:59	90	80	-10	60,3	55,4	-4,9
04:00 - 04:59	90	81	-9	130,1	131,5	1,4
05:00 - 05:59	91	82	-9	374,8	368,4	-6,4
06:00 - 06:59	89	82	-7	1051,8	1084,3	32,5
07:00 - 07:59	87	80	-7	2150,6	2195,7	45,1
08:00 - 08:59	87	81	-6	2018,9	2002,4	-16,5
09:00 - 09:59	86	79	-7	1667,9	1703,4	35,5
10:00 - 10:59	66	77	11	1676,3	1715,5	39,2
11:00 - 11:59	84	78	-6	1816,8	1796,6	-20,2
12:00 - 12:59	85	78	-7	1991,8	1999,6	7,8
13:00 - 13:59	85	77	-8	2148,6	2208,6	60
14:00 - 14:59	84	77	-7	2242,9	2300,5	57,6
15:00 - 15:59	76	75	-1	2696	2692	-4
16:00 - 16:59	57	63	6	3378	3381,5	3,5
17:00 - 17:59	51	62	11	3325,9	3227,8	-98,1
18:00 - 18:59	81	75	-6	2196,3	2052,4	-143,9
19:00 - 19:59	90	79	-11	1368,3	1307,6	-60,7
20:00 - 20:59	93	81	-12	945,4	884,1	-61,3
21:00 - 21:59	93	82	-11	806,7	759,9	-46,8
22:00 - 22:59	93	83	-10	688,3	645,3	-43
23:00 - 23:59	94	83	-11	442,4	409	-33,4

Location 7
(RWS01_MONIBAS_0121hrr1347ra)

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	98	91	-7	219,8	112	-107,8
01:00 - 01:59	95	90	-5	118	58,5	-59,5
02:00 - 02:59	94	91	-3	95,7	34,1	-61,6
03:00 - 03:59	94	92	-2	128,3	39,6	-88,7
04:00 - 04:59	96	92	-4	235,8	90,5	-145,3
05:00 - 05:59	97	92	-5	418,3	250	-168,3
06:00 - 06:59	98	91	-7	1158,5	684,3	-474,2
07:00 - 07:59	93	90	-3	1946,8	1392,7	-554,1
08:00 - 08:59	98	87	-11	1977,5	1239,9	-737,6
09:00 - 09:59	96	86	-10	1776,9	947,3	-829,6
10:00 - 10:59	90	86	-4	1843,7	930,9	-912,8
11:00 - 11:59	83	88	5	1841,4	971,3	-870,1
12:00 - 12:59	95	87	-8	1890,7	1114,2	-776,5
13:00 - 13:59	93	82	-11	1974,2	1250,6	-723,6
14:00 - 14:59	71	77	6	2067,2	1310,4	-756,8
15:00 - 15:59	52	62	10	2363,7	1670,8	-692,9
16:00 - 16:59	21	23	2	2084,4	2122,5	38,1
17:00 - 17:59	20	22	2	1986,3	2015,1	28,8
18:00 - 18:59	51	57	6	1906,6	1234,5	-672,1
19:00 - 19:59	99	89	-10	1355,2	747	-608,2
20:00 - 20:59	100	90	-10	957,5	559,8	-397,7
21:00 - 21:59	101	91	-10	787,5	522,1	-265,4
22:00 - 22:59	101	92	-9	705,5	438,1	-267,4
23:00 - 23:59	102	93	-9	557,6	281	-276,6

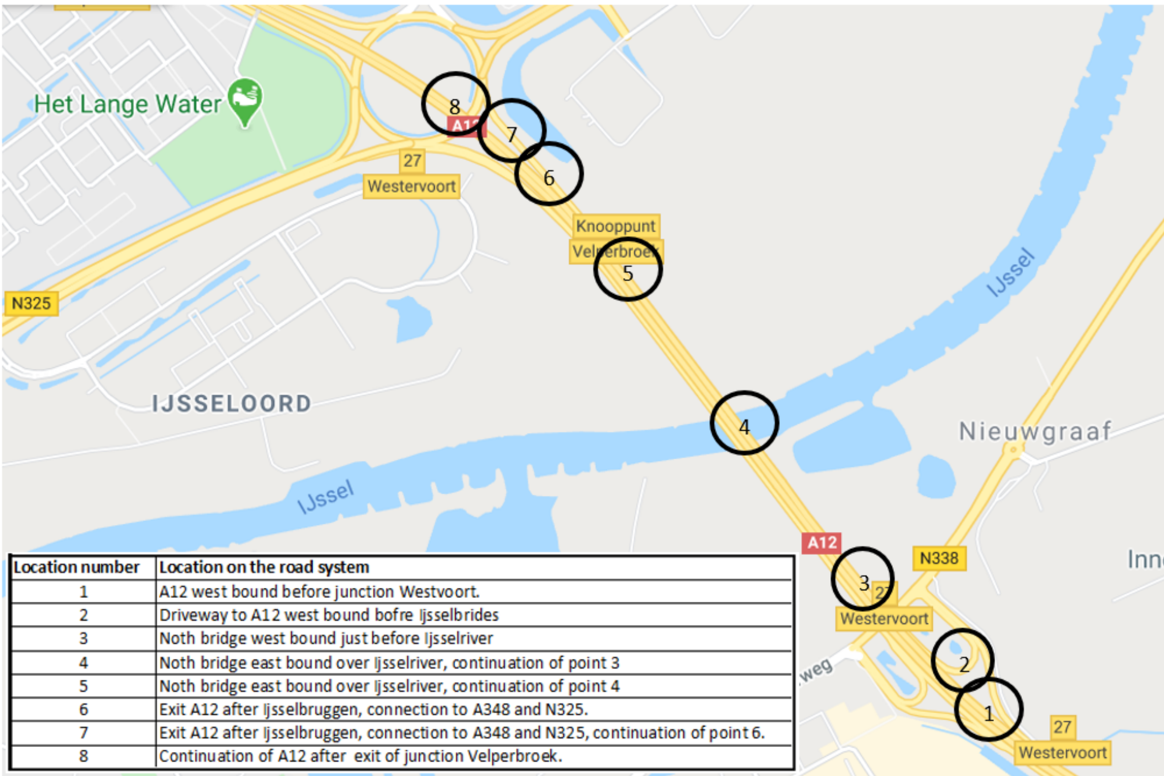
Location 8
(RWS01_MONIBAS_0121hrr1355ra)

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	96	90	-6	266,4	276,2	9,8
01:00 - 01:59	95	87	-8	156,4	169,9	13,5
02:00 - 02:59	93	88	-5	132,3	129,7	-2,6
03:00 - 03:59	93	89	-4	176,5	167,4	-9,1
04:00 - 04:59	93	89	-4	303,7	279,9	-23,8
05:00 - 05:59	93	89	-4	528,8	532,8	4
06:00 - 06:59	94	90	-4	1354,4	1373,2	18,8
07:00 - 07:59	94	91	-3	2085,4	2109,1	23,7
08:00 - 08:59	98	87	-11	2111	2133,4	22,4
09:00 - 09:59	95	87	-8	1944,6	1966	21,4
10:00 - 10:59	91	85	-6	2019,8	2017,7	-2,1
11:00 - 11:59	82	88	6	2007,9	2017,2	9,3
12:00 - 12:59	93	86	-7	2053,6	2105,1	51,5
13:00 - 13:59	93	79	-14	2140,5	2209	68,5
14:00 - 14:59	72	79	7	2192,7	2339,9	147,2
15:00 - 15:59	50	57	7	2394,5	2524,4	129,9
16:00 - 16:59	19	21	2	1831,6	1957,9	126,3
17:00 - 17:59	18	20	2	1791,5	1841,8	50,3
18:00 - 18:59	49	54	5	1989,3	1948,6	-40,7
19:00 - 19:59	97	89	-8	1503,8	1474	-29,8
20:00 - 20:59	97	89	-8	1082	1075,4	-6,6
21:00 - 21:59	98	90	-8	891,7	883,3	-8,4
22:00 - 22:59	98	91	-7	783,4	787,4	4
23:00 - 23:59	100	92	-8	626,4	590,7	-35,7

Location 9
(RWS01_MONIBAS_0120vwy1360ra)

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	91	89	-2	113,9	112	-1,9
01:00 - 01:59	91	89	-2	55	58,5	3,5
02:00 - 02:59	88	87	-1	35	34,1	-0,9
03:00 - 03:59	89	86	-3	40,8	39,6	-1,2
04:00 - 04:59	89	88	-1	87	90,5	3,5
05:00 - 05:59	89	89	0	240	250	10
06:00 - 06:59	90	91	1	589,8	684,3	94,5
07:00 - 07:59	90	91	1	1215,9	1392,7	176,8
08:00 - 08:59	91	91	0	1116,8	1239,9	123,1
09:00 - 09:59	90	90	0	861,4	947,3	85,9
10:00 - 10:59	89	88	-1	857,3	930,9	73,6
11:00 - 11:59	89	89	0	939,6	971,3	31,7
12:00 - 12:59	90	89	-1	1052,9	1114,2	61,3
13:00 - 13:59	89	89	0	1125,9	1250,6	124,7
14:00 - 14:59	89	89	0	1190,8	1310,4	119,6
15:00 - 15:59	83	86	3	1515,4	1670,8	155,4
16:00 - 16:59	41	59	18	1937,5	2122,5	185
17:00 - 17:59	46	61	15	1904,5	2015,1	110,6
18:00 - 18:59	87	88	1	1212,9	1234,5	21,6
19:00 - 19:59	92	91	-1	731,6	747	15,4
20:00 - 20:59	93	91	-2	558,2	559,8	1,6
21:00 - 21:59	93	92	-1	508,1	522,1	14
22:00 - 22:59	93	92	-1	443,6	438,1	-5,5
23:00 - 23:59	93	91	-2	286,5	281	-5,5

D.2 West Direction



Location number	Location on the road system
1	A12 west bound before junction Westvoort.
2	Driveway to A12 west bound bofre Ijsselbrides
3	Noth bridge west bound just before Ijsselriver
4	Noth bridge east bound over Ijsselriver, continuation of point 3
5	Noth bridge east bound over Ijsselriver, continuation of point 4
6	Exit A12 after Ijsselbruggen, connection to A348 and N325.
7	Exit A12 after Ijsselbruggen, connection to A348 and N325, continuation of point 6.
8	Continuation of A12 after exit of junction Velperbroek.

Figure 22: West-bound traffic measure locations used in analysis.

Location 1
RWS01_MONIBAS_0121hrl1359ra

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	95	94	-1	238	191,3	-46,7
01:00 - 01:59	90	92	2	267,4	174,5	-92,9
02:00 - 02:59	89	90	1	186,9	118,5	-68,4
03:00 - 03:59	91	93	2	238,3	165,8	-72,5
04:00 - 04:59	89	94	5	498,7	343,4	-155,3
05:00 - 05:59	93	95	2	1683,5	1175,1	-508,4
06:00 - 06:59	88	57	-31	3637,1	2151,9	-1485,2
07:00 - 07:59	84	45	-39	3608,6	1931,2	-1677,4
08:00 - 08:59	83	46	-37	3300,6	1816,2	-1484,4
09:00 - 09:59	92	65	-27	2638	1700,6	-937,4
10:00 - 10:59	92	90	-2	2284,1	1577,2	-706,9
11:00 - 11:59	92	90	-2	2289	1603	-686
12:00 - 12:59	91	90	-1	2499,9	1735	-764,9
13:00 - 13:59	93	89	-4	2535,4	1757,3	-778,1
14:00 - 14:59	92	89	-3	2609	1807,7	-801,3
15:00 - 15:59	93	91	-2	2568,2	1828,6	-739,6
16:00 - 16:59	95	89	-6	2692,9	1907,1	-785,8
17:00 - 17:59	95	76	-19	2668,1	1858,8	-809,3
18:00 - 18:59	97	94	-3	1735,1	1341,9	-393,2
19:00 - 19:59	97	95	-2	1296,8	1063,4	-233,4
20:00 - 20:59	97	96	-1	984,5	858,3	-126,2
21:00 - 21:59	98	88	-10	780,8	702,7	-78,1
22:00 - 22:59	98	85	-13	771,4	627,2	-144,2
23:00 - 23:59	98	96	-2	521,5	416,5	-105

Location 2

RWS01_MONIBAS_0120vwd1359ra

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	0	53	53	22,5	22	-0,5
01:00 - 01:59	0	52	52	9,4	11,5	2,1
02:00 - 02:59	0	52	52	7,4	7,3	-0,1
03:00 - 03:59	0	49	49	14	15,5	1,5
04:00 - 04:59	0	49	49	33,3	30,8	-2,5
05:00 - 05:59	0	52	52	181,1	182,5	1,4
06:00 - 06:59	0	50	50	589	659,8	70,8
07:00 - 07:59	0	44	44	1048	1275,7	227,7
08:00 - 08:59	0	45	45	919	1145	226
09:00 - 09:59	0	49	49	525,7	581,7	56
10:00 - 10:59	0	52	52	508,2	532	23,8
11:00 - 11:59	0	52	52	584,3	622,9	38,6
12:00 - 12:59	0	52	52	649,8	718,9	69,1
13:00 - 13:59	0	51	51	692,8	762,1	69,3
14:00 - 14:59	0	51	51	732,7	817,7	85
15:00 - 15:59	0	51	51	810,9	922,3	111,4
16:00 - 16:59	0	51	51	832	921,9	89,9
17:00 - 17:59	0	52	52	717,3	790,7	73,4
18:00 - 18:59	0	53	53	486,2	505,3	19,1
19:00 - 19:59	0	53	53	413,2	433,4	20,2
20:00 - 20:59	0	53	53	371,5	408,9	37,4
21:00 - 21:59	0	53	53	253,8	259,9	6,1
22:00 - 22:59	0	54	54	135,6	122,8	-12,8
23:00 - 23:59	0	54	54	57,5	52,1	-5,4

Location 3

RWS01_MONIBAS_0121hrl1355ra

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	94	85	-9	137,4	189,8	52,4
01:00 - 01:59	92	87	-5	155,3	167,3	12
02:00 - 02:59	90	86	-4	98,9	110,3	11,4
03:00 - 03:59	93	90	-3	144,3	158,3	14
04:00 - 04:59	92	91	-1	342,4	345,3	2,9
05:00 - 05:59	96	90	-6	1391,8	1472,5	80,7
06:00 - 06:59	87	70	-17	2837,3	2901	63,7
07:00 - 07:59	86	62	-24	2739,9	2919,8	179,9
08:00 - 08:59	80	62	-18	2487,2	2728,4	241,2
09:00 - 09:59	93	72	-21	2092	2298,6	206,6
10:00 - 10:59	93	85	-8	1844,7	1987,3	142,6
11:00 - 11:59	93	84	-9	1864,2	2051,4	187,2
12:00 - 12:59	93	84	-9	2058,2	2259,8	201,6
13:00 - 13:59	94	83	-11	2080,5	2309	228,5
14:00 - 14:59	93	83	-10	2108,2	2376,4	268,2
15:00 - 15:59	94	84	-10	2088,8	2399,5	310,7
16:00 - 16:59	96	82	-14	2143	2530,7	387,7
17:00 - 17:59	96	76	-20	2144,1	2545,3	401,2
18:00 - 18:59	99	88	-11	1493,4	1677,7	184,3
19:00 - 19:59	98	90	-8	1089,6	1216,1	126,5
20:00 - 20:59	98	91	-7	819,7	938,4	118,7
21:00 - 21:59	99	83	-16	646,3	776,6	130,3
22:00 - 22:59	98	79	-19	585,6	666,5	80,9
23:00 - 23:59	98	89	-9	383,3	405,1	21,8

Location 4
RWS01_MONIBAS_0121hrl1351ra

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	102	94	-8	176,8	168,1	-8,7
01:00 - 01:59	99	92	-7	168,5	148,2	-20,3
02:00 - 02:59	98	92	-6	114,8	97,3	-17,5
03:00 - 03:59	100	94	-6	163,8	132,3	-31,5
04:00 - 04:59	102	94	-8	349,2	267,2	-82
05:00 - 05:59	104	92	-12	1346,9	1309,9	-37
06:00 - 06:59	92	77	-15	2868,1	2773,8	-94,3
07:00 - 07:59	87	73	-14	2892,6	2949,5	56,9
08:00 - 08:59	81	73	-8	2562,8	2734,1	171,3
09:00 - 09:59	98	77	-21	2059,5	2181,6	122,1
10:00 - 10:59	99	87	-12	1800,2	1801,9	1,7
11:00 - 11:59	99	86	-13	1825,7	1875,2	49,5
12:00 - 12:59	98	85	-13	2051,1	2109,8	58,7
13:00 - 13:59	99	85	-14	2077,8	2181,8	104
14:00 - 14:59	98	84	-14	2099,4	2247,9	148,5
15:00 - 15:59	98	84	-14	2145,6	2336,6	191
16:00 - 16:59	99	83	-16	2219,5	2472,8	253,3
17:00 - 17:59	99	79	-20	2209,9	2425,7	215,8
18:00 - 18:59	104	89	-15	1539,4	1533,1	-6,3
19:00 - 19:59	104	91	-13	1146,7	1082,9	-63,8
20:00 - 20:59	105	93	-12	909,6	858,2	-51,4
21:00 - 21:59	105	91	-14	743,1	735,2	-7,9
22:00 - 22:59	105	97	-8	649,2	590,3	-58,9
23:00 - 23:59	105	97	-8	433,5	363,4	-70,1

Location 5

RWS01_MONIBAS_0121hrl1347ra

		Speed			Intensity	
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	85	88	3	185,1	183,8	-1,3
01:00 - 01:59	83	87	4	176	168,1	-7,9
02:00 - 02:59	81	87	6	120,9	110,5	-10,4
03:00 - 03:59	84	91	7	171,4	163,4	-8
04:00 - 04:59	87	92	5	365,4	349,5	-15,9
05:00 - 05:59	91	92	1	1414	1552,5	138,5
06:00 - 06:59	83	80	-3	3034,6	3143	108,4
07:00 - 07:59	77	75	-2	3052,1	3361,2	309,1
08:00 - 08:59	74	76	2	2712,3	3124,8	412,5
09:00 - 09:59	84	81	-3	2181,2	2487,9	306,7
10:00 - 10:59	87	86	-1	1908,4	2097,2	188,8
11:00 - 11:59	87	85	-2	1943,6	2179,5	235,9
12:00 - 12:59	85	85	0	2186,8	2438,9	252,1
13:00 - 13:59	86	84	-2	2221	2517,9	296,9
14:00 - 14:59	86	84	-2	2252,4	2594,6	342,2
15:00 - 15:59	85	84	-1	2322,6	2678,8	356,2
16:00 - 16:59	86	84	-2	2399,8	2845,8	446
17:00 - 17:59	86	81	-5	2351,2	2803,3	452,1
18:00 - 18:59	90	88	-2	1635,3	1810,4	175,1
19:00 - 19:59	91	90	-1	1225,8	1307,8	82
20:00 - 20:59	91	91	0	973,6	1050	76,4
21:00 - 21:59	91	90	-1	793,9	859,6	65,7
22:00 - 22:59	90	90	0	679,7	683,2	3,5
23:00 - 23:59	89	90	1	451,5	417,1	-34,4

Location 6
GEO0K_Z_RWSTI4069

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	86	84	-2	108	116,4	8,4
01:00 - 01:59	85	82	-3	68,2	76,8	8,6
02:00 - 02:59	84	82	-2	46,7	49,1	2,4
03:00 - 03:59	82	82	0	53,5	63,8	10,3
04:00 - 04:59	85	85	0	108,9	115,9	7
05:00 - 05:59	89	87	-2	402,1	388,7	-13,4
06:00 - 06:59	72	75	3	1543,9	1402,4	-141,5
07:00 - 07:59	45	60	15	2333,2	2062,2	-271
08:00 - 08:59	50	50	0	2211,9	2011,4	-200,5
09:00 - 09:59	68	66	-2	1493,4	1423,2	-70,2
10:00 - 10:59	79	79	0	1271,3	1288,5	17,2
11:00 - 11:59	79	78	-1	1341,4	1367,8	26,4
12:00 - 12:59	73	76	3	1464,3	1532,3	68
13:00 - 13:59	76	74	-2	1544	1582,6	38,6
14:00 - 14:59	73	72	-1	1641	1671	30
15:00 - 15:59	75	74	-1	1622,2	1681,1	58,9
16:00 - 16:59	56	72	16	1826,1	1841,5	15,4
17:00 - 17:59	54	61	7	1901	1933	32
18:00 - 18:59	81	77	-4	1231,7	1242,8	11,1
19:00 - 19:59	82	80	-2	984	975,4	-8,6
20:00 - 20:59	84	82	-2	760,1	789,3	29,2
21:00 - 21:59	84	83	-1	591,9	568,4	-23,5
22:00 - 22:59	84	84	0	541,2	501	-40,2
23:00 - 23:59	86	85	-1	317,8	303,2	-14,6

Location 7

RWS01_MONIBAS_0120vwc1344ra

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	82	81	-1	93	112,6	19,6
01:00 - 01:59	82	79	-3	59,2	73,8	14,6
02:00 - 02:59	82	79	-3	38,7	46,6	7,9
03:00 - 03:59	79	79	0	45,1	61,1	16
04:00 - 04:59	82	81	-1	100,3	111,8	11,5
05:00 - 05:59	84	83	-1	384,9	363	-21,9
06:00 - 06:59	67	69	2	1421,8	1264,7	-157,1
07:00 - 07:59	45	55	10	1981,3	1735,8	-245,5
08:00 - 08:59	49	49	0	1847,5	1663,3	-184,2
09:00 - 09:59	65	62	-3	1340,7	1251,4	-89,3
10:00 - 10:59	74	74	0	1194,4	1147,3	-47,1
11:00 - 11:59	73	72	-1	1227,4	1219	-8,4
12:00 - 12:59	70	70	0	1309,3	1358,1	48,8
13:00 - 13:59	70	67	-3	1405,1	1398,3	-6,8
14:00 - 14:59	66	66	0	1450,7	1462,8	12,1
15:00 - 15:59	68	67	-1	1433	1473,7	40,7
16:00 - 16:59	49	64	15	1550,4	1584,2	33,8
17:00 - 17:59	46	54	8	1599,4	1625	25,6
18:00 - 18:59	74	71	-3	1129,5	1131,3	1,8
19:00 - 19:59	78	76	-2	922,9	903,5	-19,4
20:00 - 20:59	80	78	-2	716,9	737,1	20,2
21:00 - 21:59	81	80	-1	509,6	530,2	20,6
22:00 - 22:59	81	81	0	470,4	468,9	-1,5
23:00 - 23:59	83	82	-1	275,8	288,7	12,9

Location 8

RWS01_MONIBAS_0121hrl1342ra

	Speed			Intensity		
Hour of the day	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)	15-02 to 15-03 2019	15-02 to 15-03 2020	Difference (new-old)
00:00 - 00:59	90	88	-2	186,1	171	-15,1
01:00 - 01:59	88	86	-2	176,7	161,1	-15,6
02:00 - 02:59	87	85	-2	121,2	108,1	-13,1
03:00 - 03:59	89	87	-2	171,9	163	-8,9
04:00 - 04:59	90	88	-2	363,1	346,3	-16,8
05:00 - 05:59	92	89	-3	1404,8	1515,8	111
06:00 - 06:59	84	85	1	3049	2809,1	-239,9
07:00 - 07:59	80	85	5	3056,7	2720,1	-336,6
08:00 - 08:59	81	86	5	2714,8	2532,7	-182,1
09:00 - 09:59	85	86	1	2191,9	2179,6	-12,3
10:00 - 10:59	88	86	-2	1911,4	1832,8	-78,6
11:00 - 11:59	88	86	-2	1945,7	1915,1	-30,6
12:00 - 12:59	87	86	-1	2181,3	2131,4	-49,9
13:00 - 13:59	88	86	-2	2217	2191,9	-25,1
14:00 - 14:59	87	86	-1	2256	2241,2	-14,8
15:00 - 15:59	86	87	1	2325,2	2326,7	1,5
16:00 - 16:59	89	87	-2	2403,6	2396,5	-7,1
17:00 - 17:59	90	88	-2	2349,8	2268,4	-81,4
18:00 - 18:59	92	89	-3	1638,8	1541,2	-97,6
19:00 - 19:59	93	90	-3	1223,1	1143,3	-79,8
20:00 - 20:59	93	90	-3	974,8	923,8	-51
21:00 - 21:59	94	91	-3	794,2	760	-34,2
22:00 - 22:59	94	91	-3	679,6	595,9	-83,7
23:00 - 23:59	93	90	-3	453,6	360,7	-92,9