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Design of a flexible ICT architecture for the integration of Floating Car Data in Rijkswaterstaat's Traffic Management and Information Systems

A design science research approach

TUDelft

Design of a flexible ICT architecture for the integration of Floating Car Data in Rijkswaterstaat's Traffic Management and Information Systems

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Preface

In September 2015, I embarked myself in the journey of doing a master program at Delft University of Technology. Almost two years after, I can surely say it has been a challenging but rewarding experience. Throughout my Management of Technology master program, I took several courses that allowed me to complement my technical background with a broader perspective on how to look at problems and find solutions to them.

One of the courses that grabbed my interest the most was *ICT Architecture Design* by Professor Marijn Janssen and which eventually led me to dedicate my master thesis to that field. I would like to thank Marijn for the interesting insights he shared throughout the course, for providing me the opportunity to conduct a project in the area I was most interested in and off course, for his continuous guidance as my first supervisor throughout this process. I would also like to thank my two other supervisors at TU Delft, Sander van Cranenburgh and Meng Wang for their valuable insights in the field of transport and the feedback they provided, which helped me improve this report.

This project would have not been possible without the cooperation of Rijkswaterstaat, who opened up their doors to a young researcher and provided a space within their organization to conduct this research. I am especially thankful to my two external supervisors, Gerard Avontuur and Antwan Reijnen, who patiently shared their knowledge and expertise for me to get a good understanding of Rijkswaterstaat and the domain where I conducted my research. I would also like to thank all the persons who dedicated some time from their busy agendas to have a talk with me.

I also want to thank all my friends, who have made the experience of studying and living in Delft an unforgettable one. Going together through the *thesis life* and sharing advices and suggestions definitely helped improve this process.

Last but not least, I would like to dedicate a big thank you to my family, who supported me from the distance in Colombia. Without your endless support, Miguel, Myrna, Maria and Mauricio, I would not be even here writing these words.

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Summary

In the last years, Floating Car Data (FCD) has risen as a technology that has the potential to replace legacy sensors, reduce associated installation and maintenance costs and offer new possibilities in the field of traffic management. FCD refers to the use of sources such as *in-vehicle* systems with network connectivity or road users' mobile phones to collect relevant traffic information (e.g. vehicle speed or intensity).

There is extensive literature on the feasibility of using FCD for traffic management purposes and on the added value of fusing legacy sensors data with FCD. These studies have been mostly experimental and a literature review shows that there is no academic work on how to deploy and integrate legacy sensors data and FCD in an actual live setting. Driven by that same challenge faced by the Dutch road authority Rijkswaterstaat, this research aims to fill that gap by **designing a flexible ICT Architecture that integrates FCD into Rijkswaterstaat's Traffic Management and Information Systems**.

In the literature, an ICT Architecture is defined as a formal description of a system structure, its components and the interrelationships between them. Taking an architecture point of view to address this challenge is not only novel but also appropriate because it provides a comprehensive view of what changes need to take place at different levels of the organization (business, information systems and technology) for this to happen. Flexibility is highlighted as the core characteristic of the architecture because changes in the technology (e.g. evolution of FCD), market (e.g. capabilities of data providers) and organizational (e.g. role of road authorities) landscapes should be seamlessly absorbed.

In order to guide the design process, an Action Design Research (ADR) approach is used, where four main phases can be distinguished: (1) Problem formulation, (2) Building, (3) Reflection and learning and (4) Formalization of learning. The Building phase is further subdivided into the specification of design principles and requirements and the development of the solution ICT Architecture.

ADR strongly emphasizes on the synergy gained from developing a *theory-ingrained artifact* with conducting *practice-inspired research*. On the one hand, this research is grounded in ICT Architecture design theories, which has resulted in the use of an architecture framework (TOGAF) and an architecture description language (ArchiMate). Additionally, previous work in the field of FCD has been reviewed for a better assessment of the research's contribution.

On the other hand, the research has been shaped by the organizational context where it was conducted. Designing the solution ICT Architecture has proven to be an intricate process, where finding a balance between comprehensiveness (i.e. providing *the big picture*) and detailedness (i.e. including sufficient information) was one of the major challenges. Furthermore, the numerous uncertainties surrounding the integration of FCD and its idiosyncratic characteristics add complexity to the process and differentiate it from a regular architecture design exercise. A thorough desk research of company documents along with semi-structured interviews with fifteen experts from different areas of the organization were necessary to understand the complexity of the problem and to adequately inform the design.

Moreover, the design process was highly iterative and it was necessary to go back and forth between the different ADR phases before arriving at the presented result. In total, a couple of initial draft versions in paper, four high-level versions in Visio and four elaborated versions in ArchiMate were the result of this process. ADR also highlights the importance of concurrent evaluation throughout the whole design cycle. This is achieved by using three instruments: (i) over 10 working sessions with one of Rijkswaterstaat's solution architects, which allowed to incorporate new insights in every iteration and validate the design, (ii) two workshops with a panel of nine experts with different roles at Rijkswaterstaat, who analyzed nine possible scenarios formulated by the researcher and (iii) two architecture reviews from a program manager and a solution architect, who evaluated the final version of the architecture.

This research provides several contributions to Rijkswaterstaat. Firstly, up until now, there was no architectural description for the two services this research focuses on (Automatic Incident Detection and Traffic Information Provisioning). Having such overview helps the organization better understand the capabilities, limitations and interdependencies of its systems. Secondly, the designed architecture allows to derive an explicit list of changes that need to take place at Rijkswaterstaat to make the integration of FCD possible. The conducted analysis reveals that such implementation will not be a straightforward process, rather many changes at the business (e.g. establishment of contracts with data providers), information systems (e.g. implementation of new functionality at the central systems) and technology (e.g. deployment of scalable systems) levels are required. Moreover, this research makes clear the design choices that still need to be made by Rijkswaterstaat (e.g. the stipulation of a data procurement strategy) and provides some hints on which decisions to take. Finally, the research also highlights relevant concerns and raises awareness on issues that may arise during implementation. Some examples include the need to control data quality from providers or the challenges that may result due to the need to process increasing amounts of data.

The scientific contribution of this research is twofold. First, this research contributes to filling the literature gap between conducting experimental projects and executing an actual deployment of legacy technologies along with FCD. Even when the designed ICT Architecture is targeted to a specific organization, the derived high-level requirements and the architecture functional blocks can serve as a guideline for other organizations looking to integrate FCD in their traffic management systems. Additional outcomes of the design process can be leveraged by these organizations as well: (i) a set of political, technological, legal and organizational factors that may be relevant for the implementation of FCD and (ii) a sample of use cases defining how to integrate FCD and legacy technologies and providing hints on how to move towards a scenario where legacy systems can be retired.

Second, being ADR relatively new (2011), this research is one of the few to apply this method to the design of ICT Architecture. On one side, this contributes to assessing how ADR can be put into practice and to determining what its limitations can be. Through this research, it is possible to see that even though ADR provides helpful design guidelines to researchers, it remains at a very high-level and the incorporation from other methods becomes necessary. On the other side, the lessons learned from the design process can contribute to the ICT Architecture Design field. These lessons have been abstracted into four design principles and they are an extension to the ADR design principles: (1) early incorporation of both business and technical perspectives in the design process, (2) utilization

of projection methods (e.g. scenario analysis) when implementation of the artifact is not possible, (3) *immersion* in the organization operations to acquire richer perspectives and (4) formal registry of design activities for an improved learning process.

Recommendations for further research are likewise twofold. First, the designed ICT Architecture for Rijkswaterstaat can serve as the departure point for the development of a reference architecture for the use of FCD in traffic management. This reference architecture would require a higher level of abstraction to be fully leveraged by any organization and it can be analogue to the existing reference architecture for Cooperative ITS[1] (i.e. DITCM Architecture). Second, it is recommended to build on the experience of researchers who have applied design science research (DSR) for ICT Architecture Design and elaborate on a DSR methodology applied to that field. This methodology should be able to incorporate existing architecture frameworks (e.g. TOGAF) while still giving the designer enough freedom to choose between any of them.

Keywords: ICT Architecture, Flexibility, Design Science Research, Action Design Research, Traffic Management.

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[1] Cooperative ITS (Cooperative Intelligent Transport Systems) refers to systems that allow vehicles, infrastructure and other road users to communicate with each other.

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Abbreviations

ADL	Architecture Description Language
ADR	Action Design Research
AID	Automatic Incident Detection
BPMN	Business Process Modelling Notation
CS	Central System
DAS	Distributed Acoustic Sensing
DS	Detector Station
DSR	Design Science Research
FCD	Floating Car Data
FEP	Front End Processor
ICT	Information and Communications Technology
IS	Information Systems
LIB	*Lokale Ingreep Bron* = Local Operation Source
MONiCA	Monitoring Casco System
MSI	Matrix Signal Indicator
MTM-2	Motorway Traffic Management System
NDW	National Data Warehouse
OS	Outstation
SOA	Service Oriented Architecture
TIP	Traffic Information Provisioning
TMC	Traffic Management Center
TOP	Transaction Oriented Processor
UDP	User Datagram Protocol
WKS	*Wegkantsysteem* = Roadside System

1 Introduction

"Transport is fundamental to our economy and society. Mobility is vital for growth and job creation. European Transport is at a crossroad. Old challenges remain but new have come" (European Commission, 2011, p. 3). The Netherlands, being an important gateway in Europe due to its privileged location, is an example of an economy that heavily relies on transport and logistics. In the Netherlands traffic density is relatively high when compared to other countries. This directly relates to its population's high density and to the great amount of freight transport in the country (Statistics Netherlands, 2015, p. 9).

Traffic Management becomes key to adequately address this continuous demand for road usage and to overcome any challenges derived from it. Traffic Management allows for the improvement of road operation, while optimizing the available capacity of the network infrastructure. One of the key players in the Traffic Management field in the Netherlands is Rijkswaterstaat, "the executive agency of the Ministry of Infrastructure and the Environment, responsible for the Dutch main road network, the main waterway network, the main water systems, and the environment in which they are embedded" (Ministry of Infrastructure and the Environment, 2017).

One of the main focuses of Rijkswaterstaat is what it is known as Smart Mobility: the use of ICT solutions to maintain mobility and sustain the life quality in the Netherlands (Rijkswaterstaat, 2016c). These ICT solutions help support different services such as traffic signaling during incidents or events (e.g. traffic jams) for safety purposes or traffic information provisioning to third parties who offer their own services (e.g. route planning). The development of new technologies, the offering of new services by third parties and the changing role of Rijkswaterstaat and other players in this field are most likely to transform the way these services are fulfilled.

Take for example the way the automobile industry is evolving with the development of autonomous cars and peer-to-peer communication between drivers, vehicles and the environment. Think of mobile apps that allow users to get real time information about variables in their cars or about the fastest route to reach their destination. Think of vehicles that can communicate with each other to prevent accidents or that can determine if the traffic light ahead is red or green. These developments bring great possibilities but also great uncertainties for stakeholders involved in Traffic Management: users, data and service providers and road management authorities.

In this first chapter, the problem to be dealt in this research will be specified in section 1.1. Once the problem and the context where it can be placed have been made clear, the scope of the research and a clear and achievable research objective will be defined in section 1.2. Finally, section 1.3 will present the outline of the rest of this document for the readers' clarity.

1.1 Problem Statement

In the changing scenario described before, many questions arise for Rijkswaterstaat as a road management authority. Will the services provided by Rijkswaterstaat still be needed in the future? If so, to what extent? Will Rijkswaterstaat play the same role of gathering and delivering information or will new players enter the stage (e.g. service providers providing indications during traffic jams)?

Will this future scenario look like we imagine it or will there be new technologies offering new possibilities?

These are just some sample questions that illustrate that this is a complex problem where factors such as technology path dependencies, technology diffusion and acceptance or interest of various stakeholders are at play. It is not possible to completely take these uncertainties out of the picture and come up with a definite answer to this type of questions. Nevertheless, it is important to craft a strategy to react as effectively as possible to changes and keep up with this dynamic environment. This strategy could be summarized in one word: ***flexibility***. According to Gerard Avontuur, program manager at Rijkswaterstaat, "it is important to choose a flexible path from today towards the future. A path that can be adjusted by changing insights" (Rijkswaterstaat, 2015d). Such flexibility can be reflected in many levels: design of individual systems, the procurement and replacement strategy for components of the system or the design of an overall ICT architecture.

The focus of this research is on the latter component: the **ICT architecture** that specifies what the various system components are and the relationships between them. In the context of an ICT architecture, designing for flexibility means designing an architecture (i) where components can be seamlessly replaced and integrated as technology changes and (ii) that prevents lock-ins by easily allowing different players to provide or use services within the architecture.

Designing such architecture not only allows to prepare for changes in tomorrow's landscape but it also allows to address current issues such as: what to do with legacy systems approaching their end of life or how to reduce costs of current systems and free up budget for new technologies. Developing such architecture is not only relevant for road management authorities like Rijkswaterstaat but it is useful for other stakeholders who benefit from being part of a traffic management system (e.g. road users, data and service providers). Drivers would not need to worry about changes on the service they receive when they switch from one technology to another (e.g. using a new car with connectivity capabilities instead of using their smartphones). Data and service providers could easily deploy and offer new services without having to request major changes on the existing architecture.

There are many enabling technologies that are transforming the way data is collected and processed and the way information is provided to road users. In this research project, the focus is on the use of **Floating Car Data (FCD)**, as one of the technologies leading change in traffic management applications. FCD is data obtained from *in-vehicle* sources used to generate traffic information (e.g. speed, number of cars, route). An example would be the determination of a vehicle's position via its GPS system or via a smartphone within that vehicle. In the latter case, this information can be retrieved from previously installed apps on the phone or from the cellular network itself (e.g. 3G)

There are numerous pilots where FCD has been deployed in cities all around the world. However, these pilots have been limited to the sole use of FCD and no other data sources. There is also extensive literature in the science of combining FCD and legacy sensors data but these studies remain in a laboratory setting. Due to the uncertainties at the technology, market and organization level, it has been challenging for researchers and practitioners to evolve from conducting individual projects testing FCD to carrying out a full integration with legacy technologies at a system-wide level.

The practical relevance of designing the abovementioned ICT architecture is its usefulness for Rijkswaterstaat and other parties (data and service providers). An ICT Architecture contributes to obtaining a clearer picture on when and how to invest in FCD and how the transition from a legacy to a new system landscape can be executed. The scientific relevance of designing such IT artifact is that it contributes to crossing the gap between integrating FCD and legacy technologies at an experimental level and executing an implementation in a real-life setting. This can be leveraged not only by Rijkswaterstaat but also but also by authorities and companies in other countries innovating on traffic management systems. Additionally, the findings and lessons learned throughout the empirical process can be abstracted into a body of knowledge and contribute to the ICT Architecture Design field.

1.2 Research Objective

So far we have been talking about how a flexible ICT architecture can contribute to react to changes in the dynamic environment Traffic Management is placed in. However, as it will be made clearer in section 4.1, Rijkswaterstaat fulfills a great variety of Traffic Management and Information services. In one hand, FCD has the potential to *directly* impact many of these services. For example, obtaining information from *in-car* sensors could help determine environmental conditions in the road (e.g. slipperiness) and alert other vehicles which are not equipped with such capabilities. In the other hand, implementing FCD for certain services could also *indirectly* impact the fulfillment of other services, as it will be seen in the case under study (see section 5.3).

Given the time and resource limitations of this research, it would not be possible to analyze all scenarios that FCD could impact nor to develop an architecture that would integrate it with all the services that Rijkswaterstaat provides. Therefore, the focus of this research is on two services: Automatic Incident Detection (AID) and Traffic Information Provision (TIP). The reasoning behind selecting these services is that they both rely on the use of induction loops placed in the Dutch motorways (see section 4.2) as a main source of data and FCD would offer the possibility to replace these sensors, potentially saving costs and reducing maintenance efforts (see section 5.3).

Thus, the research objective of this project is to:

> *Design a flexible ICT architecture that integrates Floating Car Data (FCD) into Rijkswaterstaat's Traffic Management and Information Systems for Automatic Incident Detection (AID) and Traffic Information Provision (TIP) services.*

1.3 Thesis Outline

The rest of this report will present how the research objective just formulated above was reached. For that purpose, the research approach that was taken throughout the project will be described in chapter 2. This includes defining the research questions that contributed to the achievement of the objective, as well as the research framework and the data collection strategy that were used.

Chapter 3 presents the literature review that sets the knowledge foundations for this research, including architecture and flexibility concepts, as well as an overview of the developments on FCD.

This will be followed by an analysis of the application domain where this research is placed in chapter 4. In this chapter, an overview of the current architecture for AID and TIP at Rijkswaterstaat will be presented, as well as an assessment of the extent to which the *as-is* architecture is flexible.

Once both theoretical and practical foundations have been set, a technology analysis of FCD will be presented in chapter 5, which will allow to understand how FCD can be used in the context of AID and TIP, what its advantages and disadvantages are and which factors may impact its implementation. With all the analysis conducted thus far, it will be possible to delineate the problem more precisely and present an architecture design in chapter 6, which will include the formulation of principles and requirements, the presentation of the ICT architecture and an evaluation of the achieved outcome.

Finally, chapter 7 will present the conclusions of the research project by introducing the practical and scientific contributions the research achieves, in addition to a recapitulation of the answers to the research questions. Moreover, a reflection on the research process and the associated limitations are presented, finalizing with a set of recommendations for Rijkswaterstaat and recommendations for future research.

2 Research Approach

In the previous chapter, the motivation and objective of this research project were specified. Before starting the research, it is necessary to determine a research approach that provides a structured means to reaching this objective. The research approach presented in this chapter consists of three elements: (i) a set of research questions that break down the problem in simpler parts (section 2.1), (ii) a research framework based on ADR (Action Design Research, section 2.2) that provide a guideline to conduct the research (section 2.3) and (iii) a strategy specifying the methods used to collect information (section 2.4).

2.1 Research Questions

As it will be elaborated in section 2.2, a design science research approach is used to conduct this project. This approach is highly iterative and the outcome of every iteration is used as input for the following iteration until satisfactory results have been achieved. In order to reach the research objective, a set of research questions is formulated in the logical sequence presented below. However, the reader should keep in mind that throughout the process it will be necessary to go back and forth between some of the questions as part of this iterative process.

RQ1 – Flexible ICT Architecture	What does the concept of a *flexible ICT architecture* in the context of Rijkswaterstaat's Traffic Management and Information systems mean?

Since the research objective of this thesis is to design an ICT architecture, it is first necessary to understand such concept. For that purpose, it is helpful to specify what elements an *ICT Architecture* should comprise by introducing architecture definitions and state-of-the-art architecture frameworks. Moreover, it is necessary to understand what *flexibility* means for an ICT architecture. By using dimensions relevant to the ICT field to better define the flexibility construct, it is possible to further apply this understanding to the context of Traffic Management and Information systems at Rijkswaterstaat.

RQ2 – Descriptive or *as-is* Architecture	What does the current architecture for the AID and TIP traffic systems at Rijkswaterstaat look like?

Once the concepts of ICT Architecture and flexibility are explored, it is necessary to understand what the current architecture for the systems that perform AID and TIP looks like. This is also helpful in determining to what extent this architecture is flexible and if it allows the integration of FCD. It is necessary to get an understanding of how the individual components of the system work and how they are all connected. With this analysis, it is also possible to understand which purposes the system serves: what it can and cannot do.

RQ3 – Technology Analysis	What are the factors that influence the implementation of FCD for AID and TIP in the context of Rijkswaterstaat's current traffic systems?

After getting a good understanding of the characteristics and capabilities of the *as-is* architecture, it is possible to start exploring the implementation of FCD in that current landscape. Integrating this new technology with existing system is not just a matter of making sure it is compatible with them but it is also necessary to determine if there are any factors that would influence its implementation (positively or negatively). This includes both internal factors, such as ongoing projects in the organization and external factors, such as technology trends.

RQ4 – Requirements and Principles	What are the design principles and high-level requirements that the ICT architecture integrating FCD for AID and TIP should meet?

Once a good overview of the current architecture is obtained, as well as from the factors influencing the implementation of FCD, it is easier to determine the principles and requirements the ICT architecture should fulfill. In an ICT landscape, every individual system can have a very detailed set of functional (*what it should do*) and non-functional requirements (e.g. performance requirements: *how well it should do it*). Given the scope of this thesis, what concerns us are the prescriptive principles that guide the architecture design and the high-level requirements for the architecture, not the systems themselves.

On one hand, it is possible to specify principles by looking at the existing Enterprise Architecture principles at Rijkswaterstaat and aligning them with this project. On the other hand, it is possible to specify requirements by analyzing the characteristics of the current architecture, as well as the characteristic of FCD and the vision for future Traffic Management and Information Systems at Rijkswaterstaat.

RQ5 – Prescriptive or *to-be* Architecture	What does a flexible ICT architecture that integrates FCD into Rijkswaterstaat's AID and TIP traffic systems look like?

With the principles and requirements at hand, it is possible to design an architecture that integrates FCD into the current traffic systems for AID and TIP. At this point, it is important to restate the fact that this is an iterative process and it will be necessary to come back to previous questions before reaching an end result. For example, coming back to stakeholders with a draft to validate, adapt or generate new requirements.

2.2 Design Science Research

With the research questions at hand, it is found useful to devise a framework based on state-of-the-art knowledge that allows to address them in a coherent way. In this section, Design Science Research (DSR) will be introduced as the selected methodology to support this project (section 2.2.1). An overview of various DSR frameworks will be presented in section 2.2.2, which will help select the final framework presented in section 2.2.3.

2.2.1 Why Design Science Research?

Given the data oriented nature of the systems this research dealt with (collecting traffic data, processing it and providing further information to users of the system), it is appropriate to place it

within the **Information Systems (IS)** discipline: "Information systems are the software and hardware systems that support data-intensive applications" (Elsevier, 2017).

(Gregor, 2006) proposes a taxonomy to classify theories in Information Systems research based on their specific goals. This taxonomy differentiates five types of theories: (i) theory for analyzing, (ii) theory for explaining, (iii) theory for predicting, (iv) theory for explaining and predicting and (v) theory for design and action. The **theory for design and action** is the most appropriate for this research, since "this theory says *how* to do something. It gives explicit prescriptions (e.g., methods, techniques, principles of form and function) for constructing an artifact" (Gregor, 2006, p. 620), which in this case is an ICT Architecture[2].

For this project, a **design science research (DSR) approach** is selected as an methodology that has been given importance and validity in the Information Systems literature (Hevner & Chatterje, 2010; Hevner, March, Park, & Ram, 2004). A useful definition of DSR is presented below.

> "Design Science is knowledge in the form of constructs, techniques, methods, models and well-developed theory for performing the mapping between the know-how for creating artifacts and satisfying given sets of functional requirements. Design Science Research is research that creates *this* type of missing knowledge using design, analysis, reflection, and abstraction".
>
> (Vaishnavi & Kuechler, 2015, p. 3)

Gregor reports that research associated to this type of theory (design and action) has received different denominations. Some examples include *software engineering research* (Gregg, Kulkarni, & Vinzé, 2001), *constructive type of research*, *prototyping*, *systems development approach* (Nunamaker, Chen, & Purdin, 1991), and *design science* (Gregor, 2006, p. 628). Among all these approaches, the latter one was chosen for two main reasons:

- Given the highly practical nature of this research, where a solution for a specific problem and organization should be crafted. Design science is fundamentally a problem-solving paradigm (Hevner et al., 2004, p. 76).
- Given the emphasis that design science gives to evaluating and generalizing results to create knowledge (as it will be seen below), allowing to make this research scientifically relevant by reflecting on the design process.

Further elaborating on the first point, it is important to remark that design science allows to address the study of *wicked organizational problems*, which typically require innovative and creative solutions. (Hevner & Chatterje, 2010, p. 11) indicate that "this type of problems is characterized by:

- Unstable requirements and constraints based on ill-defined environmental contexts,
- complex interactions among subcomponents of the problem,
- inherent flexibility to change design processes as well as design artifacts (i.e., malleable processes and artifacts),

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[2] (Vaishnavi & Kuechler, 2015, p. 12) state that the outputs of design science research can be artifacts such as constructs, models, frameworks, architectures, design principles, methods and instantiations.

- a critical dependence upon human cognitive abilities (e.g., creativity) to produce effective solutions, and
- a critical dependence upon human social abilities (e.g., teamwork) to produce effective solutions."

As described in section 1.1, the process of integrating FCD in Rijkswaterstaat's current Traffic Management and Information Systems is surrounded by technological, market and organizational uncertainties, which make requirements and constraints on the system be subject to constant change. Moreover, the elements and actors within the system have complex relationships between them, requiring creative solutions where the perspectives from the various stakeholders are to be considered. Hence, it is appropriate to address the problem at hand through a design science research approach: "design science supports a pragmatic research paradigm that calls for the creation of innovative artifacts to solve real-world problems. Thus, design science research combines a focus on the IT artifact with a high priority on relevance in the application domain" (Hevner & Chatterje, 2010, p. 9).

Regarding the second point, it is important to highlight the fact that this is an important differentiating point between design science and the other approaches mentioned by Gregor. The scientific community has accentuated contribution to theory on the design science literature, making it a very mature field in this respect. "Recent papers including (Gregor, 2006), (Gregor & Jones, 2007), (B. Kuechler & Vaishnavi, 2008), (Arazy, Kumar, & Shapira, 2010), (W. Kuechler & Vaishnavi, 2012) and (Gregor & Hevner, 2013) explicitly mention theory as an output from a design science research and they present methods for developing such theory during its course" (Vaishnavi & Kuechler, 2015, p. 19).

According to (Vaishnavi & Kuechler, 2015, p. 15), "design theory is the desired form of knowledge contribution from a design science research project. However, a well-developed and general design theory in a research area may take years of effort by the research community in the area. It is thus more likely for a design science research project to contribute a nascent design theory that is not so well developed". This research can be placed in that "preliminary" category, where the designed artifact (the ICT Architecture) does not form a design theory in itself but its design process could contribute to a future architecture design theory: "[reference] architectures are hardly developed using design science and there is no best or proven method available to develop [reference] architectures" (Gong, 2012, p. 263).

2.2.2 An overview of DSR frameworks

(Simon, 1996) can be considered the well-recognized proponent of the theory for design and action mentioned above and many others have followed his lead (Gregor & Jones, 2007). However, almost a decade later, this design-oriented type of research was still lacking in large part the support of design methodology. It was when **(Verschuren & Hartog, 2005)** introduced a six-stage design cycle with operations, guidelines and criteria for evaluation for each stage (First hunch, Requirements and assumptions, Structural specifications, Prototype, Implementation and Evaluation), constituting an explicit methodology to conduct design science research.

A relevant paper by **(Hevner, 2007)** was then published, elaborating on previous work from (Hevner et al., 2004). In this paper, he presents a very precise conceptual framework, along with specific guidelines to execute and evaluate the research. In this framework, he defines three spaces: Environment, IS research and Knowledge Base. He overlays three research cycles on them: the relevance cycle (which connects the environment and the design science research), the design cycle (a continuous iteration of the design activities) and the rigor cycle (which bridges the research and the knowledge base informing the project).

In that same year **(Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007)** introduced a design science research methodology incorporating principles, practices and procedures needed to conduct this type of research. This methodology includes six steps: Problem identification and motivation, Definition of the objectives for a solution, Design and development, Demonstration, Evaluation and Communication. On their model, they highlight the need for iteration between the different steps and they indicate possible research entry points to start the cycle. A year later, **(B. Kuechler & Vaishnavi, 2008)** presented the DSR Cycle, a design science research process model where they link the knowledge flows (knowledge contribution) with the process steps (Awareness of problem, Suggestion, Development, Evaluation and Conclusion) and the outputs of the research (Proposal, Artifact, Performance measures and Results). In this model, they also highlight the cognitive processes that arise during the design science research: abduction, deduction, reflection and abstraction.

One of the latest works in the field was presented by **(Sein, Henfridsson, Purao, Rossi, & Lindgren, 2011)** who proposed Action Design Research (ADR) as a new design science research method that made a conceptualization of the three closely related activities: building the artifact, intervening in the organization and evaluating the artifact along the process. On their method, they propose a four-stage process (Problem formulation, Building, intervention and evaluation, Reflection and learning and Formalization of learning), which are guided by principles representing various assumptions and values.

2.2.3 Selecting a DSR framework

After reviewing the previous design science research frameworks, (Sein et al., 2011) **Action Design Research** (**ADR**) is selected as a guideline for this research project, complemented with (Verschuren & Hartog, 2005) **Design Cycle**, as it will be presented in section 2.3. The reasoning behind the first choice is that when compared to other frameworks, ADR "emphasizes the core of the discipline as the development and use of IT artifacts in organizations" (Sein et al., 2011, p. 38). Since the IT artifact (ICT Architecture) is tightly bounded to an organization (Rijkswaterstaat), it is crucial to recognize the role of the organizational context in shaping its design.

(Sein et al., 2011, p. 38) state that "there is a disconnect between research and practice, originated by the conflicting interpretations of the core of the discipline, the difference in the research approaches and values of design- oriented and organization-oriented researchers and the conflict between responding to practitioner concerns and the methodological rigors required for academic contributions". For example, the method proposed by (Peffers et al., 2007) does not acknowledge that IT artifacts should materialize in parallel with organizational elements.

Other methods such as that proposed by (B. Kuechler & Vaishnavi, 2008) are too sequentially formulated. In this method, the formulation of the problem comes initially, it is then followed by the development of the artifact and it finalizes with evaluation. "This sequencing, which separates building from evaluating, does not meet the needs of a research method that has built-in relevance and rigor cycles for designing innovative ensemble artifacts" (Sein et al., 2011, p. 39). For that reason, ADR highlights the importance of (Hevner, 2007) relevance cycle and it proposes design principles that allow to interweave the building, intervening, and evaluating activities in a joint research effort.

As far as for the second choice, (Verschuren & Hartog, 2005) design cycle is selected to complement ADR because even though this framework includes a "building" stage, it is not very specific in the exact steps that should be followed within it. (Verschuren & Hartog, 2005) do provide a six steps process, which will be integrated with ADR, as it will be seen in section 2.3.

2.3 Research Framework

As it was just mentioned in the previous section, two different frameworks are selected to guide the research. They will be briefly presented in section 2.3.1 (ADR) and section 2.3.2 (Design Cycle). Finally, in section 2.3.3, the derived research framework based on a combination of the two of them will be introduced.

2.3.1 Action Design Research

(Sein et al., 2011) propose Action Design Research (ADR) as a solution to address the problem of other methods relegating the evaluation of the designed artifact to a subsequent and separate phase. "ADR combines theory with researcher intervention to solve immediate organizational problems. Thus, ADR aims to link theory with practice, and thinking with doing" (Sein et al., 2011, p. 39). They propose a four-stage process, guided by principles that capture various assumptions and beliefs, as illustrated in Figure 1.
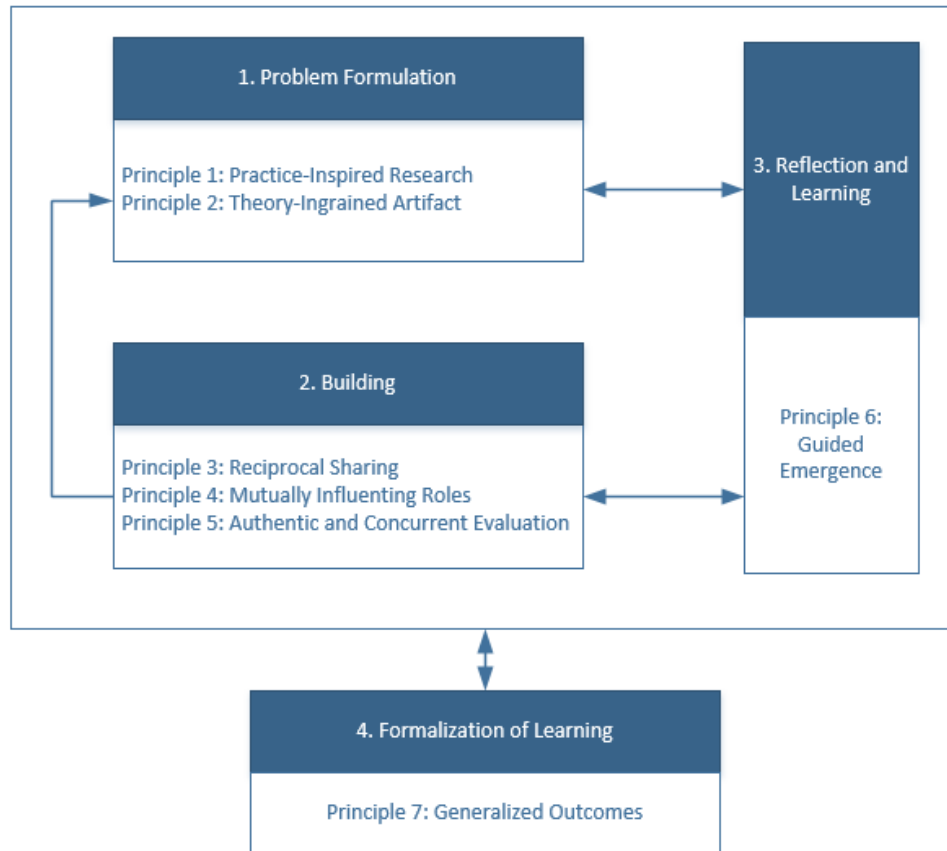
Figure 1. Action Design Research Stages and Principles (copied from (Sein et al., 2011, p. 41))

1. Problem Formulation. It aims at describing a problem that was identified in practice or predicted by researchers. In this stage, field problems should be seen as opportunities to create knowledge (*practice-inspired research*) and theories should inform the artifacts designed via ADR (*theory-ingrained artifact*).

2. Building, Intervention and Evaluation (BIE). This phase is conducted as an iterative process and it closely links Building the artifact, Intervention in the organization and its Evaluation. In this stage, the IT artifact and the organizational context mutually influence each other (*reciprocal shaping*) and there's mutual learning between researchers and practitioners as well (*mutually influential roles*). The great emphasis to evaluation being closely interwoven to building and intervening is made clear in this stage (*authentic and concurrent evaluation*).

3. Reflection and Learning. Throughout the design process, it is critical to continually reflect on the formulation of the problem, the design activities and the supporting theories to guarantee a contribution to knowledge (*guided emergence*). This is illustrated as this stage being parallel to the first two stages.

4. Formalization of Learning. It should be possible to generalize the solution developed through the ADR process and apply it to a broader class of problems (*generalized outcomes*). Depending on the level of development, these outcomes can come in the form of design principles, as contributions to existing theories or as completely new ones.

2.3.2 Design Cycle

Verschuren & Hartog propose a structured methodology to conduct the designing process with six steps, as displayed in Figure 2. Although they present these steps in a linear order, they also emphasize on the fact that the design process should be highly iterative. Evaluation may show that the artifact does not yet fulfill the goals or requirements from stakeholders and a second iteration of the design cycle should be started. Moreover, "although the two final stages of the designing cycle explicitly aim at evaluation, it is important that evaluation takes place during the whole process of designing" (Verschuren & Hartog, 2005, p. 738).
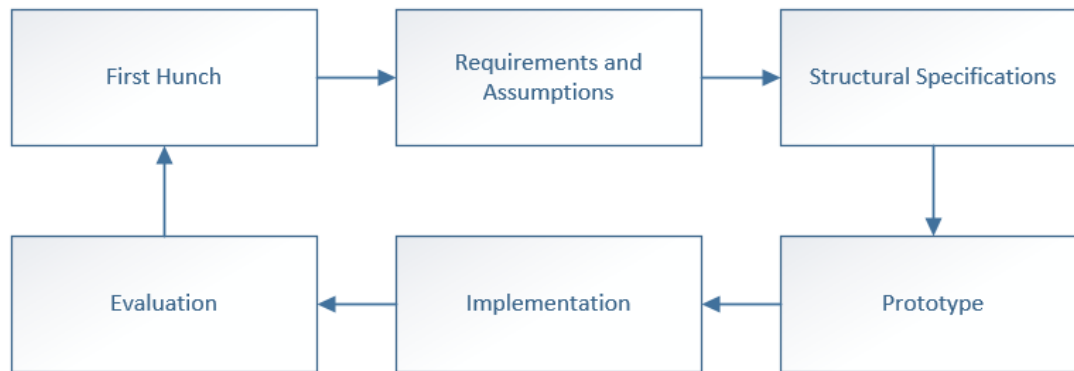
Figure 2. Design Cycle. (Verschuren & Hartog, 2005)

1. First Hunch. In this stage, the motivation to design a new artifact will arise. The outcome of this stage should be a set of goals, which the envisioned artifact should be able to fulfill.
2. Requirements and Assumptions. In this next step, the requirements that should be realized by the artifact should be made explicit, as well as the assumptions regarding the users and the context of the design.
3. Structural Specifications. In this stage, the specific characteristics or components of the artifact should be derived from the requirements and assumptions previously set.
4. Prototype. The next step is the actual design of a prototype, which incorporates the formulated requirements and assumptions and represents the structural specifications.
5. Implementation. In this stage, the developed artifact should be implemented in practice, ideally in a real setting.
6. Evaluation. The last step of the cycle is to assess if the implementation of the artifact does satisfy the formulated goals and if it fulfills the expectations of all stakeholders.

2.3.3 Combining ADR and the Design Cycle

The models described above are combined to define the research framework that is used as a guideline throughout the research process, as displayed in Figure 3. The research questions formulated in section 2.1 are mapped to different areas of the framework as well. Given the scope of this project, the designed artifact will not implemented nor a formal evaluation after implementation will take place. Based on these facts, the adapted design framework consists of:

1. Problem Formulation. Equivalent to Verschuren & Hartog's First Hunch. In this stage, the goal to be achieved with the designed ICT Architecture is made explicit.
2. Building (from BIE). Only Sein et al's Building sub-phase is included and it is decomposed into two of the Verschuren & Hartog's Design Cycle steps. The *prototype* phase has been renamed to *design* to avoid confusions with prototyping terminology. Structural specifications are not included, as they are the "bridging" step between requirements and design and they are not explicitly covered.
   a. Requirements and Assumptions. In this step, the design principles and high-level requirements the architecture should fulfill are specified, as well as any assumptions that need to be considered.
   b. Design. In this step, a design of the ICT architecture is developed based on the gathered requirements and on the process of iterating through the whole design cycle.
3. Reflection and Learning. This phase can be understood as the continuous evaluation of all activities during the design science research.
4. Formalization of Learning. This final phase allows to abstract the knowledge gained during the design process and generalize it to contribute to the knowledge base.
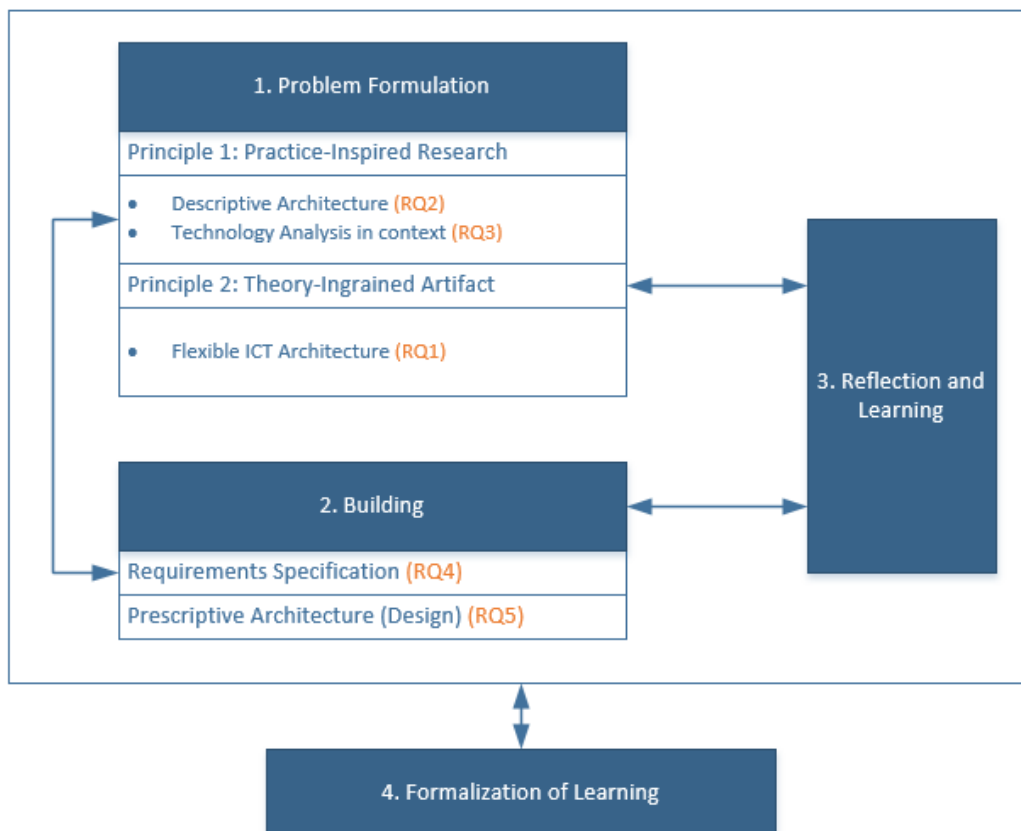
Figure 3. Research Framework. Based on (Sein et al., 2011) and (Verschuren & Hartog, 2005)

2.4 Data Collection Strategy

(Vaishnavi & Kuechler, 2015, p. 6) state that "DSR is primarily research using design as a research method or technique". In chapter 6, when presenting the ICT Architecture, it will be possible to see how the four phases of ADR are used to guide the design process. However, a limitation found in this methodology is that it provides little direction on how to operationalize these phases. Even when ADR provides enough freedom for the researcher to choose certain strategies, the method remains at a very abstract level and it may also generate some disorientation on how to conduct the research. For example, there is no indication on how a precise definition of the problem can be elicited, on how to gather and validate requirements or on how to conduct continuous evaluation.

ADR is chosen in this research as a DSR method that puts a great emphasis on the existence of an organizational problem as a driver to conduct research that generates knowledge. To conduct the three abovementioned activities, it is necessary to specify a concrete strategy to gather the required inputs. When conducting research, an in-depth understanding is gained through various and intensive methods for generating data (Verschuren & Doorewaard, 2010). In this research, four different methods are utilized to collect and validate information.

Desk research
In order to better understand the challenge that Rijkswaterstaat faces with the implementation of FCD, it is necessary to get a good understanding of the capabilities, limitations and interdependencies of its systems, as well as a good overview of its business processes and core competencies. This allows to identify where the causes of the problem might be originating from and how difficult it might be to tackle any of those issues. One of the greatest challenges in this process is that there is no existing architectural document at Rijkswaterstaat for the two services this research focuses on.

Thus, it was necessary to conduct an extensive desk research and dive into various company documents to start building a picture of Rijkswaterstaat's current architecture, including:

(i) Higher-management documents such as the *Visie op verkeersmanagement* (Vision for Traffic Management) or what it is known in Rijkswaterstaat as *i-Strategie* (focus and guidelines on how to execute information provisioning).

(ii) Program and project documents such as the *Programmaplan Wegkant en Omgeving* (a strategy to innovate roadside systems) or the *CHARM PSA* (a project start architecture for a new system that will centralize several traffic management applications).

(iii) Technical documents such as the *MTM-2 OS Specification* (a manual specifying the functions of roadside units) or the *MTM-2 TOP-FEP AID Processing* (a thorough description of how Automatic Incident Detection works).

Reviewing these documents was challenging because not all information regarding one topic (e.g. a system or a process) could be found in a single document or there was no explicit reference to other documents in many cases. Moreover, the information was not always consistent throughout these documents or there were some missing details, which were necessary to clarify during the interviews.

A desk research was chosen as one of the data collection methods because it allows to get a deeper understanding of processes and systems (specially at the technical level), even when there are experts who can share this information during an interview. As a matter of fact, it was possible to notice during the interviews that many of these experts were not aware of all details or technicalities. Thus, even when more time-consuming, desk research proved to be a necessary task.

<u>Individual semi-structured interviews</u>
A second method for data collection were **semi-structured interviews**, which were mainly conducted within Rijkswaterstaat. The interviewees included fifteen experts from various areas and departments and a complete list of names, roles and dates can be found in Appendix A. Since the purpose of the interview varied from one to another, a standard interview protocol could not be used, rather a customized protocol had to be sketched every time. It is possible to divide the conducted interviews into three categories based on their purpose:

    (i) Business-oriented Interviews. These interviews were conducted with the purpose of getting strategic and tactical information about what the interests of the organization are with respect to its role as a road authority (e.g. how they perceive their role may change with the introduction of new technologies), about the direction they may take when innovating in the Traffic Management and Information field or about external trends that may influence the integration of FCD (e.g. the penetration of self-driving cars). Examples of interviewees included directors, traffic engineers, business managers or senior advisors.

    (ii) Project-oriented Interviews. The purpose of these interviews was to get more information about ongoing or planned projects that may have an influence in the integration of FCD in the current landscape. These interviews were not oriented towards gathering technical details, rather more general information about what functionality in Rijkswaterstaat's traffic systems would change with that project implementation or the timeline for its execution. Examples of interviewees included functional managers, project managers or program managers.

    (iii) Technically-oriented Interviews. These interviews were conducted with the purpose of gathering more detailed information about how certain systems work or about available applications at the organization that could fulfill certain functions for FCD. These interviews were also useful to validate many of the information collected during the desk research. Examples of interviewees included application managers, technical managers and solution architects.

This diversity of backgrounds was an interesting challenge because the researcher had to figure out every time the best approach to conduct the interview given the expertise and role of the interviewee. The reasoning behind selecting such an ample set of profiles is that an architecture needs the input from many different levels of the organization to provide a picture that is comprehensive enough. Moreover, the interviewees were selected as some of the persons with the most expertise in their corresponding areas.

Since no standard interview protocol was used, an approach that was helpful was the investigation of the interviewees' profiles prior to the interviews. The interviews were rather exploratory and in most cases, just a few questions were pre-formulated to elicit more key questions during the interview. Thus, it was found useful to have some knowledge of the person's position and their latest

work in Rijkswaterstaat in advance. This was achieved by checking the organization's intranet, by reviewing reports that had been recently published by them or by inquiring the person who initially referenced the interviewee.

<u>Architecture working sessions</u>
In addition to the one-time interviews with experts from different areas, more than ten working sessions with one of Rijkswaterstaat's solution architects were conducted. These sessions were useful to realize continuous iterations throughout the whole design process, where it was necessary to go back and forth the first three phases of the design cycle (problem formulation, principles and requirements specification and design). The purpose of these sessions was to validate that the information conveyed in the architecture was correct, to obtain feedback about the design and to integrate the perspectives from an architect with an experience in the traffic management domain.

Initially, a couple of versions were drafted in paper, where some ideas were sketched and discussed and served mainly as a brainstorming tool. As progress was made with the interviews and as we continued conducting the sessions, it was possible to obtain four iterations drafted in Visio, from which the last one was used as an input for the workshops described in the sub-section below. After those workshops and with a clearer idea of design decisions and assumptions that should be made, it was possible to generate four iterations in ArchiMate. The last version is presented in section 6.4 and it was used for the architecture review, as described below.

In chapter 6, only the final version of the architecture in Visio and ArchiMate will be presented. To avoid making this report too extensive, the reader will not be able to see what changes the architecture underwent throughout the design cycle. What it is important to highlight here is that these iterations were the product of not only the working sessions and the input gained from the workshops but they were also sustained by individual reflection from the researcher. The changes refer to things like how a business process is decomposed, which abstractions are utilized to represent underlying services in a better way, which functionality is needed and in which application, what elements are important to depict as supporting technologies, among others.

<u>Group scenario analysis workshops</u>
As it has been shortly mentioned in section 1.1 and as it will be seen with more detail in section 6.1, the implementation of FCD in Rijkswaterstaat's traffic systems is surrounded by uncertainties at the technology, market and organizational level. These uncertainties bring challenges to the design process because many decisions (see section 6.2) that are relevant for the architecture have not yet been taken by Rijkswaterstaat. Thus, the purpose of the workshops was to attempt to counteract these uncertainties by laying down alternative scenarios which can be evaluated in a group setting. Such setting is helpful because people can share different insights and get further triggered by comments from others.

These workshops were organized as two sessions on different days, where nine experts with different roles (e.g. solution architects, program managers, technical managers, information analysts) came together (see details in section 6.2). A diverse group of experts was selected to participate in the workshops for three main reasons: (i) they have expertise in different fields, thus offering different perspectives, (ii) they have some knowledge about the processes and systems involved in this research and / or (iii) they perform their role within the same program this project

is placed in (*Wegkant en Omgeving*). Initially a presentation was given to the participants where possible scenarios depicting future traffic management situations were introduced. Afterwards, the participants were divided into three groups and each group was assigned a set of scenarios for them to evaluate. During that discussion, the groups talked about the advantages, disadvantages and use cases for their assigned scenarios and compared them versus the other scenarios. Finally, the groups shared their main findings and based on them, a set of conclusions was derived. These conclusions also served as input for the design assumptions, as it will be seen in section 6.3.

Individual architecture reviews

The last method was used for evaluation purposes. As it was seen in section 2.2, it is possible to distinguish two types of evaluation in ADR. The first one refers to the ongoing evaluation that occurs under the Reflection and learning phase, in parallel to the other two phases. The architecture working sessions and the scenario analysis workshop can be considered part of this evaluation, in addition to the individual researcher's reflection throughout the design process. A second type of evaluation refers to the third phase of the BIE (Building, Intervention and Evaluation) and it constitutes a more formal evaluation after the designed artifact has been implemented somehow (e.g. in the form of an alpha or beta version). Given the scope of this research, an actual implementation of the ICT Architecture could not occur, thus it was not possible to do a post-intervention evaluation in a strict sense.

The method used to conduct the evaluation is an architecture review. The purpose of this review is to get general impressions about the design and to assess whether the architecture fulfils the formulated requirements (see section 6.3). (Babar & Gorton, 2009) conducted a study that indicated that the most common techniques to evaluate architecture are experience based-reasoning (expert reviews) and prototyping. To evaluate the designed architecture, the first approach is used due to the incipient nature of the designed artifact. Prototyping would imply conducting simulations or doing partial implementations, which goes beyond the scope of this project. Moreover, an architecture review is a first logical and needed step to validate and readjust the design, before utilizing prototyping tools.

There are different approaches to conduct an expert review. According to (Maranzano et al., 2005, p. 34), "the participants of an architecture review should include a *project team*, a *review team* and an *architecture board*. This increases the likelihood that a system architecture will be complete and consistent". Since there is no project associated to the implementation of the architecture yet, it was not possible to have a *project team*, who would most likely be the people implementing the architecture. Due to time limitations, it was only possible to conduct the review with two experts (a program manager and a solution architect), who can be called the *review team*. These experts were selected given their deep understanding of the topic and because they could provide insights from at a business and technical level respectively. No one else at Rijkswaterstaat has such simultaneous understanding of the requirements, processes and associated systems, which would have made it difficult to include other experts in the review team.

To conduct the review, the solution architecture was presented to the reviewers in two separate sessions, where we looked at the elements of the architecture in a holistic and individual way. Based on this analysis, they provided their general impressions and comments on the design. This included

evaluating whether the architecture design looked complete or whether it was understandable. Afterwards, we went through the formulated high-level requirements and validated to what extent the design fulfilled them. Even when the reviewers provided a yes or no answer for every requirement, the evaluation was qualitative in nature, since they described how they perceived the architecture fulfilled them.

3 Literature Review

In order to appropriately address the research questions posed in section 2.1, it is necessary to conduct a literature review to set the theoretical foundations the research can rely on. As it was presented in section 2.2, one of the guiding principles when conducting ADR is that its output should be a *theory ingrained artifact*. Four main topics are explored for this purpose: ICT Architecture, Architecture Description Language, Flexibility in the context of architecture and Floating Car Data. The information gathered from these areas allows to build the theoretical base which contributes to realize the design of the architecture, along with the insights gathered from the application domain.

Section 3.1 introduces the concept of ICT Architecture by differentiating between architecture principles, components and implementation guidelines. Section 3.2 introduces the concept of Architecture Description Language, focusing on ArchiMate as the language used in this project. Then, the construct of flexibility in the context of an ICT Architecture is defined in section 3.3. Finally, a brief overview of what FCD is and the latest developments in the field are presented in section 3.4. The first three sections allow to address research question 1 (RQ1): "*What does the concept of a flexible ICT architecture in the context of Rijkswaterstaat's Traffic Management and Information systems mean?*"

3.1 ICT Architecture

There's no generally accepted definition of ICT Architecture (Ross, 2003). The trend in the last years has been to use the concept of Enterprise Architecture as the bridge that closes the gap between business and ICT in an organization. In this report, the focus is on developing a solution for specific business services provided by the organization (Rijkswaterstaat) rather than addressing the architecture of the organization itself. However, a great emphasis on the relationship between IT and the organization's strategy will still be maintained: "an IT architecture is the organizing logic for applications, data, and infrastructure technologies, as captured in a set of policies and technical choices, intended to enable the firm's business strategy" (Ross, 2003, p. 32). As it will be seen in section 6.1, a linkage between the designed architecture and Rijkswaterstaat's Enterprise Architecture still exists.

Throughout the years, several architecture frameworks have been developed to capture the essence of what an ICT Architecture is and to provide guidance to its implementation. The first architecture framework was proposed by Zachman in 1987, where he defined it as "a logical construct for defining and controlling the interface and the integration of all of the components of the information system" (Zachman, 1987, p. 276). (Sowa & Zachman, 1992) revised the original framework and proposed a thirty elements matrix, where five rows describe various stakeholders' views (e.g. the planner) and six columns indicate different abstractions of the system (e.g. data). Moreover, the framework outlines the deliverables that must be created, supports stakeholders' communication during the design process and allows to revise the development of the systems in time by including a structure for storage and version control.

In the United States, several public institutions have also put efforts on developing architecture frameworks (Urbaczewski & Mrdalj, 2006). That is the case of the Department of Defense Architecture Framework (DoDAF), which proposes three views (operational, system and technical) where descriptions of the final product or system are provided to ensure consistency among all of them. Another framework is the Federal Enterprise Architecture Framework (FEAF), which was developed by the US Federal Chief Information Officers Council. This framework provides standard definitions for the various Enterprise Architecture domains and it seeks to ease collaboration between different entities of the federal government. This framework provides five reference models: business, components, technical, data and performance. Another US framework that is worth mentioning is the Treasury Enterprise Framework (TEAF), developed by The Department of Treasury to map the interrelationships between its various organizations and manage IT resources more efficiently. This framework includes descriptions of products for documenting and modeling enterprise architectures and provides alignment tools with DoDAF and FEAF components.

The mention to some architectural frameworks above was just made to illustrate the point that there are various definitions of architecture and many approaches to developing one. The purpose of this research is not to provide a thorough review of architecture frameworks or provide a comparison between them. However, the ISO/IEC/IEEE 42010 (Systems and software engineering – Architecture description standard) presents a good overview which helped in the process of understanding what various architecture framework include (International Organization Of Standardization, 2011).

For this research, **The Open Group Architecture Framework** (**TOGAF**) is used as a guideline. There are two reasons behind this: (i) this is a widely accepted and used framework both in the private and public sphere and (ii) Rijkswaterstaat uses TOGAF as its standard, making the design of the solution architecture coherent with its existing architecture. According to TOGAF,

> *"Architecture has two meanings depending upon the context:*
>
> 1. *A formal description of a system, or a detailed plan of the system at component level to guide its implementation".*
> 2. *"The structure of components, their interrelationships, and the principles and guidelines governing their design and evolution over time".*
>
> (The Open Group, 2011, p. 9)

The definition presented above helps obtain a better idea of some of the building blocks of an architecture. This can be summarized in three main concepts, which will be further elaborated in the following subsections.

- (i)   a set of design principles (section 3.1.1)
- (ii)   a description of the system structure and its components (section 3.1.2) and
- (iii)   implementation guidelines (section 3.1.3).

3.1.1 Design Principles

The design of the solution architecture is guided by principle-based design practices. According to Bharosa and Janssen, "principles are normative, reusable and directive guidelines, formulated towards taking action by the information system architects" (Bharosa & Janssen, 2015, p. 472). Moreover, as defined by TOGAF, "a good set of principles will be founded in the beliefs and values of the organization and expressed in language that the business understands and uses. Principles should be few in number, future-oriented, and endorsed and championed by senior management. They provide a firm foundation for making architecture and planning decisions, framing policies, procedures, and standards, and supporting resolution of contradictory situations" (The Open Group, 2011, p. 237).

TOGAF suggests having a template to formulate principles, including: (i) a name that represents the essence of the rule, (ii) a statement that communicates the fundamental rule, (iii) a rationale indicating the benefits of complying with it and (iv) the implications for fulfilling the principle. Moreover, they provide some criteria to appropriately formulate a set of principles, as indicated in Table 1.

Table 1. Criteria for formulating principles (copied from (The Open Group, 2011, p. 237))

Understandable	The underlying tenets can be quickly grasped and understood by individuals throughout the organization. The intention of the principle is clear and unambiguous, so that violations, whether intentional or not, are minimized.
Robust	Enable good quality decisions about architectures and plans to be made, and enforceable policies and standards to be created. Each principle should be sufficiently definitive and precise to support consistent decision-making in complex, potentially controversial situations.
Complete	Every potentially important principle governing the management of information and technology for the organization is defined. The principles cover every situation perceived.
Consistent	Strict adherence to one principle may require a loose interpretation of another principle. The set of principles must be expressed in a way that allows a balance of interpretations. Principles should not be contradictor y to the point where adhering to one principle would violate the spirit of another.
Stable	Principles should be enduring, yet able to accommodate changes. An amendment process should be established for adding, removing, or altering principles after they are ratified initially.

3.1.2 System Structure and Components

Typically, when designing an architecture, a layered approach is used to organize the various architecture components. This allows to provide an understandable picture of what each layer does and the relationships between them. This way, "higher layers use services provided by lower layers and they are sufficiently loosely coupled to allow changes in one layer without affecting other layers" (Janssen, 2009, p. 112).

TOGAF comes back again as a useful layered framework, where it is possible to describe the system structure and components in a clear and comprehensive way. To do so, they propose a three-layered model as summarized in Table 2 and further explained below.

Table 2. TOGAF Architecture Layers (copied from (The Open Group, 2011, pp. 20, 23, 25, 32))

Layer	Subdivision	Objective
Business Architecture		A description of the structure and interaction between the business strategy, organization, functions, business processes, and information needs.
Information Systems	**Data Architecture**	A description of the structure and interaction of the enterprise's major types and sources of data, logical data assets, physical data assets, and data management resources.
	Application Architecture	A description of the structure and interaction of the applications as groups of capabilities that provide key business functions and manage the data assets.
Technology Architecture		A description of the structure and interaction of the platform services, and logical and physical technology components.

Business Architecture

The business architecture sets the base for the further development of the overall solution architecture, as it demonstrates the business value to all stakeholders and sets the scope of the business processes or functions that will be included. In many scenarios, some key elements of the business architecture may have been already specified in other activities of the organization, such as the mission, vision or strategy. In these cases, it might be necessary to verify currently documented business efforts or bridge the relevant business requirements to the particular architectural design. In some other cases, it is possible that little or no business architecture efforts have been conducted. Then, it is necessary that the architecture team researches and specifies key business objectives and processes that the architecture should support (The Open Group, 2011, p. 80).

Data Architecture

"A structured and comprehensive approach to data management enables the effective use of data to capitalize on its competitive advantages" (The Open Group, 2011, p. 97). This includes developing a good understanding about the data entities utilized by each business function, process or service. This includes data creation, storage, transportation and reporting. Secondly, it is important to identify any data migration requirements and if any data transformations will be needed, indicating its complexity. Finally, data governance is key to guaranteeing the proper functioning of this layer, as it identifies the owners of the different data entities who ensure their integrity throughout the whole business process.

Application Architecture

This layer is closely linked to the data layer, to the extent that sometimes they are put together as a big whole. In general, it will be necessary to combine some activities from these two layers. There are

some advocates of a data-driven approach, where data is considered the driver for specifying application functions and interactions. In some other cases, there are major application systems (e.g. ERP) which take an application-driven approach and where key applications are identified as core of the business processes and hence take its implementation as the focus of the architecture design (The Open Group, 2011, p. 94).

Technology Architecture
The level of detail to describe the technology architecture will vary depend on the scope of the architecture. If there are any new technology blocks, this should be defined in this phase. Existing technology blocks may need to be redefined to guarantee they fit the new architecture. Some diagrams that could be included in a technology architecture are: environments and locations diagram, platform decomposition diagram, processing diagram, networked computing/hardware diagram or communications engineering diagram (The Open Group, 2011, p. 125).

3.1.3 Implementation Guidelines

An implementation guideline should provide direction on how organizations can adopt and implement the designed architecture, departing from the existing architecture, if any. (Gong, 2012, p. 30) indicates that there is a fundamental difference between an architectural principle and an implementation guideline: "architectural principles are the rules that must be followed in using the reference architecture. In contrast, implementation guidelines provide a more operational and tangible refinement of the principles".

For this purpose, TOGAF proposes the creation of an architecture roadmap and a supporting implementation and migration plan. This is a very extensive process, where the gaps between the descriptive and prescriptive architectures are considered and mapped into changes at different areas of the enterprise. The architecture roadmap basically identifies what it is known in TOGAF as work packages (a logical group of changes) and places them in a timeline that will help fulfill the end architecture. This process is rather gradual, where transition architectures are used to describe the current state of the enterprise at an architecturally significant point between the descriptive and prescriptive architecture (The Open Group, 2011).

The implementation and migration plan presents a set of projects that contribute in the realization of the end architecture. Some activities defined in this plan include the assessment of dependencies, costs and benefits of these projects in the context of other change activities within the enterprise.

3.2 Architecture Description Language

When designing an architecture, it comes handy to have an architecture description language that allows to specify the various architecture components and its relationships in a structured way. "Architecture Description Languages (ADLs) are computer languages describing the software and hardware architecture of a system. The description may cover software features such as processes, threads, data, and subprograms as well as hardware component such as processors, devices, buses, and memory" (Björnander, 2011, p. 2). There are several ADLs such as AADL, ACME, Rapide, Darwin, Aesop, TASM or UML.

The Open Group also proposes its own ADL, which is highly aligned with TOGAF but which can be used independently with other frameworks. "The **ArchiMate** Enterprise Architecture modeling language provides a uniform representation for diagrams that describe Enterprise Architectures. It includes concepts for specifying inter-related architectures, specific viewpoints for selected stakeholders, and language customization mechanisms" (The Open Group, 2016, p. 1). Since TOGAF has been selected as the framework to be used to design the solution architecture, choosing ArchiMate would be a logical decision. Not only does it allow to easily incorporate concepts from TOGAF but it is also used within Rijkswaterstaat to describe architecture models.

Another advantage is that ArchiMate incorporates the concept of a service-oriented architecture, which strongly reinforces flexibility, as it will be seen in section 3.3. It does so by referencing three layers (Business, Application and Technology), where higher layers make use of services provided by lower ones. At the business layer, ArchiMate defines some core concepts such as business actors, business roles, business processes and business functions. At the application layer, it is possible to find application components, application interfaces, application interactions and data objects. In the technology layer, elements such as system software, devices and communication networks are defined. Moreover, different types of relationships between all these components are specified, including access, composition, realization or triggering relationships. A summary of ArchiMate notation can be found in Appendix B.

3.3 Architecture and Flexibility

Flexibility, as defined in the Cambridge dictionary is "the quality of being able to change or be changed easily according to the situation" (Cambridge Dictionary, 2017). This concept can be further elaborated depending on the field of study. In the management domain, definitions of flexibility have been extensively described, especially in operations management and supply chain. However, there are fewer definitions for the IT domain (Gong & Janssen, 2010) and no particular definition in the context of ICT Architecture.

For this project, the definition of the flexibility construct for IT infrastructure from Byrd & Turner will be useful:

> *"IT infrastructure flexibility is the ability to easily and readily diffuse or support a wide variety of hardware, software, communications technologies, data, core applications, skills and competencies, commitments, and values within the technical physical base and the human component of the existing IT infrastructure"*
>
> (Byrd & Turner, 2000, p. 172).

For this construct, Byrd & Turner propose a set of dimensions that can help describe more precisely the flexibility construct, some of which can be relevant for the context of ICT Architecture (Byrd & Turner, 2000), as indicated in Table 3.

Construct	Definition
Connectivity	Ability of any technology component to attach to any of the other components inside and outside the organizational environment.
Modularity	Ability to add, modify, and remove any software, hardware, or data components of the infrastructure with ease and with no major overall effect.
Compatibility	Ability to share any type of information across any technology component.
Data transparency	Free retrieval and flow of data between authorized personnel in an organization or between organizations regardless of location.

At this point, it will be useful to also introduce the concept of a **Service Oriented Architecture** (**SOA**), an inheritably flexible approach to designing architectures. SOA is all about service-orientation as a design paradigm, where the most fundamental unit of logic is the service: "a service can essentially act as a container of related capabilities. It is comprised of a body of logic designed to carry out these capabilities and a service contract that expresses which of its capabilities are made available for public invocation" (Erl, 2007, p. 70). SOA is based on a set of eight design principles, as presented in Table 4.

Table 4. Principles of a Service Oriented Architecture. Extracted from (Erl, 2007, pp. 71, 72, 73)

Standardized Service Contract	When designing a service, specific considerations should be taken when designing the service's public interface and assessing the type of content that will be published.
Service Loose Coupling	The designing of the services should have a continuous emphasis on minimizing the dependencies between the service contract, its implementation and consumers.
Service Abstraction	Service contracts should only contain essential information and there should be an emphasis in "hiding" the underlying details of a service as possible.
Service Reusability	Design considerations should be taken to guarantee that the services capabilities are appropriately defined with an "agnostic" logic and can be reused in other contexts.
Service Autonomy	The underlying logic of a service should have sufficient degree of control over the environment and the resources it is running on.
Service Statelessness	To remain as available as possible, services should be designed to remain stateful only when required.
Service Discoverability	Services should be effectively discoverable and interpretable so that they can be used at any reuse opportunity.
Service Composability	Services should be able to compose other services regardless of the size or complexity of such composition.

Using a SOA approach allows for a high level of flexibility because, as it can be interpreted from the previous design principles, services can be changed or replaced easily without affecting other parts of the system (loose coupling). Moreover, since these services are highly autonomous and can be

reused in different contexts, more possibilities to adapt to changing conditions (e.g. new technologies that can be used within the architecture) become available.

3.4 Floating Car Data

The first references to the term Floating Car Data (FCD) date back to the mid-eighties, when systems such as Ali- and Euroscout (Siemens) and SOCRATES (Philips) were developed with the intention to provide dynamic guidance to a destination by using participating vehicles to acquire speed-related parameters, as well as vehicle position (so called floating cars) (Huber, Lädke, & Ogger, 1999). Since then, the concept has evolved with the evolution of cellular technology, GPS and in-car technology.

Floating Car Data can be defined as information used for Traffic Management purposes coming from mobile sources such as:

- Vehicle navigation systems (via GPS)
- Mobile phones (via the use of previously installed apps or via the cellular network directly)
- Other systems in the vehicle with network connectivity (via WiFi-P[3])

With data coming from these sources (e.g. vehicle position and timestamp), basic traffic information such as vehicle speed and travel time can be calculated. However, with the development of *in-vehicle* sensors and V2X[4] communication, FCD has the potential to provide much richer information, including state of the road, environmental conditions or incident reporting.

According to (Lorbacher et al., 2015, p. 4), "FCD is applied in varies cities throughout the world for many years now, including among others taxi FCD in Berlin, Hamburg, Nuremberg, Munich, Stuttgart, Graz, Vienna, Gothenburg, Stockholm, Beijing, Ningbo, Chengdu, Hefei, Hangzhou, and Shanghai". In their own research, FCD was used to detect, measure and visualize traffic flows in real-time in the city of Hanoi, Vietnam. This study was part of REMON, a Vietnamese-German project which resulted in a web-based traffic viewer that displays real-time traffic information based on FCD.

Even when these projects have implemented FCD in a real-life setting, in none of them a system has been developed where both legacy sensors data (e.g. induction loops) and FCD are integrated together. The only identified case where this might be happening is in the province of Bavaria, Germany, where an analysis conducted by an independent company confirmed that FCD from INRIX could be effectively used to cover the 'blind spots' between the existing road sensors. INRIX's website states that "through the use of FCD, Bavarian citizens will benefit from more accurate traffic updates. In addition, the Bavarian Traffic Management Center is now better equipped to make more accurate predictions on future traffic trends by using a combination of both FCD from INRIX and the information from road sensors" (Inrix, 2015). Unfortunately, it is not very clear whether this is already occurring in an actual setting and there is no information that has been further published about it.

---

[3] WiFi-P is a standard that allows wireless communication for vehicles. "It defines enhancements to the WiFi protocol required to support Intelligent Transportation Systems (ITS), including data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure (V2X communication)" (ITS Standards Program, 2009).
[4] V2X refers to Vehicle to Vehicle and Vehicle to Infrastructure communication.

There is extensive literature in the science of fusing legacy sensors data with FCD for traffic management purposes. Particularly, recent studies have been conducted in France, such as (Cohen & Christoforou, 2015), who checked the compatibility of both types of data at different levels in the region of Lille or (Lovisari, Canudas de Wit, & Kibangou, 2015) who conducted a trial where a data fusion algorithm was used to incorporate data from the Grenoble Traffic Lab fixed sensor network and INRIX FCD. In The Netherlands, some efforts have been also conducted by the scientific community in this topic. This includes (Van Lint & Hoogendoorn, 2010) who proposed a data fusion algorithm to combine various sources of traffic data, (Klunder, Taale, & Hoogendoorn, 2013) who studied the effects of different loop detector distances and FCD penetration rates for a queue tail warning system and (Van Erp, 2015) who investigated the added value of FCD for freeway traffic state estimation when fusing it with loop data. However, all these developments still remain at an experimental level.

Some other test projects have been conducted within Rijkswaterstaat and they will be described in section 5.2.

4 Application Domain

Once a solid theoretical foundation for the research is set, the next step is to understand the application domain where it is placed. As it was seen in section 2.2, the first stage of ADR deals with problem formulation and it follows the *practice-inspired research* principle. Chapter 4 will allow to satisfy this principle by setting the research in context.

In section 4.1, an overview of Traffic Management in the Netherlands and the role of Rijkswaterstaat will be presented. As it was introduced in section 1.2, this research focuses on two services at Rijkswaterstaat: Automatic Incident Detection (AID) and Traffic Information Provisioning (TIP). In section 4.1, it will be made clear where these services can be placed within the organization. Finally, section 4.2 and section 4.3 will provide clarification about what exactly AID and TIP mean and how these services are fulfilled. These sections allowed to answer research question 2 (RQ2): "*What does the current architecture for the AID and TIP traffic systems at Rijkswaterstaat look like?*"

Finally, in section 4.4, an assessment about the extent to which the current architecture is flexible and whether it makes the integration of FCD possible will be presented.

4.1 Rijkswaterstaat and Traffic Management

"Rijkswaterstaat is the executive agency of the Dutch Ministry of Infrastructure and the Environment, responsible for the Dutch main road network, the main waterway network, the main water systems, and the environment in which they are embedded. Rijkswaterstaat facilitates smooth and safe flow of traffic, keeps the national water system safe, clean, user-friendly and protects the Netherlands against flooding" (Ministry of Infrastructure and the Environment, 2017).

Within the Traffic Management domain, Rijkswaterstaat is responsible for effective and efficient Traffic Management in The Netherlands. The definition of Traffic Management at Rijkswaterstaat includes all the activities that they conduct to allow users to mobilize easily and safely throughout the network (Rijkswaterstaat, 2015a). A domain architecture based on TOGAF has been set up for this domain at Rijkswaterstaat. At the business layer of this architecture, a portfolio of business services has been defined, as depicted in Figure 4. These business services define what Rijkswaterstaat does for the ministry and the society, independently from its internal organization and they create the bridge between the goals of Rijkswaterstaat and its processes. The portfolio is made up of seven large categories, which at the same time are composed of smaller services, providing more level of detail. A complete overview of all defined services can be found in Appendix C.
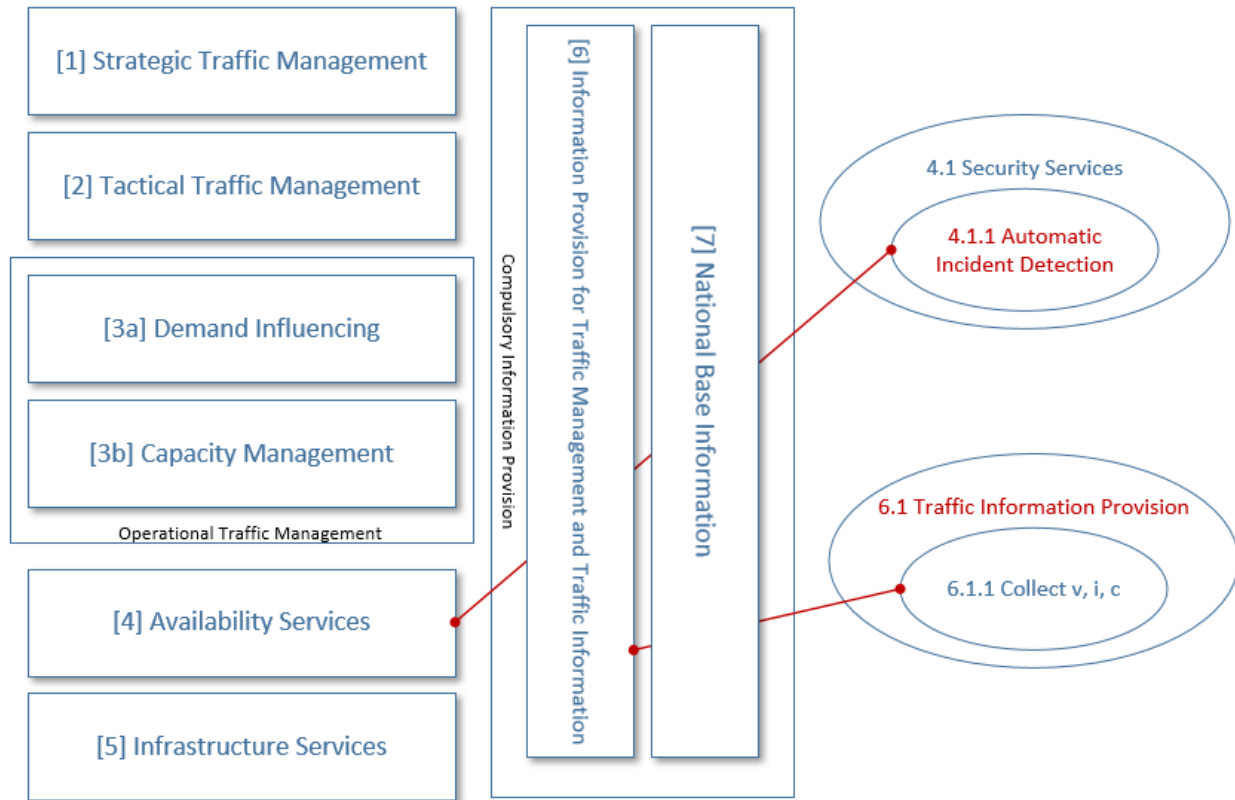
Figure 4. Business Services Portfolio. (Rijkswaterstaat, 2015a)

As it was mentioned in section 1.2, the scope of this research project is the integration of FCD in the current Traffic Management and Information systems with a focus on two services: AID and TIP. As it can be seen in the figure, AID is a security service, which at the same time makes part of the Availability Services category. On the other hand, TIP makes part of the Information Provision for Traffic Management and Traffic Information category.

The next two sections will provide an overview of what these services are and how they are fulfilled. At this point, it is important to highlight that there is no existing architecture document associated to these services at Rijkswaterstaat. The purpose of these sections will not be to develop a proper architectural description, rather to just describe the services in the three TOGAF layers identified in section 3.1: Business, Information Systems and Technology. For the same reason, Visio diagrams will be used to depict the functionality at each layer, instead of using ArchiMate language. These diagrams depict a simplified picture from the complexity of the Traffic Management domain at Rijkswaterstaat. A more complete picture of its application landscape can be found in Appendix D, as an example of such complexity.

4.2 Automatic Incident Detection (AID) Service

In the Netherlands, Rijkswaterstaat manages the highways, which in 2016 summed up to a total of 5340 km of road (Centraal Bureau voor de Statistiek, 2016). A great amount of these roads is motorways, which are conflict free roads used by fast motorized vehicles such as cars, buses or

trucks. Motorways in the Netherlands are composed of two carriageways (one for each direction) with two or more lanes.

As depicted in Figure 5, **induction loops** are placed under the road throughout the motorway, typically every 500 m. These loops are connected to **detector stations** (**DS**) placed along the roadside, which in most cases are integrated into what it is known as **outstations** (**OS**) (a network of local computer systems in the roadside). Only in a few cases, DS are a separate piece of equipment. Loops rows placed downstream the outstation are used to collect traffic data from that segment of the road. Each row is controlled by a DS which supplies the traffic information it has collected to one or more OS. This information includes individual vehicle passage, vehicle length (used to determine vehicle category) and vehicle speed at that point.

The OS uses this traffic speed information to determine the exponential average speed of the last few vehicles (number set in the configuration) in every lane and can thus determine if there is any significant slowing down of traffic at various distances (corresponding to the detector rows) downstream of it. Once the speed goes below a certain threshold (typically 35 km/h), the OS generates an "**AID AAN" congestion flag** to indicate there is congestion downstream. Conversely it can also detect when slow traffic starts to speed up (when speed goes above another threshold, typically 50 km/h) and it generates an **"AID UIT" congestion flag** (Rijkswaterstaat, 2013c).

This information is generated by the OS on a **traffic stream** basis, a logical grouping of one or more lanes that exhibit a similar behavior (i.e. speed) and two things can be done with it:

Central AID. The data is sent to a **central system** (**CS**), where the information collected from all OS is analyzed and a complete set of speed recommendations, known as a **measure**, is generated. This information is communicated back to the necessary OS, which display the speed recommendations in the corresponding **matrix signal indicators** (**MSI**) (one MSI gantry is controlled by one OS). The OS also sends back a confirmation of the displayed signs to the CS.

The Central AID incorporates not only the calculated measures for the congested lane but it also includes legends to be displayed in neighboring lanes and the expansion of these legends to MSI upstream the congestion to give a lead-in and prevent traffic from suddenly encountering a very slow speed limit.

Local AID. When there are communication problems between the OS and the CS, the OS reverts to a local mode. In this scenario, it will directly display a set of speed recommendations on the MSI it controls. Once communication is back, the OS sends the latest signs it placed on its MSI to the CS.
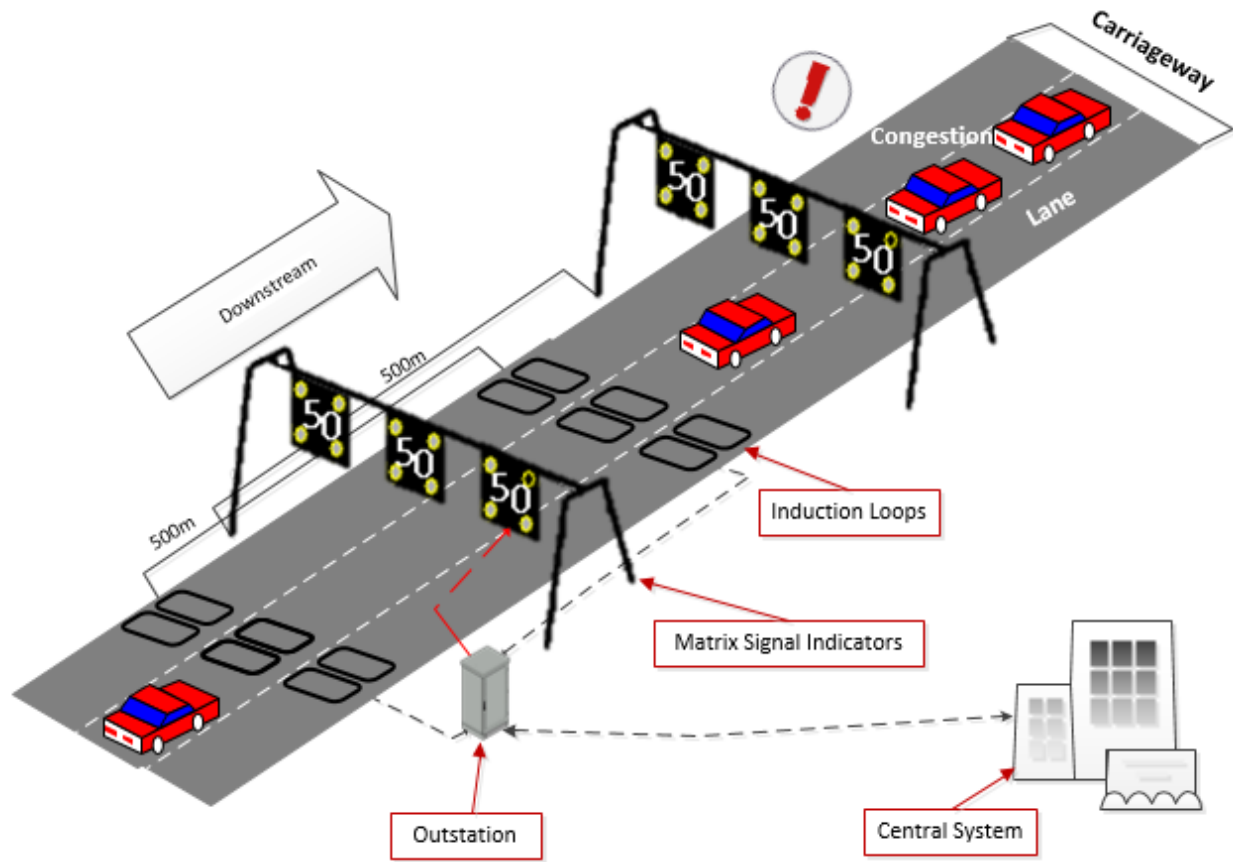
Figure 5. Traffic data collection in Dutch motorways

The functionality just described above is part of Rijkswaterstaat's **Motorway Traffic Management System** (**MTM-2**), a system that provides visual signals to control traffic on the Dutch motorways and distributes the collected traffic information to other systems (see section 4.3). The request to display signals in the MSI can come from different sources:

- (Automatic) Central AID Requests
- (Automatic) Local AID Requests
- (Automatic) LIB requests
- (Manual) Central Operator requests

The first two sources have been already briefly covered. LIB (*Lokale Ingreep Bron*) requests come from local systems that are in the surroundings of the OS. This can be the case when traffic lights in tunnels light up and road users upstream should be advised to lower their speed. Finally, operator requests refer to the ability of traffic operators to input a manual request at any of the five Traffic Centers in the Netherlands. It is important to mention that there is a hierarchy of traffic signs to be displayed on the MSI. For example, if an operator requests to place an 'X' (lane closed) on the road, this sign will overrule a '50' sign that has been requested by AID. This logic exists both in the Central and Local AID algorithms.

4.2.1 Business Layer

The AID process just described above can be represented in a high level with the BPMN (Business Process Modelling Notation) diagram in Figure 6. For the sake of clarity, the two involved systems have been differentiated (OS and CS) but we can consider this process to be carried out by one single actor, Rijkswaterstaat. The other actor involved in this business process is road users who benefit from the AID service.
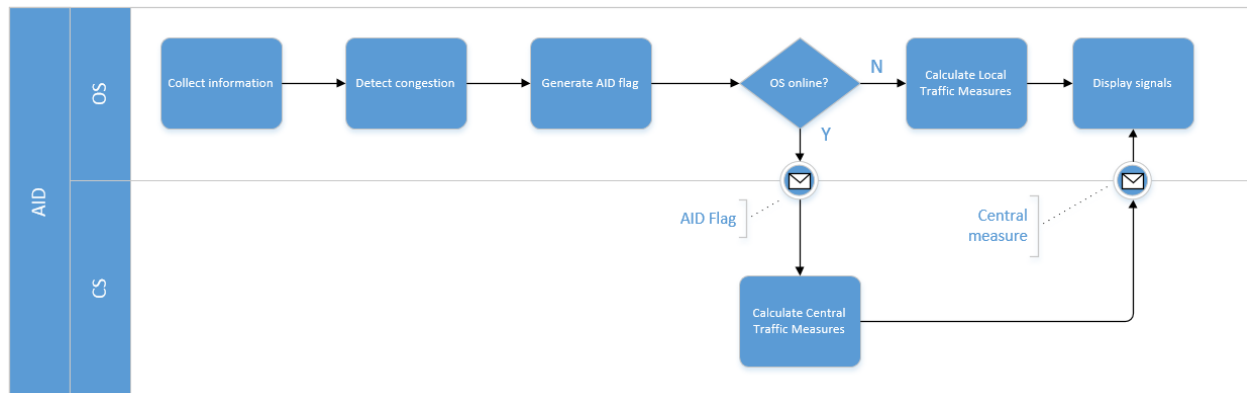
Figure 6. AID - Business Layer

4.2.2 Information Systems Layer

Figure 7 represents a simplified Information Systems diagram for the Central AID process, which is fulfilled via the depicted applications. The functionality of the OS is contained within what is known as a WKS (*Wegkantsysteem*). There are currently two types of WKS: An UDP WKS and a Partyline WKS. Both systems fulfill the same functionality and the only difference between them is the way they communicate with the CS. The UDP WKS utilizes UDP to exchange information with the CS, whereas the Partyline WKS uses a serial protocol that was custom made for this specific application.

The CS is composed of several applications, where the most relevant ones for the AID process are the FEP and the TOP. The FEP (Front End Processor) is the interface of communication with the OS and there is a type of FEP for each WKS (UDP FEP and Party line FEP). The TOP (Transaction Oriented Processor) processes the information coming from the OS and executes the Central AID algorithm (applying traffic engineering and business logic rules). The TOP also sends this information to other systems (see section 4.3). Moreover, the TOP is connected to the DIP, which is further divided into two functional applications. The BCG which holds a database of current and historical items and the BEP which provides the interface to the system to traffic operators. Through this last interface is where operator requests can be input into the system.
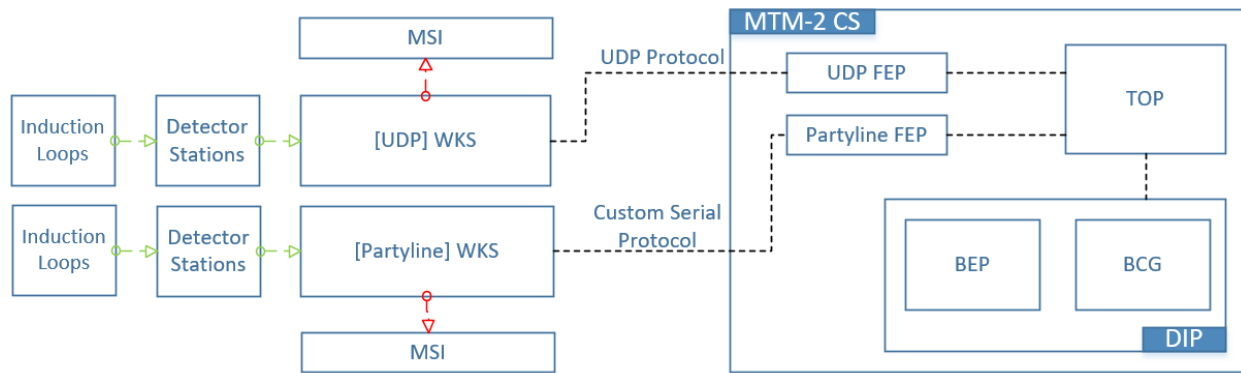
Figure 7. AID – Information Systems Layer

4.2.3 Technology Layer

The existing WKS hardware and software is implemented by four different vendors: Siemens, Peek Traffic, Swarco and Vialis. Currently there are 2500 UDP WKS and 3200 Partyline WKS (Rijkswaterstaat, 2017c), as represented in Figure 8. The CS exists at each one of the five Traffic Centers in the Netherlands (VCNWN te Velsen, VCZWN te Rhoon, VCMN te Utrecht, VCNON te Wolfheze and VCNON te Geldrop), where the MTM-2 CS applications run on different servers. The FEP runs in Solaris (a Unix Operating System), the TOP runs in Linux and the BCG in Linux 2. Each WKS is connected to only one Traffic Center, being UDP WKS connected via an IP fiber network called VICnet and Partyline WKS via copper lines.
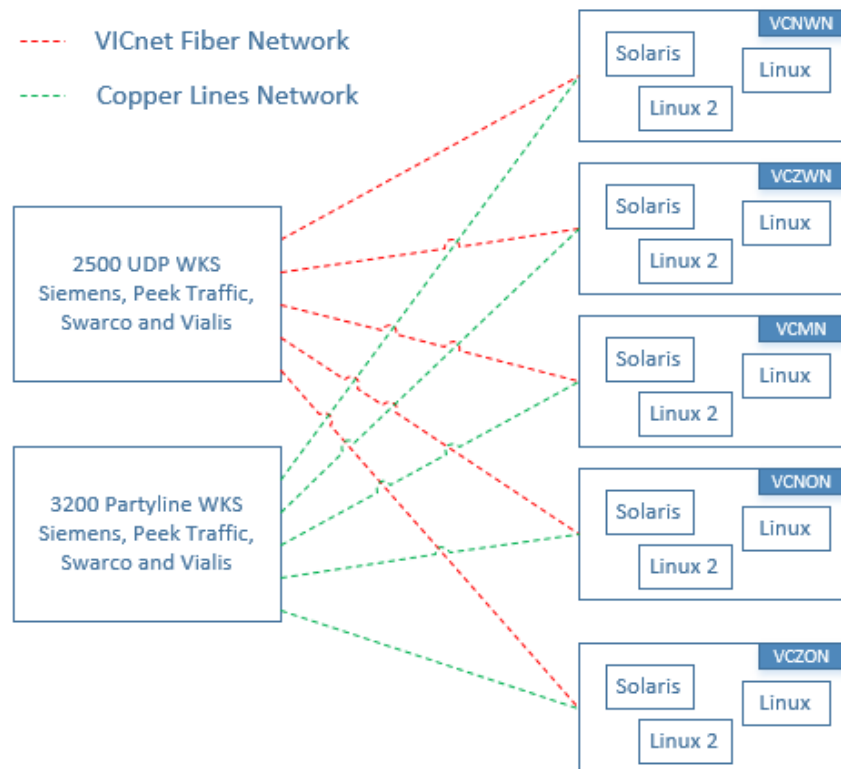
Figure 8. AID - Technology Layer

4.3 Traffic Information Provisioning (TIP) Service

In the previous section, the arrangement of detectors, outstations and matrix signal indicators throughout the motorways in the Netherlands was detailed, as well as the setup of the central system in the various Traffic Centers.

The traffic information collected from induction loops supports some other services other than AID. For example, it is used to estimate travel times and provide route recommendations to users by third parties. It can be said that this type of services relies on a more fundamental service, simply called Traffic Information Provision (TIP). This service entails collecting vehicle speeds (v), vehicle intensities (i) and vehicle categories (c) and distributing this information to other systems which use it for various purposes.

It was mentioned before that induction loops are placed approximately every 500m and detector stations can measure individual vehicle speed, passage (= intensity) and length (used to determine category). The OS collects this information from every detection point and aggregates it to **minute-based information** before sending it to other systems (Rijkswaterstaat, 2013c).

4.3.1 Business Layer

The TIP process can be represented in the high-level process depicted with the BPMN diagram in Figure 9. The OS continuously collects information from the detector stations (every vehicle passage is an observation), validates this information (checking if an observation is complete and reliable) and aggregates the collected data per minute. This minute-based information is then sent to the MTM-2 CS, which will forward it to other systems.
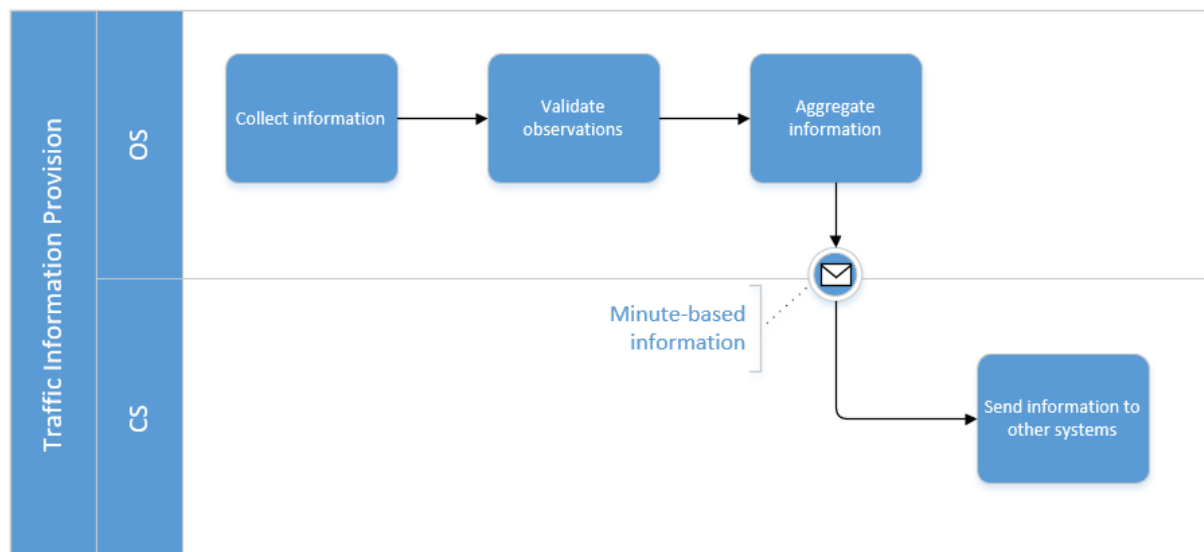
Figure 9. TIP - Business Layer

For the sake of clarity, the two involved systems have been differentiated (OS and CS) but in practicality, we can consider this process to be carried out by one single actor, Rijkswaterstaat. Other

actors involved are private and public institutions who consume this information after it is sent from the CS to other systems to be further processed and made available, as presented in Figure 10.
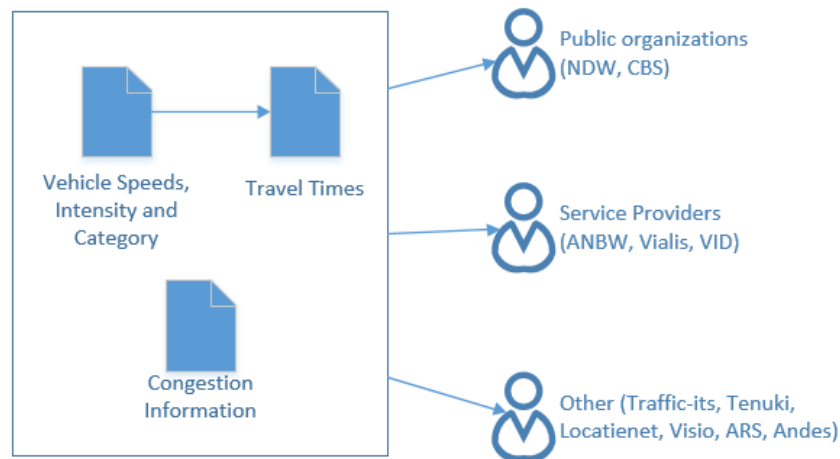
Figure 10. TIP - Users

4.3.2 Information Systems Layer

At the Information Systems layer, the relevant applications for this service are depicted in Figure 11. For this service, there are two scenarios:

- The WKS sends the minute-based information to the FEP in the MTM-2 CS, which then transfers it to the TOP. The TOP finally distributes the information to MONiCA (Monitoring-casco System) (via the SIMONE interface).
- The WKS sends the minute-based information directly to MONiCA.
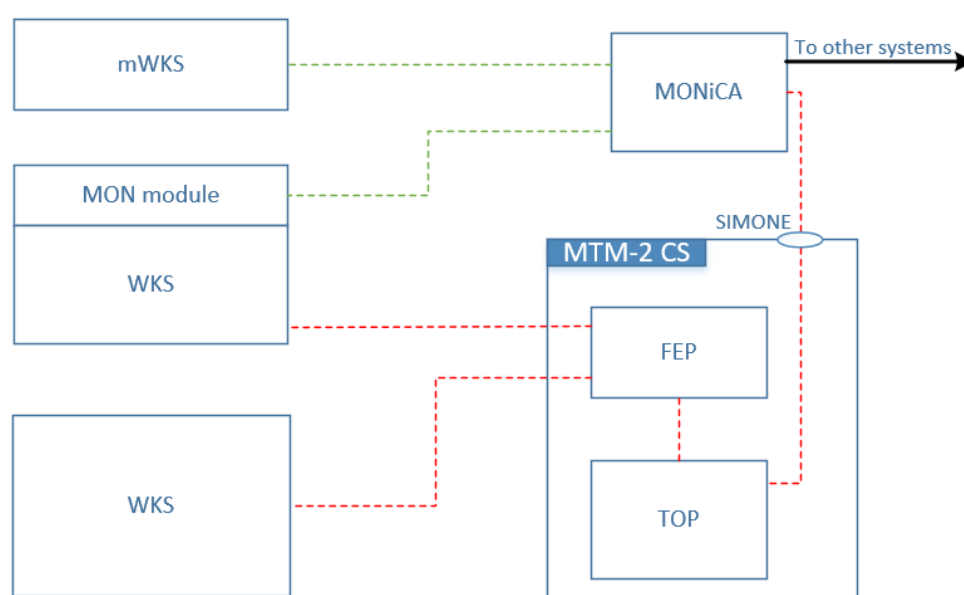
Figure 11. TIP - Application Layer

MONiCA is a monitoring system that gathers traffic information from the WKS and further distributes it to other systems. Other than that, MONiCA performs some validations (e.g. make sure that speed has a valid value below 200 km/h) and all valid messages are put together in a file that is transferred to other systems. For example, to a system known as Trefi, which calculates travel times and generates congestion notifications. The information sent to MONiCA is on a detection point basis.

In the previous section, two different types of WKS have been distinguished (UDP and Partyline). For this service, it is important to make some more distinctions at the WKS level. The MTM-2 system and its signaling functionality (including AID) is only available in the major motorways in the Netherlands. In these areas, it is possible to find both UDP and Partyline WKS that send minute-based information via the TOP in the CS (red line in Figure 11). There are some other WKS which also have the same type of connection (red line) but that have a separate monitoring module with a direct connection to MONiCA (green line in Figure 11). Finally, in remote areas where there is not a large traffic density, systems known as mWKS (Monitoring WKS) are placed along the road to only aggregate and send minute-based information. These mWKS don't have AID capabilities and have a direct connection to MONiCA (green line) as well.

In this section, the focus was on the provision of vehicle speeds, intensities and categories as it refers to the service pointed within the Traffic Information Provision category. Nevertheless, it is important to mention that the information about congestion (i.e. congestion indication, AID recommendations and current signs in the MSI) is also sent to other systems after being collected at the TOP.

4.3.3 Technology Layer

In the previous section, it was already mentioned that the OS hardware and software is implemented by different vendors. That is also the case for WKS with a MON module and for mWKS. As it was also mentioned, the MTM-2 CS applications run on different serves at each of the five Traffic Centers in the Netherlands. Since MTM-2 is a mission critical application, it runs on machines different than where MONiCa does. However, MONiCa also runs in each of the five Traffic Centers, so only an internal connection between these two applications is needed. The technology layer diagram presented in section 4.2 for the AID service also applies to this scenario.

4.4 Current Architecture Assessment

In the previous two sections, we saw a description of how the AID and TIP services are fulfilled at the Business, Information Systems and Technology layers at Rijkswaterstaat. The presented diagrams do not indicate a complete architectural picture since the interrelationships between the different layers is not depicted. The purpose is just to provide a good and simple overview to the reader of the current situation at Rijkswaterstaat. This was not an easy task to achieve, since the Traffic Management domain at Rijkswaterstaat is a very complex network of business services, applications and infrastructure assets. It was necessary to conduct an extensive review of company documents and to interview experts from different areas to come to a deep understanding of this landscape and then translating it into simplified but comprehensive terms.

With that understanding, it is easier to assess whether the current architecture at Rijkswaterstaat is flexible and to what extent it would allow the integration of FCD. It is possible to highlight five main characteristics that are problematic in the *as-is* architecture landscape:

(i) The current OS installed along the road cannot process data coming from sources other than induction loops.

(ii) It is very difficult to modify the OS behavior since the software is vendor dependent and it cannot be configured remotely.

(iii) The communication protocol between the OS and the CS is very dependent on the way the OS is programmed, making it impossible to send new type of information to the OS, without changing the OS behavior itself.

(iv) The applications in the CS do not support the processing of information other than that coming from the OS (i.e. information derived from loop data).

(v) The applications in the CS (FEP and TOP) are very monolithic and implementing new functionality in them would be a complicated process, which would also implicate taking into account their life cycle.

As we can see from these points, the current architecture cannot be characterized as flexible. Following the four constructs defined in section 3.3, this architecture is neither *modular* nor does it have a high degree of *connectivity* or *compatibility*. Modularity would imply that it is possible to easily add, remove or modify components without causing a major impact, which is not the case for the roadside and central systems. Having a high degree of connectivity suggests that data providers could easily "attach" to the applications in the central systems, but for the same previous reasons, it would not be possible to do so. Being compatible would mean that any new type of information could be shared between components; however, roadside systems are unable to accept new forms of data. Nevertheless, the architecture does have some degree of *data transparency* since it is currently possible to retrieve traffic information and make it accessible to other systems or parties.

This implies that integrating FCD in the current architecture would not be a straightforward process of just creating an interface with service providers to collect their data. Further changes in the systems' functionality and the way they communicate with each other would be required.

5 Technology Analysis: FCD in context

With a good understanding of the current architecture at Rijkswaterstaat and of the way AID and TIP are fulfilled at different layers, it is possible to explore whether FCD could fulfill the requirements imposed by these services. As it was already introduced in section 1.2, as technology develops (for example with the increasing installation of in-car sensors), FCD has the potential to provide richer information than induction loops do. Moreover, removing loops could represent costs savings and a reduction in maintenance efforts. FCD has the potential to be used to fulfill many of the Traffic Management services Rijkswaterstaat has defined in its portfolio. But as it was already explained, given the scope of this project, FCD is evaluated only in the context of the AID and TIP services.

In this chapter, an analysis of the potential and limitations of FCD will be introduced by means of a SWOT analysis in section 5.1. Additionally, an influence map will be presented in section 5.2, indicating which external and internal factors (to Rijkswaterstaat) need to be considered when implementing FCD for AID and TIP in the current landscape. These factors allow to have a clear understanding of what elements should be kept in mind when designing the solution architecture and allow to answer research question 3 (RQ3): "*What are the factors that influence the implementation of FCD for AID and TIP in the context of Rijkswaterstaat's current traffic systems?*"

5.1 FCD in the context of AID and TIP

In section 4.2 and section 4.3, an overview of how the AID and TIP services are fulfilled by Rijkswaterstaat was presented. As it was mentioned, the main source to obtain information about vehicle speed, intensity and category are induction loops placed under the road connected to outstations in the roadside which process this information and send it to the central system.

FCD offers new possibilities to collect this type of data in a different way. Data coming from systems or mobile phones in the car can be used to at least obtain vehicle speed information. If this information satisfies the information quality requirements needed to fulfill the AID and TIP services, FCD could represent many other advantages. Figure 12 represents a simplified picture of the Strengths, Weaknesses, Opportunities and Threats (SWOT) for the use of FCD for AID and TIP. This analysis is derived in the context of the progress achieved through different projects working with FCD in Rijkswaterstaat.

STRENGTHS	WEAKNESSES
• Induction loops installation and maintenance cost savings. • More fine-grained information. • Available market parties that can provide GPS/4G FCD*.	• Not able to provide intensity and category information. • Undefined stakeholders' roles. • Unavailable infrastructure for WiFi-P FCD. • Undetermined FCD quality from providers.
• Developments in smart cars industry unlocks WiFi-P potential. • Possibility to improve service with GPS/4G technique improvement.	• Emergence of other technologies. • Uncertain technology and market evolution.
OPPORTUNITIES	THREATS

Figure 12. SWOT Analysis of FCD.

Strengths

One of the main motivations to use FCD is the costs savings that it could represent. Since induction loops are placed under the road, installing new pairs or maintaining existing ones represents high costs and considerable effort. With the gradual replacement of loop data with FCD, these costs would start reducing and they would be eliminated once FCD technology can fully replace loops. Another great advantage is that FCD could provide more fine-grained information than what loops can. As mentioned before, loops are usually placed every 500 m in the road, allowing the collection of information only at these points. Since FCD comes directly from vehicles, it is possible to have continuous information along the road. Finally, what makes FCD a realistic alternative is the fact that there are currently market parties who are able to deliver GPS/4G FCD. This is the case of service providers who can obtain information from their user base or from other sources. Some concrete examples can be found in section 5.2.

* Whether the type of information that market parties are currently able to provide fulfills the requirements for it to be used for AID has not been completely determined yet, as it will be seen in section 5.2. This is indicated in the last point of the weaknesses quadrant in the SWOT analysis.

Weaknesses

One of the main drawbacks given the current capabilities of FCD is that it is not able to provide vehicle intensity and category information. Since FCD comes from a sample of the total vehicle population, it does not provide an exact picture of how many vehicles cross a certain point. Currently, FCD is only able to provide speed information at a carriageway level, not lane level. Moreover, since FCD for AID is on a test phase to validate its reliability (see section 5.2), it is not yet clear what the role of the

various stakeholders should be. Currently, Rijkswaterstaat collects, processes and provides information back to users. With FCD, it is yet uncertain up to what level providers should take up these roles. Finally, whereas there is some more progress in obtaining FCD via GPS and 4G, there is less development in the WiFi-P FCD area. On one hand, this would require cars with WiFi-P capabilities (which depends to a great extent in the car industry) and in the other hand, the deployment of a WiFi-P infrastructure in the roadside that can collect data from these sources.

Opportunities

What is considered today as a weakness is most likely to change in the coming years. Even though there is still very little development for WiFi-P FCD, the car industry is moving towards the development of smart cars that incorporate V2X communication, as part of the global IoT trend. This is an opportunity that may dramatically change the role of road authorities in Traffic Management. If cars in the future are able to react to their environment, the function of AID may be no longer needed. Another latent opportunity is the possible enhancement to the AID functionality or to the richness of traffic information. With the continuous improvement of the techniques that service providers use to acquire and process information, FCD could offer data of better quality and an improved execution of AID.

Threats

One possibility that can be considered a threat for the use of FCD to fulfill the AID and TIP services is the emergence of new technologies. On one hand, this can represent an opportunity for Rijkswaterstaat, since these new technologies could provide further enhancements and possibilities. On the other hand, this can be considered a threat in the sense that large investments could be made in FCD, making it difficult to make further investments in new technologies. A second threat is represented by the uncertainty in the technology and market developments for FCD. There is not a clear picture of what kind of improvements service providers could do to their current techniques or which parties may enter or exit the market, making the implementation of FCD (at a system and contractual level) somewhat more challenging.

5.2 Factors that influence the use of FCD

There are many factors that may influence the way FCD is integrated into the current Traffic Management System, as well as drivers that encourage or steer its use. Figure 13 represents an influence map with the identified influencing factors for the use of FCD for AID and TIP. In the left side of the picture, internal factors are identified: organizational drivers in yellow and ongoing projects in purple. In the right side of the picture, external factors are identified: political factors in blue, related or supporting technologies in red and legal factors in green. Table 5 presents a summary of examples of these factors but a full overview can be found in Appendix E.

Table 5. Summary of factors influencing the implementation of FCD

External Factors		
Political	Encouraging Policies	An example are policies at the European level (e.g. CEF Transport Calls) which encourage innovation in the transport field and make funding available to institutions like Rijkswaterstaat.
Technological	Car Industry	The trends in the card industry indicate the shift towards more traffic functions fulfilled by vehicles themselves, which represent a transformation of the road authorities' role.
	Alternative Technologies	The emergence of alternative technologies (e.g. DAS) to collect traffic information should be considered when crafting a procurement strategy to collect FCD.
	Data Trends	Trends such as Big Data and Open Data also apply to the Traffic Management field. They indicate the increasing amount of FCD that will be possible to collect and which Rijkswaterstaat should be able to process and make available.
	Mobile Networks Development	The development of 5G as a next generation telecommunications network could accelerate the usability of FCD for mission critical traffic applications.
Legal	Traffic Regulations	There are existing regulations, such as the *Wet Geluidhinder* in The Netherlands which require the collection of specific traffic information (i.e. vehicle intensity and speed).
	Privacy Standards	When using FCD, the anonymization of data should be guaranteed and privacy standards should be follow to facilitate acceptance of the technology.
Internal Factors		
Organizational	Organizational Vision	Higher Management initiatives such as the "Better informed in the road" program encourage the shift towards new technologies.
	Budget Constraints	On the other hand, some organization-wide programs prescribe the reduction of costs. A strategy that can allow the transition to FCD, while taking into account the expected savings would be needed.
	Data Centralization	Rijkswaterstaat aims to have a centralized point of data collection (i.e. the NDW). FCD may not come directly from providers, rather it would go through this central point.

Internal Projects	PPA	A large-scale test to experiment with innovations in car and roadside systems. Several tests have been carried out with FCD and market providers.
	Cooperative ITS Corridor	International project in cooperation with Germany and Austria, where WiFi-P is being deployed to offer *in-car* services such as Road Works Warning.
	Talking Traffic	Partnership between the central government, different regions and several market parties. The objective is to bring information *in-car* such as speed signs through the 4G network.
	FCD – BeMobile	Online pilot where FCD collected from users of the Flitsmeister App was used to calculate AID congestion flags.
	FCD – Vodafone	This is also a pilot that aims to use FCD from Vodafone users to execute AID. However, they are still on the development phase and no final results have been achieved.
	i-WKS	New generation WKS that will replace legacy WKS and offers much more flexibility by separating software and hardware, using standard IP components and allowing the use of alternative sensors.
	i-Infra	Project that aims to install a glass fiber structure throughout The Netherlands. This *plug-and-play* network would have an impact on the locations where FCD could be deployed.
	CHARM	This project will replace many of the silo traffic applications in Rijkswaterstaat in one central system. MTM-2 is partially in the scope of CHARM, where all functionality should be implemented in this new system, except for the FEP.
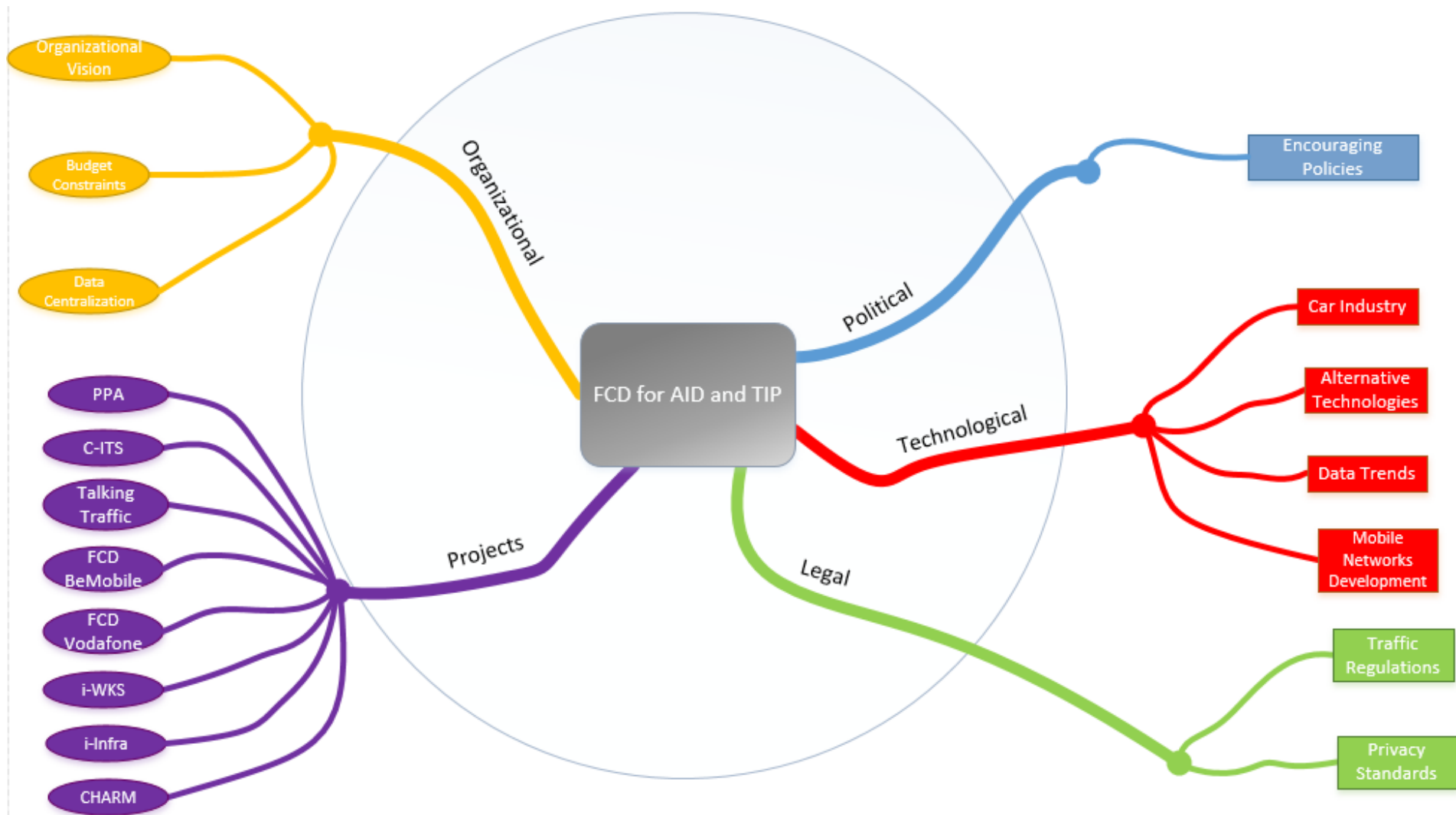
Figure 13. Factors that influence the implementation of FCD for AID and TIP

6 Architecture Design

After having set a theoretical framework the research can rely on, together with an exploration of the application domain where it can be placed and an evaluation of FCD in the context of AID and TIP, it is possible to start the designing process.

In section 2.3, the research framework used within this project was introduced. This framework is an adaptation from (Sein et al., 2011) Action Design Research and (Verschuren & Hartog, 2005) Design Cycle. This chapter will follow the structure presented in that adapted framework (see Figure 3). The first stage in ADR is the Problem Formulation, which will be covered in section 6.1, as well as the goal that wants to be achieved with the designed ICT Architecture.

The second stage in ADR is the Building, Intervention and Evaluation (BIE) phase, from which only the Building part is addressed in this project for the reasons explained in section 2.3. This Building sub-phase is decomposed in two steps from the Design Cycle: Requirements and Assumptions (Principles have been included as well) and Design, which will be presented in section 6.3 and section 6.4 respectively. These sections allow to answer research question 4 (RQ4): "*What are the design principles and high-level requirements that the ICT architecture integrating FCD for AID and TIP should meet?*" and research question 5 (RQ5): "*What does a flexible ICT architecture that integrates FCD into Rijkswaterstaat's AID and TIP traffic systems look like?*"

The third stage in ADR is Reflection and Learning, which should not be considered a "step", rather an activity that occurs in parallel of all other design activities. The first formal evaluating activity conducted in this research is a scenario analysis workshop. This workshop has been conducted to explore potential traffic management scenarios and to be able to make better informed design decisions. An overview of the workshop is presented in section 6.2 (before going into the Building phase) for the reader to better understand how the final set of requirements and the final design were derived.

(Hevner et al., 2004, p. 78) state that "the design cycle is typically iterated a number of times before the final design artifact is generated. During this creative process, the design-science researcher must be cognizant of evolving both the design process and the design artifact as part of the research". The sections presented below do not allow to see the iterative process that has been followed. For the sake of clarity, only the final result of every stage is presented but the reader should keep in mind that continuous iteration and evaluation was crucial to arrive at the presented outcomes.

6.1 Problem Formulation

ADR puts a great emphasis on the development of a design research project as a structured way to address a problematic situation identified in a particular organization, while generating prescriptive design knowledge (Sein et al., 2011). (Verschuren & Hartog, 2005) call this first stage, where the problem is identified the First Hunch, which results in an initiative to construct a material or immaterial artifact.

Formulating the problem in a punctual and accurate way has been as complex as any of the other stages of the design process. It was necessary to gain a good understanding of the organizational setting where the project was being conducted, understand why the situation is classified as a problem and where it originates from. The use of semi-structured interviews for problem elicitation has been particularly useful at this stage, as they allow to get the perspectives from different stakeholders in an open manner, avoiding to limit their responses.

Section 1.1 already presented a problem statement in very general terms that this research should address, including its practical and scientific relevance. Once a better overview was provided about the application domain where this research was placed and about FCD in the context of AID and TIP, it is possible to formulate the exact problem to be addressed through the ICT Architecture design.

It was mentioned that *due to the uncertainties at the technology, market and organization level, it has been challenging for researchers and practitioners to cross the gap between deploying individual (test) projects involving FCD and carrying out a full integration of this technology at a system-wide level*. What do these uncertainties refer to when positioning this statement in the context of FCD for AID and TIP?

Technology uncertainties
As it was seen in chapter 5, FCD is still a technology under development. The number of vehicles that can be used as a sample fluctuates between techniques and market providers. It is not possible to establish a fixed penetration rate to indicate the amount of data collection points that are available at different moments of the week or day; neither to establish to what extent this penetration rate will grow in the future.

Being AID a mission critical service (as it provides safety to road users), the need for information with sufficient quality is higher than in other services where FCD could be used in a more experimental way (e.g. to indicate route suggestions). In order to fully deploy FCD for AID, Rijkswaterstaat must be certain that the same service levels can be met. Moreover, investing in long term contracts (to acquire data) and in systems infrastructure (to integrate FCD) might be considered a risky investment since it is not certain that FCD will become a dominant technology in future traffic systems (i.e. as it was mentioned in section 5.2, alternative technologies are already available) or when it will be replaced by emerging technologies (e.g. fully autonomous cars).

With regards to TIP, FCD is still unable to provide a sufficient amount of information to fulfill this service completely. Since FCD is based on samples from the vehicle population, it does not provide exact data about the intensity of vehicles that pass through certain points. It is also uncertain whether and when FCD will be able to provide this information.

Market uncertainties
Tightly related to the technology uncertainties just posed above, uncertainties at the market level are also found in this scenario. There are currently no service or data providers in The Netherlands that can offer a full FCD provision service that matches all the requirements for AID and TIP. This also due to the fact that the technology is still under development and many of these providers are working on their own algorithms to achieve the needed quality.

It is uncertain for Rijkswaterstaat when these providers will have a ready-to-sell product or service and when so, what type of contract to establish with them (i.e. for how long, how much data, for which areas of the country) since it is also unknown how FCD will be deployed at a national level. Moreover, it is not certain if these providers will manage to have coverage in the whole Dutch territory. Another question that arises is whether to establish contracts only with one provider (to avoid duplicated data) or if it would be desirable to establish contracts with different providers (to guarantee resiliency).

Organizational uncertainties

Finally, and related to the previous types of uncertainties, organizational uncertainties exist too. Firstly, this refers to the fact that it is uncertain how the role of Rijkswaterstaat will change with the introduction of new players in the fulfillment of AID services. On one hand, since AID is a mission critical service, Rijkswaterstaat desires to keep close control of it. On the other hand, the trend in the coming years is that these functions will be increasingly taken by vehicles themselves. Thus, it is uncertain for the organization what type of data it would be preferable to acquire from providers. Raw speed data would allow them to keep more control, whereas speed signs information would move control towards the provider side, as it will be seen in section 6.2.

Secondly, there are some ongoing internal projects (see section 5.2) that have an impact in the way traffic systems work within Rijkswaterstaat and which influence the way FCD would be integrated in the current landscape. These projects experience uncertainties on their own and the organization cannot surely determine when or how certain functions will change due to them.

With an overview of these uncertainties, the problem formulation can be now more clearly understood, as well as the goal of designing a flexible ICT Architecture as indicated in the research objective, which is repeated below:

> *Design a flexible ICT architecture that integrates Floating Car Data (FCD) into Rijkswaterstaat's Traffic Management and Information Systems for Automatic Incident Detection (AID) and Traffic Information Provision (TIP) services.*
>
> Research Objective

In this goal definition (or research objective), the need for flexibility must be highlighted. Given the technology, market and organizational uncertainties presented above, it is necessary that the designed ICT Architecture is capable of handling changes in any of these three dimensions.

6.2 Scenario Analysis Workshop

An ICT architecture provides a high-level overview of the systems and their interrelationships but it should also provide a sufficient level of detail to guide its implementation. The uncertainties described in section 6.1 make it difficult to take final decisions about the functionality of certain systems, the roles stakeholders should take and the time to roll-out certain features.

To bring some clarity into these subjects and avoid the use of too many "black-boxes" in the architecture design, a decision framework is formulated as depicted in Figure 14. This decision

framework considers the initial decisions that should be taken to move forward with the implementation of FCD in the current landscape.
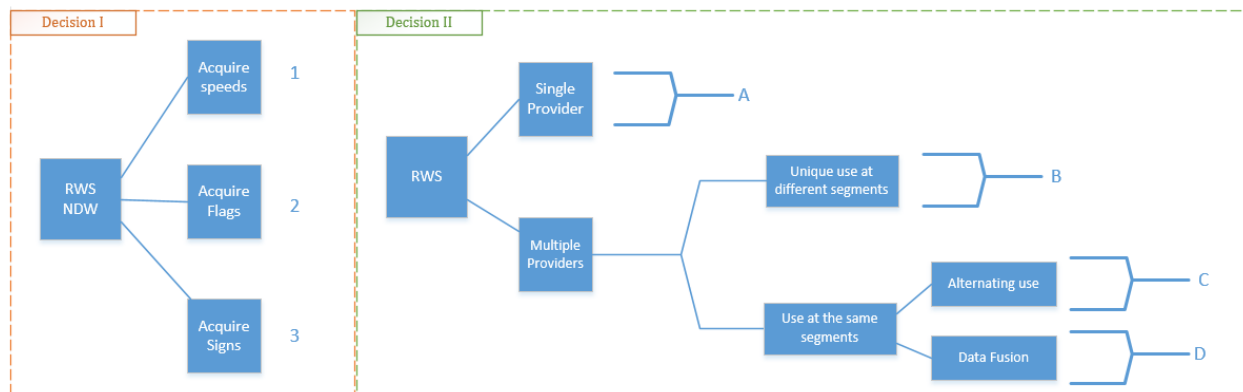
Figure 14. Decision Framework for the implementation of FCD

Decision I aims to determine what type of data to acquire from providers: (1) raw speeds, (2) congestion flags or (3) speed signs. This is a procurement decision that could be taken in cooperation with NDW, as the organization that centralizes data for all public authorities in The Netherlands and who procures data from different providers. On one hand, this decision should be taken by considering a procurement strategy that addresses concerns such as the contract terms that should be agreed with the provider, whether there are related contracts with this or other providers or whether the information being acquired can be used for purposes other than AID.

On the other hand, this decision also implicates defining the role that Rijkswaterstaat would like to have when providing this service. Deciding to acquire speeds implicates that Rijkswaterstaat has more control over the way AID is performed and thus has a closer overview of quality but it also implies a greater burden on their central systems (more functions to be carried out). In the other end, acquiring signs would imply having less control over the process and the associated data but it would also reduce the processing that needs to be done on its central systems.

Decision II seeks to determine the approach to take when using FCD and integrating it with induction loops data. One possibility would be to acquire FCD only from one provider (A) but this option will not be further elaborated since it is a simplification of the other options. The other three options contemplate having multiple providers of FCD (or data originated from other methods, such as DAS).

A first option would be to utilize one type of data for only one road segment (B). For example, using FCD from one provider for the road Ax, loop data for the road Ay and data from another technology in road Az. A second option would be to use different sources of data for the same road segment but with alternating use in time (C). This would mean, for example, using FCD from one provider during peak hours in road Ax and using loop data at night or weekends in that same road. A third option would be to use different sources of data in the same road segment as well but utilizing data fusion technology. Data fusion implicates taking raw speed data from different sources and fusing it to obtain better quality data.

Combining the options resulting from these two decisions yielded nine scenarios: B1, B2, B3, C1, C2, C3, D1, D2 and D3. For each of these scenarios an architecture diagram has been drafted and presented to an experts' panel during a workshop organized at Rijkswaterstaat. Since not all the participants in the workshop would have specific knowledge on architecture notation, the diagrams were sketched in Visio and they don't represent a complete architecture rather an overview of the most relevant changes to the systems. It is important to highlight that the creation of these diagrams has also been an iterative process with versions that were continuously adjusted based on the simplification of the content to be presented during the workshop and the input from Rijkswaterstaat's solution architect, Antwan Reijnen and program manager, Gerard Avontuur.

The final version of the diagrams presented during the workshop can be found in Appendix F. Initially a presentation was given to the participants where the different scenarios were explained, as well as the drafted architecture for each of them. During this time, there was also room for questions and there were already some remarks about the various scenarios. Afterwards, the participants were divided in three groups and each of the groups was assigned one set of scenarios (B, C and D). A sheet with guiding questions was also delivered to the participants to guide the discussion (see Appendix G). Each group had to discuss about the advantages, disadvantages and use cases for their assigned scenario and compare it versus the other scenarios. After the discussion, the groups shared their main findings and it was possible to make some more remarks regarding those findings. Once the workshop was finalized, it was possible to derive a set of conclusions.

Decision I. There was general agreement on the fact that **acquiring raw speed data** would be the most desirable option to go for. There were four main arguments that the groups shared:

- Acquiring raw speed data allows Rijkswaterstaat to keep more control over the execution of AID. Being a mission critical service, it is important for the organization to be able to define and execute the traffic engineering logic behind AID. If third parties were to execute this logic, Rijkswaterstaat would need to share with them this expertise, which is part of their core competencies.
- The process of controlling and ensuring data quality would be easier for Rijkswaterstaat if they acquired raw speeds. Particularly, if they acquire data from different providers, it would be simpler to compare raw data than data that has been processed through different methods and potentially different logic.
- If congestion flags or speed signs were to be acquired, there would be few applications where this information could be used. On the other hand, if raw speed data was acquired, this information could be potentially used for other services.
- It would be easier for providers to provide raw speed data since it would not require further processing on their end. This would mean that integration of FCD could be sped up since it would not be necessary for them to implement additional traffic logic.

Decision II. Regarding scenario A versus the other three scenarios, it was agreed that it would be necessary to **acquire data from several providers** at least in the initial stage of FCD deployment. Since the technology is not yet mature, it would be better to have data from different providers to compare their accuracy and performance. Moreover, in case a provider is down, other providers could be used as back up.

There was no definite agreement on whether to solely use scenario B, C or D. Some arguments that are worth highlighting are:

- Scenario B would be a valid use case, since there are roads where there are no loops at all and FCD could be solely used for those segments.
- A group stated that FCD should only be used for roads where there are no loops available, yielding scenario B. The argument is that loop data already provides good quality levels and allows to fulfill the AID service.
- Scenario C would imply double costs, since both sources (loop data and FCD) would need to be made available in parallel.
- A valid use case for scenario C would be a testing scenario. If the data quality of certain provider would like to be tested, it could be "switched on" for certain period and then "switched off" to continue using loop data.
- Scenario D seemed to be a popular option among the groups, since it would allow to start reducing costs. When a loop is damaged, it would not be necessary to repair it since FCD could "fill in those gaps".
- One of the groups perceived scenario C to be a special case of scenario D, where data fusion would be at its minimum (use no FCD) or at its maximum (use only FCD).

There was a general concern for the costs that FCD may bring, since the purpose of many ongoing projects (such as WKS Light) is to reduce costs. One of the groups expressed a very valid point: as with many innovations, the initial costs would be high but in the long term, they would start decreasing and provide savings.

In conclusion, we can say that the designed architecture should be able to **support a combination of these scenarios**. Scenario B would be needed in any case for those roads with no loops. Scenario D seems to be a preferred option and scenario C could be understood as a version of scenario D.

6.3 Building: Principles, Requirements and Assumptions

(Sein et al., 2011) do not explicitly introduce a phase to elicit, elaborate and specify design principles, requirements and assumptions within ADR. The use of design principles has been referred to by other authors in design science research (W. Kuechler & Vaishnavi, 2008) and it is important to emphasize its use as a mean to guide the design in a prescriptive level within the framework of requirements: "whereas requirements often involve individual systems, principles are included in an architecture to ensure that all further developments and improvements adhere to these principles" (Bharosa & Janssen, 2015, p. 472). For that purpose and before start building the artifact a set of relevant principles is extracted from Rijkswaterstaat's Enterprise Architecture, as it will be seen in section 6.3.1.

Oppositely, requirements and assumptions are not set at once, rather they continuously evolve along with the design. Requirements and assumptions are not referenced in ADR and that is why the research framework presented in section 2.3 (see Figure 3) is complemented with (Verschuren & Hartog, 2005) design cycle. They highlight the importance of (1) designing an artifact that meets the

demands of future users (i.e. requirements) and (2) specifying user and context characteristic that make possible an effective use of the artifact (i.e. assumptions).

As it was already anticipated given the nature of ADR, the final set of requirements and assumptions as presented in section 6.3.2 and 6.3.3 is the result of multiple iterations of the Building stage based on Reflection and learning, as advised by (Sein et al., 2011).

6.3.1 Design Principles

To give direction to the activities that Rijkswaterstaat conducts, a strategy known as *i-Strategie* (ISTRAT) was formulated in 2015. The *i-Strategie* is a document that analyzes the process needs from Rijkswaterstaat and its partners and translates them into what information provisioning would be necessary to satisfy them (Rijkswaterstaat, 2015b). Within this strategy, the importance of an Enterprise Architecture has been devised, as a means to get an insight and overview of the relationships between legislation, products and services, processes and supporting supplies at Rijkswaterstaat (Rijkswaterstaat, 2015b).

Rijkswaterstaat's Enterprise Architecture (EA) specifies four layers: Business, Information and Data, Technical and Industrial Automatization. Moreover, a Security block is defined to apply to all layers. Every layer specifies a set of principles, which were useful to guide the design. "Principles are generic by nature and thus do not constrain designer creativity or possible solutions, they provide architects with freedom in designing and using artefacts based on the needs of their own organization" (Bharosa & Janssen, 2015, p. 473).

However, these principles sum up to fifty-nine (see Appendix H for a complete overview of all principles) and they not always apply to every situation or project. (The Open Group, 2011) recommends that principles should be few in number; for that reason, a smaller set of principles to guide design has been selected, as presented in Table 6.

Table 6. Principles from the EA relevant to the solution architecture

Name	Statement	Implications
EP-3	We align the execution of our tasks with all our stakeholders.	Since service providers will play an increasing role in Traffic Management when providing FCD, there should exist clear communication channels with them and they should be engaged in early stages of the FCD integration process.
EP-8	Security is taken integrally in the development of processes.	With an increasing need for data exchange with third parties, it should be ensured that processes, access to applications and infrastructure remain secure.
EP-10	First "reuse", then "buy", then "have made".	The first option to implement needed functionality is the use of existing data, applications or services. If new components are needed, they should be standard commercial products or services. If nothing is readily available in the market, it is possible to have them made.
AP-3	RWS uses standards.	Systems should use standards for data, applications, communication protocols, interface descriptions, hardware components, etc.
AP-5	Innovation and maintenance take place under architecture.	Implementation of FCD should be conducted from an architecture perspective to make sure other systems are being considered. This report contributes to this principle.

Additionally, every layer from the EA is further specified in what it is known within Rijkswaterstaat as Domain Architecture. There are eight domains: Water, Navigation, Living Environment, Crisis Management, Design, Maintenance and Asset Management, Operational Management, IV-process and Traffic (where this project was situated). For the Traffic Management domain, Rijkswaterstaat's higher management formulated a 'Traffic Management Vision' (Visie op verkeersmanagement, VVM) in 2014. This is a document containing a series of guiding statements that are aligned with the "Better informed in the road" program (see Appendix E) and which help define Rijkswaterstaat's role and position in Traffic Management (Rijkswaterstaat, 2014). These statements have also been reviewed to provide direction to the design and align it with Rijkswaterstaat's vision. They are not presented in this section but a complete list can be found in Appendix I.

6.3.2 Design Requirements

As already anticipated when describing the nature of design science research, the process of deriving requirements for the solution architecture is an iterative process (Gregor & Hevner, 2013). Not only design science literature emphasizes this fact but also TOGAF prescribes requirements management to be "a dynamic process where requirements for enterprise architecture and subsequent changes to them are identified, stored and fed into relevant phases of the architecture design and between the design cycles" (The Open Group, 2011, p. 168).

Requirements Engineering is a very extensive field, where complete books have been written spanning various subjects such as requirement domain analysis, elicitation, negotiation and agreement, specification, specification analysis, documentation and evolution (Van Lamsweerde,

2000, p. 1). However, "there are rare definitions of architectural requirement in literature, which reflects the less attention on architectural requirements in the academia" (Gong, 2012, p. 154).

(Hoogervorst, 2009, p. 296) indicates that "architectural requirements should relate to areas of concern, which pertain to the system's development, its operation or any other aspects that are critical". Following this line of thought, the requirements specified for the developed architecture do not refer to specific system requirements or performance measures, rather they are a very high-level expression of the main areas of concern of the application domain where it is placed.

An initial set of requirements was deducted from the analysis of the current architecture (section 4.2 and section 4.3) and the analysis of FCD in the context of AID and TIP (section 5.1 and section 5.2). After that, it was possible to start drafting some possible architectures for the scenario analysis workshop, as it was presented in section 6.2. While iterating between these drafts, it was possible to also update requirements and assumptions based on the insights that considering alternative situations gave.

According to (Verschuren & Hartog, 2005, p. 738), "the designer continuously goes back and forth between the several stages (at least mentally), looking what repercussions a decision in one stage has for earlier as well as for later stages". Table 7 presents a final version of the derived requirements but in order to arrive at them, it was particularly necessary to alternate between this and the design phase (see section 6.4). Asides indicating the requirement in a clear statement, a category under which it could be located is also presented.

Table 7. High-level requirements for the solution architecture

Requirement	Description
Main Requirement	The solution architecture should allow for the integration of FCD in the current Traffic Management systems.
Service Fulfillment	The solution architecture should allow systems to meet current service levels to fulfill the AID and TIP services. • AID: Real time data acquisition to timely detect congestion. • TIP: Minute based speed, intensity and category information every x meters, made openly available to other systems / parties.
Compatibility	The solution architecture should allow the use of loop data and FCD in parallel, while a full transition to FCD (potentially) occurs.
	The solution architecture should allow the integration with legacy systems, until they are retired.
Interoperability	The solution architecture should provide an interface to adequately acquire FCD from providers.
Modularity	The solution architecture should allow to add, modify and remove components with no major effect.
Scalability	The solution architecture should allow the integration of new technologies, new data providers and new functionality.
Reusability	The solution architecture should provide the ability to reuse building blocks (applications, services, data) for other purposes (other services).

6.3.3 Design Assumptions

"When defining the requirements, also numerous assumptions are made about those qualities that the users and the context should possess to turn the IT artifact into a success. These assumptions are created by the ADR Researcher to check the feasibility and credibility of the IT artifact" (Keijzer-Broers, 2016, p. 99). Just as like with the requirements, assumptions were also updated with every iteration of the design. They were mainly derived from the conclusions obtained through the workshop presented in section 6.2 and from the technology analysis conducted in chapter 5. Assumptions can be summarized as follows:

- It is assumed that Rijkswaterstaat will acquire raw speed data for its further processing to fulfill the AID service.
- It is assumed that Rijkswaterstaat will acquire data from different data providers, including not only FCD but also other technologies.
- It is assumed that FCD would provide improved (or keep the same) service levels for AID and TIP.
- It is assumed that the quality of the data provided by the data providers is sufficient (e.g. accuracy, timeliness and reliability).
- It is assumed that FCD will become a dominant technology for Traffic Management and Information applications in the next years.

6.4 Building: Solution Architecture

After the Enterprise Architecture and the (Traffic Management) Domain Architecture, the next level of detail is the Solution Architecture, which is how the designed architecture in this project can be classified. (The Open Group, 2011, p. 31) defines it as "a description of a discrete and focused business operation or activity and how IS/IT supports that operation. A Solution Architecture typically applies to a single project or project release, assisting in the translation of requirements into a solution vision, high-level business and/or IT system specifications, and a portfolio of implementation tasks".

At the moment, there is no specific project within Rijkswaterstaat responsible of moving these changes forward or implementing the designed architecture. However, it will serve as a vision for the end state the organization should move towards and it will be helpful when a team is commissioned to assess the feasibility of the project.

The Building phase from ADR has been subdivided into a (1) principles, requirements and assumptions specification sub-phase, presented in the previous section and a (2) design phase following (Verschuren & Hartog, 2005) design cycle. They distinguish between *materialization* for material artifacts and *realization* for immaterial artifacts. The designed architecture can be classified as an artifact from the latter type, since it will be presented as a graphical representation of the traffic system components and its interrelationships utilizing architecture description language.

The theories and frameworks introduced in chapter 3 have been useful throughout the design process. In section 3.1, an ICT architecture was defined as being composed of three core elements: (1) a set of design principles, which were already introduced in section 6.3 and which were used to inform the design at a high-level, (2) a description of the system structure and its components, which will be addressed in the following subsections and (3) implementation guidelines. This last component can be developed after executing a gap analysis. In such analysis, the shortfalls between the descriptive and prescriptive architecture are highlighted. Once the missing elements have been identified, migration planning techniques can be used. This can come in the form of architecture plateaus, "a relatively stable state of the architecture that exists during a limited period of time" (The Open Group, 2011, p. 101). Different plateaus can reflect transition periods of the architecture, showing incremental states the organization can move between. Given the time scope of this project, these implementation guidelines will be limited.

In order to describe an ICT system structure, its components and the interrelationships between them, the use of architecture frameworks becomes handy as a standardized means to structure design. As it was introduced in section 3.1, (The Open Group, 2011) Architecture Framework (TOGAF) is used as the reference framework for the design of the solution architecture. The architecture concepts and definition of architecture layers that has been and will continue to be used in this report stem from TOGAF.

Additionally, (Janssen & Cresswell, 2005, p. 2) suggest that "(enterprise) architectures should be understandable by all stakeholders in order to make it work. The creation of a shared vision, communication among stakeholders and evaluation of the impact seem to be crucial aspects". With

that purpose, a modeling and visualizing approach is used as a means to create a shared understanding. ArchiMate, a visual architecture description language, is used to convey the architecture design to stakeholders, as it was introduced in section 3.2.

A very important detail to take into consideration when designing an architecture is the resulting *level of abstraction*. "A model at a too high abstraction level could be too vague, while a model at a low abstraction level, including all details, might not only lead to long data collection time, but also to confusion instead of understanding" (Janssen & Cresswell, 2005, p. 3). In this scenario, it is necessary to provide an overview of the system that could be comprehensive but also understandable to stakeholders other than architects. Moreover, many of the details that are known about the systems or about considerations for implementation have not been included in the ArchiMate diagram to avoid overwhelming and unclear information. These details are described in text.

The core of TOGAF is the Architecture Development Method (ADM), "a process for developing architectures that includes establishing an architecture framework, developing architecture content, transitioning, and governing the realization of architectures in an iterative way", as depicted in Figure 15 (The Open Group, 2011, p. 10). In this project, the focus is on describing phases B (Business Architecture, section 6.4.1), C (Information Systems Architecture, section 6.4.2) and D (Technology Architecture, section 6.4.3), taking as an Architecture Vision (phase A) the work that was done in the Problem Formulation (section 6.1) and the Building: Principles, Requirements and Assumptions (section 6.3) stages.
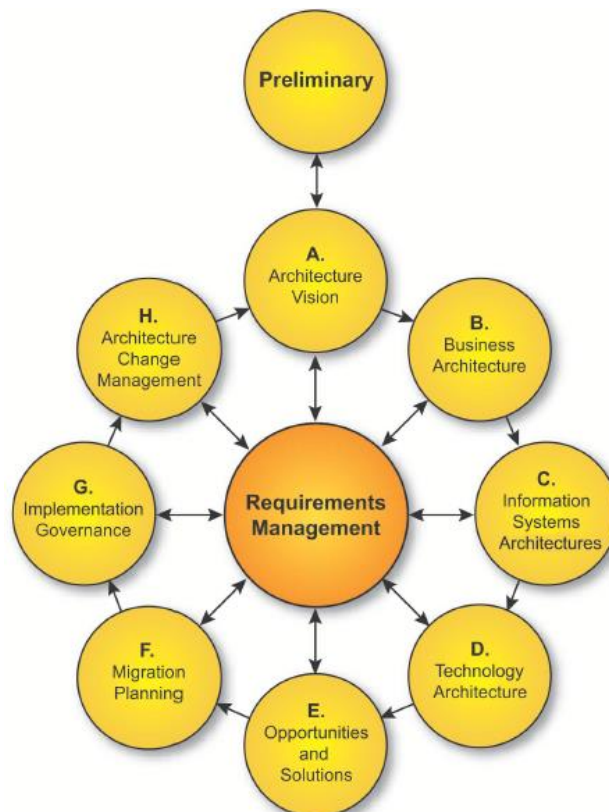

Figure 15. Architecture Development Method (copied from (The Open Group, 2011, p. 48))

6.4.1 Business Architecture

"The business architecture is a description of the structure and interaction between the business strategy, organization, functions, business processes, and information needs" (The Open Group, 2011, p. 23). Figure 16 depicts the designed business architecture. As it can be seen, the most relevant change is the incorporation of a new business actor (market parties) who now participates in the fulfillment of the AID and TIP services. With the entry of this new player, there is also a change in the actors accountable for the AID business process and the introduction of new services. For clarity purposes, this business layer has been subdivided into four sections, as follows.

Traffic Management Business Services
In this section, it is possible to see which services from the Traffic Management Domain Architecture (see section 4.1) business services portfolio are supported through the AID business process. As the main requirement indicated (see Table 7), the solution architecture should allow to fulfill the same services as the current architecture, so it is logical that this section does not change throughout time.

Business Actors
In this section, we find two business actors who collaborate to execute the AID business process: Rijkswaterstaat on its role of road authority and various Market Parties on their role of Data Providers, who offer FCD as a product. A key point in this section is the need for a contract between the two parties, an agreement where the rights and obligations associated with the product are specified (The Open Group, 2016). In this contract, it is important to establish a service level agreement (SLA) that the providers should fulfill and where data quality is central, as a means to ensure the reliability of traffic management calculations. This contract is a component still to be further specified.

Business Process
In this section, a high-level representation of the AID business process is depicted, consisting of four main steps. The first step is to *collect traffic information*, process for which both the data provider and Rijkswaterstaat are responsible. Secondly, the *generate congestion information* process uses the collected information to detect congestion and Rijkswaterstaat is the accountable actor for it. There is an associated business object with this process, which represents every location where congestion has been detected (from 1 to *n*). Thirdly, the *calculate congestion measures* is also taken care of by Rijkswaterstaat, which consists in generating a set of measures (based on traffic engineering logic) that should be placed along the road. Finally, the *combine all sign requests* process implies integrating existing signs in the road with new signs generated by AID and any operator requests, for which Rijkswaterstaat is also accountable. Rijkswaterstaat is also responsible for the overall AID process, that means, ensuring that the process outcomes are accurate and timely.

Underlying Data Services
The underlying data services are conceptual services which help make a connection with the applications that support the business processes. The *collect traffic information* process is supported by *RWS Traffic Data Services* (i.e. data collected from loops) and by *External Traffic Data Services* (i.e. data collected by multiple providers). The data generated by Rijkswaterstaat is represented in the

form of business objects and they include *minute-based data (v, i, c)*, as well as *Real Time Speeds*[5] and *(WKS) Congestion Flags* (generated by the roadside systems). On the other hand, the data generated by providers is represented as the *Alternative Traffic Data* object, which is in a format that must be yet determined. What can be assumed from the conclusions reached at the scenario analysis workshop is that this data would come in the form of raw speed data.

Next to these services, *Data Fusion Services* should also exist. As described in section 6.2, these services would need to use the different data sources and result in *Fused Traffic Data* which represents fused raw speed data from all these sources. These services may require some business logic to determine in which locations each data source will be used or allow for the combination of multiple sources at the same location. This service needs to be further specified (e.g. will it be done in a new application?) and the actors who should fulfill them should also be determined. At the end, the *generate congestion information* should be able to whether use the *(RWS) Congestion Flags* object directly or the *Fused Traffic Data* object to generate congestion flags.

ESB Services
Additionally, the information originated from the *generate congestion information* and the *combine with existing signs* is respectively made available to any other systems or parties through a *Congestion Flags Service* and a *Signs Service* that reside on the ESB. Currently, this is only available for the information generated by MTM but the idea would be to also make available the information generated via FCD (or other sources).

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[5] Only a small number of legacy WKS can deliver real time speed data. The new i-WKS would be able to perform this function.
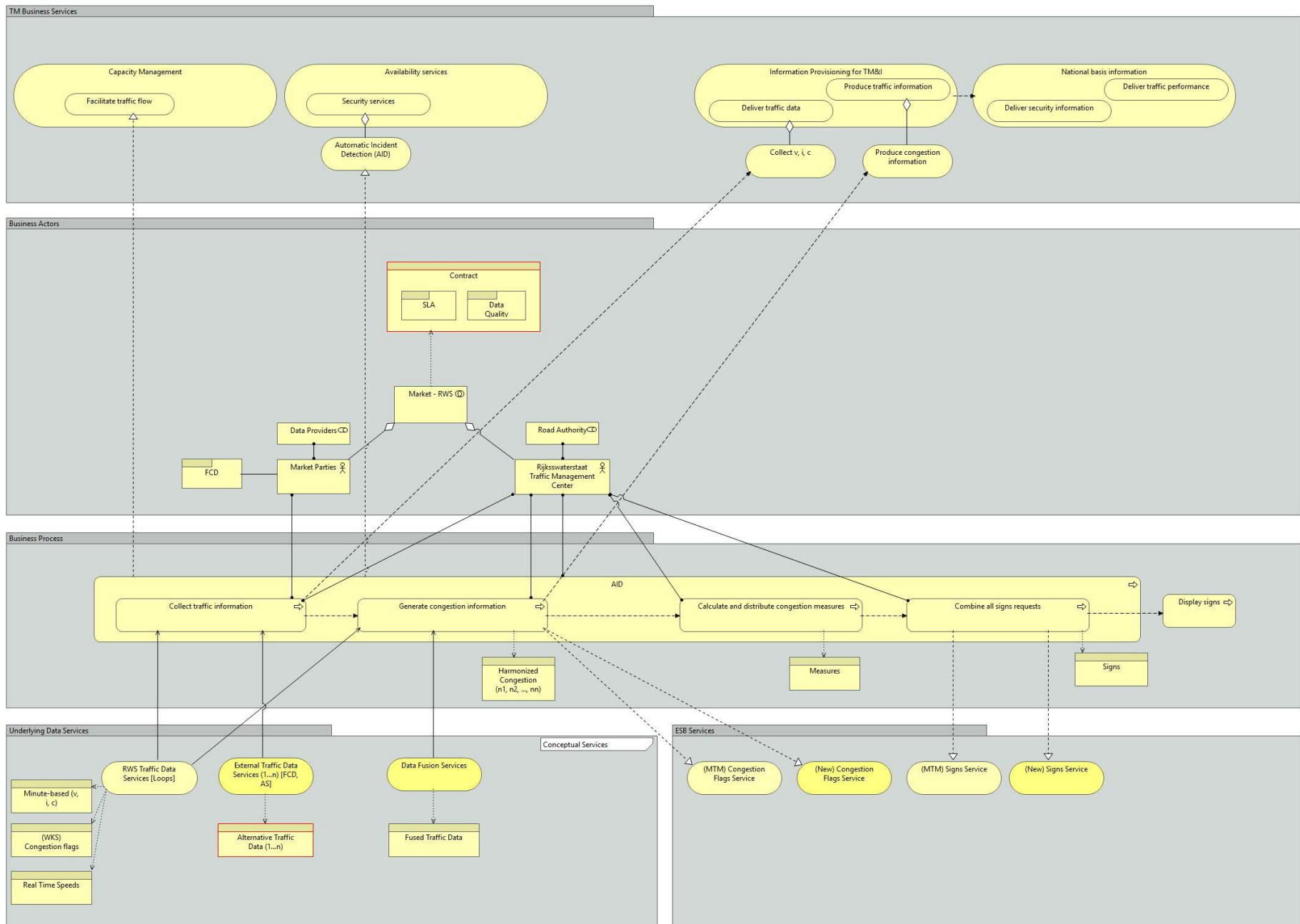
Figure 16. Solution Architecture. Business Layer

6.4.2 Information Systems Architecture

In Figure 17, it is possible to see both the Information Systems Architecture and the Technology Architecture. Moreover, a layer of business services has been depicted in this figure to make more visible the linkage with the applications that make those services possible.

Applications – Roadside
In this section, it is possible to find the roadside systems. We can see the *Legacy WKS*, which can collect data from loops, generate congestion flags based on that data, perform the Local AID algorithm, display traffic signs in the MSI and combine AID measures (existing and new) with operator requests as well (this latter function allows to fulfill the *Combine all signs requests* process at the Business Architecture). The *Legacy-WKS* supports the *RWS Traffic Data Services* by making available the business objects depicted in the Business Architecture. The way this system connects to the central systems is via the FEP interface.

The *i-WKS* is also able to execute all those functions and make the same information available, thus allowing to fulfill the *RWS Traffic Data Services* as well. Additionally, all *i-WKS* would be able to forward real time speed data (only some *Legacy WKS* can do this, hence it has not been depicted). A very important function that *i-WKS* should be able to execute is the TOP/i-TOP integration. This means that the *i-WKS* should be able to communicate in parallel with both central systems. Since the TOP functionality cannot be modified, the *i-WKS* should also send "fake messages" to the TOP to make it believe everything is operating as expected, while it is (in reality) using the information coming from the i-TOP (see more details below). For this reason, the *i-WKS* will be able to communicate with the central systems both via the FEP interface and the i-TOP interface.

Applications – Provider
There is not much detail in this section, since it will be transparent to Rijkswaterstaat how providers collect, process and stream the speed data information. What it is important to highlight here is that this *Provider Application* allows to fulfill the *External Traffic Data Services*. Something pending to define is how Rijkswaterstaat connects to the provider interface. This could be done via NDW, via the Domain Service Bus or directly via the i-TOP.

Applications – RWS-Provider
This is one of the most critical applications for the integration of FCD. However, there are still many uncertainties surrounding it. On the *Data Fusion Application,* there should be an interface that can receive all the raw speed data coming from both Rijkswaterstaat and providers. It is still undefined what components would connect to the interface of this application (e.g. the ESB or the i-TOP). With that data, the application can utilize data fusion mechanisms to generate the final set of *Fused Speed Data* that will be used to generate congestion flags. It is also undetermined if this data fusion will be conducted by an external party (provider) or by Rijkswaterstaat itself. The functionality of generating congestion flags based on this fused data has been placed under this application for illustration purposes but it is also pending to be defined if this will be done there or in the central systems, e.g. in the i-TOP.

<u>Applications – TMC</u>

In the Traffic Management Center, we can find the existing FEP and TOP applications. In the TOP, Central AID measures are calculated and distributed to the roadside systems, function that allows to directly fulfill the *calculate and distribute congestion measures* process at the Business Architecture. Additionally, the TOP can integrate the operator requests and forward them to the roadside systems, where they will be combined with existing and new AID measures, as it was mentioned above. Finally, the TOP can also distribute traffic information to other systems, allowing to fulfill the Traffic Information Provisioning service. The *(MTM) ESB Services* mentioned in the Business Architecture are made available by the TOP via a SOA stub, which exposes them to the public.

In the Traffic Management Center, some new functionality will be needed to integrate FCD. This is currently represented as a set of functions denominated as i-TOP because it has not been yet defined whether this will be deployed as a new application, a set of services in the ESB or any other possibility. The i-TOP should be able to calculate Central AID measures based on the congestion flags generated from the *Fused Traffic Data*. Before the i-TOP can distribute the AID measures it calculated, a very important function needs to take place: Harmonize (MTM) and (Data Fusion) AID measures. This is relevant for those roads where both AID based solely on loop data (*Legacy WKS*) and AID based on data fusion (*i-WKS*) will exist in parallel. The i-TOP would read the information from the *(MTM) Signs Service* (made available through the ESB) and harmonize that information with the AID measures it calculated. This way, it can be ensured that consistent signs will be placed along the road.

It is important to notice that the integrate operator requests function is not present in the i-TOP. Since these operator requests are input via a legacy system (DIP) that can only communicate with the TOP, it would be easier for the *i-WKS* to obtain these operator requests via the FEP, while it obtains the AID measures via the i-TOP. Finally, the distribution of traffic information would also be possible via the i-TOP. However, it is likely that this function will not be used in the medium term, since minute-based information that can fulfill Rijkswaterstaat requirements can only be obtained from loop data (i.e. from the TOP).

6.4.3 Technology Architecture

The Technology Architecture has been depicted together with the Information Systems Architecture in Figure 17. This is a very simplified representation, since at this point of the process, it is not relevant to go into details in this layer.

Basically, an infrastructure section presents the WKS and i-WKS physical devices, where all the functionality explained in the Roadside Applications runs. These devices are connected via IP to Rijkswaterstaat's Traffic Management Network. Likewise, the applications at the Traffic Management Center run in physical devices that are also connected via IP to this network. It is possible that the i-TOP is deployed in the ESB, which may be supported by next generation systems.

What should be highlighted in this layer is the importance of Integration Middleware, which in this case is represented as a Domain Service Bus (DSB). The DSB is an enterprise service bus based on Java that serves as an integration platform, easing the connection of applications and exchange od data. "The advantages of using middleware over direct interaction are that fewer connections need to be established and maintained and that changes need to only be made at one place in the overall

ICT-architecture" (Janssen, Wagenaar, & Beerens, 2002, p. 4). In this scenario, the DSB would allow the interconnection of legacy applications such as the TOP with new applications (to be developed) such as the i-TOP, where the latter one could make use of the data generated by legacy applications very easily.

Moreover, the use of the DSB supports a Service Oriented Architecture (SOA), where reusable services can be hosted and exposed to be used by other applications or services. In the designed solution architecture, these services included the *Congestion Flags Service* and the *Signs Service* (which as a matter of fact is already used by other traffic management applications and by some projects like Talking Traffic). In the future, this can evolve to a larger service portfolio, where all sorts of information are made available in the form of services. In the Application Architecture, it was also mentioned that it is not certain how the providers should connect to Rijkswaterstaat central systems. A very likely possibility is to make use of the DSB, which would facilitate them plugging in. The same applies for the connection to the Data Fusion Application. The service bus would allow the integration of these and any other future applications that may use different underlying technologies or communication protocols.

The exact capabilities of this service bus (currently a platform from the MuleSoft company) have not been explored in this report. This would imply evaluating if the DSB can process large amounts of real time data, how resilient it is and to what extent it can scale up. In this layer, it will also be important to emphasize the use of Commercial Off-the Shelf (COTS) components for any next generation systems that need to be deployed. According to (Janssen et al., 2002, p. 4), "COTS components replace the traditional scenario of developing unique system components with the promise of a fast, efficient acquisition of cheaper components and implementations".
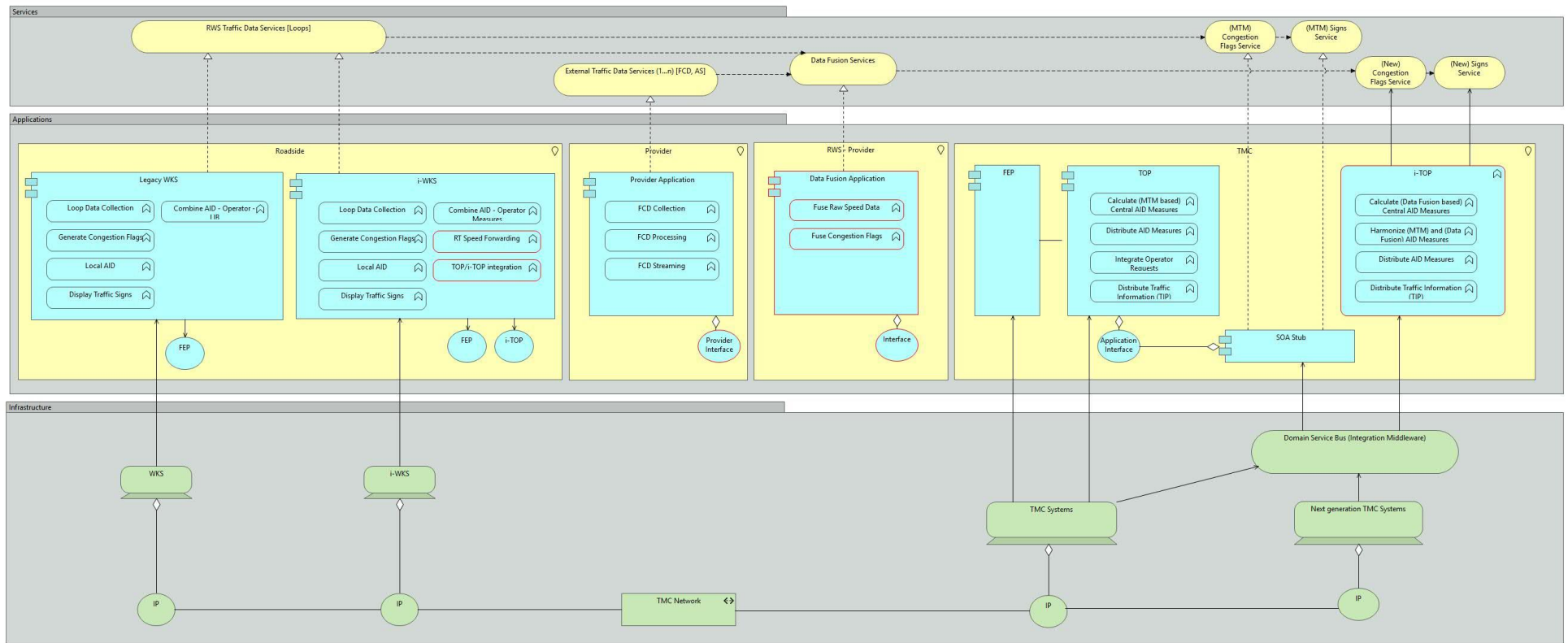
Figure 17. Solution Architecture – Application and Technology Layer

6.4.4 Architecture Implementation

In the previous sections, an overview of the system structure and its components at different layers was presented, as well as the interrelationships between them. As it was mentioned in the introduction of section 6.4, many details about these systems or about the implementation of this architecture have not been included in the ArchiMate diagram to provide a clearer overview to stakeholders. At this point, it is important to elaborate on how this architecture can be operationalized by describing some use cases and indicating the changes required for a shift from the *as-is* to the *to-be* architecture to occur. However, the reader should remember that it is outside the scope of this research to provide extensive implementation guidelines, which typically come in the form of gap analysis, migration plans and architecture plateaus.

Use Cases
The scenarios formulated in the scenario analysis workshop in section 6.2 not only help minimize some of the uncertainties related to the implementation of FCD but they also provide the space to think about how a roll out of FCD in the roads could occur. The solution architecture just presented above can support three use cases:

Use Case 1. For those roads where there are no induction loops currently installed, FCD could represent an alternative to provide the AID service to users. In this case, we would have roads where FCD is fully used and roads where loops are fully used. Since the rollout of i-WKS would be gradual, the latter scenario would be expected to exist. For this use case to be possible, the installation of i-WKS in the selected roads would be needed, as well as the i-TOP functionality and the ability to generate congestion flags based on this data.

Use Case 2. In case FCD cannot be reliably used as a sole source of data and loop data would like to be used in combination with it, data fusion is a possibility. In this case, it might be necessary to use real time speed data collected at the roadside to perform data fusion. If data from many loops needs to be continuously sent to the central systems, it could cause a large load on the network. However, this is something dependent on the development of data fusion algorithms. It may be the case that only minute-based information is needed. For this use case to be possible, asides the i-WKS and the i-TOP, the Data Fusion Application would also be needed.

Use Case 3. There might be also roads where there will be WKS that perform AID with induction loops data until some point of the road and for the rest of the road, it will be possible to perform AID via i-WKS with FCD. In these cases, it would be important that i-WKS (a smarter system) are placed upstream WKS. This way, when the WKS place some measures on the road, the i-WKS can know through the i-TOP which measures to place upstream to make them consistent. For this use case to be possible, the Harmonize AID Measures function at the i-TOP is central.

Required Changes
For a shift from the current to the new architecture to occur, there are many changes that need to be executed. These changes can be inferred when making a comparison between the two scenarios and they can be described per layer as it will be seen below. Moreover, as the reader may have noticed, there are some components in the architecture presented in Figure 16 and Figure 17 that have a red

border. These are components that need special attention to transition to the new architecture and where some more thought should be put into.

Business Layer. At the business level, it was possible to see how the use of FCD would require the role of another actor to fulfill the AID service: data providers. For an actual implementation, it would be necessary to define contracts with these data providers, where service level agreements are made explicit, specially to guarantee data quality.

Another element that needs attention is the format in which the alternative traffic data delivered by providers will be made available. In this design, it was assumed that this data would be raw speed data but nothing has been specified about characteristics such as the frequency or resolution of this data. Moreover, since there will be new sources of data in the chain, it will be necessary to devise a mechanism that Rijkswaterstaat can use to verify this data quality. Particularly, since it was assumed that data would be acquired from multiple providers, this mechanism should also allow a comparison between them.

Information Systems Layer. At the information systems level, a transition from legacy (WKS 1.X) to new generation (i-WKS) roadside systems will be necessary for roads where FCD is to be deployed. Asides keeping the capabilities of the current systems, these i-WKS should also be able to fulfill new functions. In the first place, it may be necessary that the i-WKS perform real time speed forwarding. This is not yet certain, as it may be possible that data fusion algorithms offer satisfactory results only using minute-based data. In the second place, the i-WKS should have the ability to operate both with legacy (TOP) and new (i-TOP) central systems. The i-WKS should be able to move from one mode to the other. In case it is using the i-TOP to receive AID measures, it may still need to listen to the TOP to receive operator requests and it should be able to "make the TOP believe" that it is functioning as a normal WKS (it should be remembered that the TOP is a very rigid system where changes are difficult to be implemented).

Moreover, it will be necessary to add some functions in the central systems in the form of new applications or services, something still pending to be defined. First, it should be defined if the Data Fusion application will be controlled by a provider or Rijkswaterstaat and exactly which functions this application should fulfill. It will be also critical to define how the interface with providers and the interface for this Data Fusion application will be deployed. It is still undefined if these interfaces will be connected to the NDW, the DSB or directly to the i-TOP. This also implies a close collaboration with the market, since there should be agreements on how data will be exchanged and which technologies providers will use on their end.

In the Traffic Management Center, it will be also necessary to develop the functions summarized as the i-TOP, which could be in the form of a new application, services in the DSB or any other way. Great attention should be dedicated to the business logic of this application and determine if it is more efficient that these functions are placed in the central systems or if some of them should be done in the roadside systems.

Technology Layer. At the technology level, integration middleware in the form of an Enterprise Service Bus will need to be used. This middleware will allow to integrate many applications and exchange data in an easy way. Moreover, it will allow the deployment of a Service Oriented

Architecture (SOA), where services can be made easily available to third systems or parties. However, an assessment still needs to be done regarding the capabilities of such integration middleware. It should be explored if the DSB would be able to process large amounts of real time data, its level of resiliency and to what extent it can scale up.

Additionally, it will be necessary to upgrade the network infrastructure to a *plug-and-play* fiber network to install new generation roadside systems in those places where FCD would like to be deployed.

Moreover, systems should be ready to process increasing amounts of real-time data. This means that both the infrastructure supporting the systems and the logic embedded in them should be scalable and allow for very low to no levels of latency. How to fulfill these requirements was not covered in the designed architecture, since it requires a higher level of detail. This would be a matter of ensuring that the underlying hardware, software and network resources are adequate, as well as developing efficient application logic and optimal transfer of information.

6.4.4 Architecture Evaluation

When looking at the ADR process, it is possible to differentiate two types of Evaluation. The first one refers to the third sub-phase of the BIE (Building, Intervention and Evaluation), where a formal evaluation is conducted after (at least) an alpha or beta version of the artifact has been implemented in the organization. This type of evaluation could not be conducted in this research because there was no implementation of the ICT Architecture. A second type of evaluation refers to the ongoing Reflection and learning phase that occurs in parallel to the whole design cycle. This evaluation can take a more implicit form, as the researcher *mentally* goes back and forward between the different design steps.

In this section, an evaluation of the solution architecture will be presented that can be considered to be somewhat in between these two types of evaluation. This evaluation did take place after the solution architecture was finished but, as it was already mentioned, no implementation was conducted beforehand. According to (Maranzano et al., 2005, p. 34), "the participants of an architecture review should include a project team, a review team and an architecture board. This increases the likelihood that a system architecture will be complete and consistent".

In this scenario, there is no project associated to the implementation of this architecture yet. For this reason, and given the scope of this research, the architecture review has been conducted with only two experts: Gerard Avontuur and Antwan Reijnen. The advantage of making the review with these two persons is that they have different roles and perspectives on the problem. Gerard Avontuur is a program manager, hence his insights are closer to the business; whereas Antwan Reijnen is a solution architect, contributing with a more technical point of view.

"The objectives of an architecture review are to assess an architecture's ability to deliver a system capable of fulfilling the formulated requirements and to identify potential risks" (Gong, 2012, p. 177). To conduct the review, the final architecture design (as depicted in Figure 16 and Figure 17) was presented to the reviewers in two separate sessions. Initially, they provided their general

impressions and comments on the design. Afterwards, we went through the high-level requirements as formulated in Table 7 and analyzed to what extent the design fulfilled them.

General impression on the design

According to Gerard Avontuur, an architectural representation has the advantage that it allows to show a complete picture of the system landscape. However, it may not be always completely comprehendible to non-architects. He states that the diagrams presented during the scenario analysis workshop were more clear to him, even though they did not represent everything that has been represented in the designed solution architecture.

Nevertheless, he emphasizes the importance of having an architecture to guide implementation and states that the design is very complete and that it has an adequate level of detail. He recognizes that the challenges that Rijkswaterstaat faces for implementing FCD are well represented in the design. He acknowledges that the design represents a good simplification from the complex system landscape at the Traffic Management domain in Rijkswaterstaat, as "it allows to focus on the important components and identify what were the points that still need to be addressed".

The review session with Rijkswaterstaat's architect raised some concerns that still need to be addressed on the design. Antwan Reijnen agrees that the architecture allows to have a good overview of the pending issues; however, he says that some things in the design can be modified to make it more clear. Additionally, he mentions that there are some components in the design that cause some confusion (e.g. what the *combine signs requests* truly represents) and that could be rearranged or further specified in the form of subcomponents. There are also some elements from the business logic (e.g. different levels of combination for generated signs) that are not addressed in the architecture design and that are very relevant to obtain a complete picture.

The feedback provided by him during this session has been summarized in Appendix J and it should be used for a next iteration of the design.

Requirements validation

Once a general understanding from the architecture was conveyed to the reviewers, we validated to what extent the high-level requirements formulated in Table 7 were satisfied.

Main Requirement. Both reviewers agree that the solution architecture fulfills the main requirement, i.e. its purpose: to integrate FCD in Rijkswaterstaat's current Traffic Management and Information systems. This is directly reflected in the specification of new functions such as the i-TOP, which allow to process FCD and the highlight of interfaces to connect to providers.

Service Fulfilment. This requirement indicates that the new architecture should still be able to fulfill the AID and TIP services. AID is the focus of the designed architecture. It can be easily seen that the design addresses the whole AID process and how it is enabled through various services and applications.

As far as for TIP, it can be noticed that it is not fully depicted in the solution architecture. Only some elements such as the *minute-based (v, i, c)* business object and the *distribute traffic information* application function are depicted. The TIP process is much more simple than AID (as it was seen in section 4.3) and it only implies the transmission of information from the roadside (WKS) to the

central system (TOP) and from there to other systems (MONiCA). This solution architecture still allows for this flow to happen. However, two important points should be emphasized:

(i)   Even though FCD aims to replace induction loops and data fusion should allow for the gradual removal of these legacy sensors, there are some factors that still compel the use of induction loops. This is the case of the *Weg Geluidhinder* (as mentioned in section 5.2), which requires the collection of vehicle intensity at certain points. This would mean that loops can be gradually removed from the road but some will still need to be kept for TIP purposes.

(ii)   In the designed architecture, the *distribute traffic information* has also been placed within the i-TOP to indicate that the information collected from alternative sources could also be forwarded to other systems. This is something that still needs to be evaluated. First, FCD does not have the same nature as loop data (e.g. it cannot provide vehicle intensity) and second, Rijkswaterstaat can make data that it generates itself openly available, however the question remains as to how it should proceed with data it purchases from market parties.

Compatibility. This requirement prescribes the use of loop data and FCD in parallel, as well as the integration of legacy and new systems while a full transition occurs. Both reviewers agree that this requirement is satisfied. As it can be seen from the design, the i-WKS gives the possibility to utilize both types of data at the roadside. The design allows the operation of both legacy and new systems for those roads where only loop data will be used and those where only FCD will be used. Finally, the Data Fusion application allows the use of loop data and FCD in the same road and the i-TOP handles the business logic to operate roads where a segment uses one type of data and another segment, other type of data.

Interoperability. Interoperability can be understood as the ability of a system to exchange and make use of information from other systems. This requirement indicates the need to provide an interface to adequately acquire FCD from providers. This is represented in the design as the interface at the provider side; however, it should be remembered that this is an element that needs further specification. This requirement has a strong relationship with the previous requirement, as interoperability could also be extended to the ability of legacy and new applications to exchange information. This is achieved through the use of integration middleware, as specified in the technology layer.

Modularity. This requirement indicates the ability to add, modify and remove components with no major effect in the architecture. The design has been made in such a way that the new systems are loosely coupled from the legacy systems. This means that when the time comes to retire these legacy systems, all processes and services will still be able to be fulfilled. Overall, the design follows a service oriented approach. This can be specially seen in the use of an Enterprise Service Bus, where the i-TOP functions are most likely to be deployed.

Scalability. This requirement prescribes the possibility to integrate new technologies, new data providers and new functionality. Both reviewers also agree that this requirement is satisfied. The development of functionality at the i-TOP makes it possible to perform the AID calculation based on any new type of data. Here, it is importance to emphasize once more the use of the Enterprise Service

Bus. As integration middleware, it would facilitate the plug in / out of data providers. An important remark to make here is the challenges that the use of increasing amounts of data could create. This point has not been addressed in this architecture design, since it is more related to the capabilities of the underlying infrastructure (e.g. hardware, software, network resources) supporting the systems. Gerard Avontuur notices that the architecture supports the choice of both executing more processing in the roadside or centrally, which would be a way to address this challenge.

Reusability. The last requirement refers to the possibility to reuse building blocks (applications, services, data) for other purposes (other applications or services). Both reviewers agree that the designed architecture fulfills this requirement. On the one hand, the architecture exploits the reuse of the functionality of legacy systems to ease implementation. On the other hand, the service oriented nature of the design allows the creation of functionality in the form of services, which are hosted in the ESB and can be exposed to any other systems and parties.

An important point that arose from the architecture review with Antwan Reijnen was the use of Rijkswaterstaat's System/Subsystem Design Description (SSDD). This is a document that describes the overall design from systems that are realized in the SOA architecture of the Traffic Management Domain. In this document, the ten principles of SOA design are highlighted and requirements are prescribed on how to develop systems within the Traffic Management Domain. This would be a next step for the implementation of the solution architecture, as it comes closer to the system design level (e.g. indicate the use of standard components or protocols).

As a conclusion to the evaluation of this design, it is possible to say that it fulfills the main goal of constituting a flexible architecture, as it is prescribed in the research objective. This is directly reflected in the fulfillment of requirements such as Compatibility, Interoperability, Modularity, Scalability and Reusability.

6.5 Formalization of Learning

The last stage of ADR is the formalization of learning, which mainly draws on the *generalized outcomes* principle. In this stage the researcher should move from the specific-and-unique to a generic-and-abstract dimension, which can be challenging given "the highly situated nature of ADR outcomes that include organizational change with the implementation of an IT artifact" (Sein et al., 2011, p. 44).

(Sein et al., 2011, p. 44) propose three levels of abstraction to achieve this: (1) generalization of the problem instance, (2) generalization of the solution instance and (3) derivation of design principles. In section 1.1, the problem was formulated as the challenge that researches and practitioners face when trying to cross the gap between deploying individual (test) projects involving FCD and carrying out a full integration at a system-wide level due to uncertainties at the technology, market and organizational level. These uncertainties were further detailed in section 6.1 in the context of using FCD for AID and TIP in Rijkswaterstaat's Traffic Management and Information system.

This problem can be generalized beyond this specific context as not only addressing the concerns specific to Rijkswaterstaat and to these two services, rather as a class of field problems: use of FCD for Traffic Management applications. This problem can be extended to other organizations (both

within and outside Rijkswaterstaat) which would like to implement FCD in their systems and experience uncertainties similar to those described in section 6.1. Likewise, the developed solution can be considered part of a class of artifacts: flexible ICT Architectures. Even though the architecture presented in section 6.4 is meant to be used for the AID and TIP services, the overall design logic could be replicated in other contexts (i.e. in the form of design principles). Moreover, given the service oriented nature of the architecture, its modular components should be able to be reused for other services within Rijkswaterstaat.

The third level of abstraction proposed by (Sein et al., 2011) is the derivation of design principles. In order to do so, it is necessary to first assess to what extent the ADR principles have been incorporated in the design of the ICT Architecture.

Principle 1: Practice-inspired research
"This principle emphasizes on viewing field problems as knowledge-creation opportunities, which are found at the intersection of the technological and organizational domains" (Sein et al., 2011, p. 40). In this scenario, this field problem refers to the use of FCD for Traffic Management applications (technology) and it can be said that this principle has been followed, since the situation at Rijkswaterstaat (organization) exemplifies this class of problems.

(Verschuren & Doorewaard, 2010) identify five stages when carrying out a practice-oriented research: (1) problem analysis (make clear what the problem is), (2) diagnosis (identify the causes of the problem), (3) design (solution for the problem), (4) intervention (implementation in the organization) and (5) evaluation (verify the changes have solved the problem). In this case, there was an already identified problematic situation at Rijkswaterstaat. They have been experimenting with FCD in test settings and conducting studies to assess the feasibility of using FCD at a traffic engineering level but there were still questions on how to implement this in a live setting. Thus, it was not necessary for the researcher to identify the problem or bring it to the attention of the organization (phase 1).

However, several interviews were necessary to clarify the scope of the problem and identify where the main impediments lied (phase 2). Initially, it was not clear which services should be fulfilled through the new architecture, rather the problem was formulated in terms of the motivation Rijkswaterstaat had to replace induction loops with FCD. Integrating FCD in Rijkswaterstaat's systems has the potential to impact many services but the problem formulation stage helped clarify which services were central to the plan of replacing these legacy sensors. Interviews with the program manager (Gerard Avontuur) particularly helped formulate the problem in clearer terms, since he has a good insight into related ongoing projects and a vision of where Rijkswaterstaat wants to move towards in the Traffic Management field. Additionally, interviews with the solution architect (Antwan Reijnen) were helpful to better identify where the implementation challenges lied at the architectural level. These interviews, together with the analysis of company documents, further give rise to the *practice-inspired research* principle.

Principle 2: Theory-ingrained artifact
"This principle emphasizes that the ensemble artifacts created and evaluated via ADR are informed by theories" (Sein et al., 2011, p. 40). ICT Architecture frameworks, Architecture Description

Languages, flexibility constructs and developments in FCD constitute the main theories used in this research. A review of these theories also contributed to the problem formulation phase, since they allowed to clarify what exactly the deliverables for the research would be.

Following the analysis made for the previous principle, the organization already had in mind that a solution to the identified problem would come in the form of an architecture. By using the theories reviewed in chapter 3, it was possible to determine what this architecture could look like and provide guidance as to which information was necessary to be gathered throughout the research. It is valid to say that the *theory-ingrained artifact* principle was present during the research process, since TOGAF, ArchiMate and SOA practices (reviewed in the theoretical framework) are incorporated in the design, as presented in section 6.4.

Principle 3: Reciprocal shaping
"This principle emphasizes the inseparable influences mutually exerted by the two domains: the IT artifact and the organizational context" (Sein et al., 2011, p. 43). ADR proposes a BIE (Building, Intervention and Evaluation) cycle, from which only the Building phase has been covered in this research. The (internal) factors influencing the integration of FCD for AID and TIP in section 5.2 was already a demonstration of how the organizational context influences the way the IT Artifact is built. However, since the Intervention phase did not occur during this project, it was not possible to see a direct influence of the developed IT Artifact in the organizational context.

The artifact presented in section 6.4 can be thought of as a version that still needs to be implemented in the organization and it might be subject to change when other factors that were outside the scope of this project are taken into account (e.g. available budget or contracts signed with providers). When an actual implementation occurs, it would be possible to further see the *reciprocal sharing* principle put in action.

Principle 4: Mutually influential roles
"This principle points at the importance of mutual learning among the different project participants" (Sein et al., 2011, p. 43). ADR is inspired in Action Research (AR), a research method that seeks to interweave the generation of theories with the intervention of the research with the purpose of solving an identified problem in an organization (Baskerville & Wood-Harper, 1998). ADR draws from this fundamental intervening characteristic of AR and combines it with Design Science with the purpose of designing IT Artifacts.

Throughout this research project, this principle was put into practice since the researcher was immersed in the day to day operations of the organization, allowing for a closer interaction with its employees. It would have been possible to only visit the company for interviews and to request company documents to collect the necessary information. However, the experience of attending meetings to hear about the progress of other projects or joining meetings with suppliers provided additional and useful insights. A clear example of the *mutually influencing roles* principle can be seen through the scenario analysis workshop that was presented in section 6.2. During this workshop, there was mutual exchange of opinions, as participants reacted to the scenarios created by the researcher.

Principle 5: authentic and concurrent evaluation

"This principle emphasizes a key characteristic of ADR: evaluation is not a separate stage of the research process that follows building" (Sein et al., 2011, p. 43). This is also highlighted in (Verschuren & Hartog, 2005). Even though their design cycle has a separate and final stage for evaluation, they explain the importance of evaluation taking place during the whole process of designing.

As it was already mentioned at the beginning of this chapter, the described results represent the outcome that was reached at each stage and they do not explicitly let see the continuous evaluation during the process. However, the design process consisted of multiple iterations, where the problem formulation, requirements and assumptions and the artifact evolved as a result of the input from other stages. This evaluation mainly consisted in the researcher reflecting on how new insights obtained through the interviews should be incorporated in the design. A more explicit example of the *authentic and concurrent evaluation* principle is seen in the scenario analysis workshop and the architecture review sessions.

Principle 6: Guided emergence

"This principle emphasizes that the ensemble artifact will reflect not only the preliminary design (see Principle 2) created by the researchers but also its ongoing shaping by organizational use, perspectives, and participants and by outcomes of authentic, concurrent evaluation (see Principle 5)" (Sein et al., 2011, p. 44). This principle can be seen as a combination of what has been said for the previous principles, thus it will not be further elaborated.

Principle 7: Generalized outcomes

This principle provides guidance to the stage under analysis in this section (Formalization of learning). As it was mentioned at the beginning of this section, a third level of abstraction that helps reaching generalized outcomes is the derivation of design principles. According to (Sein et al., 2011, p. 45), "the design principles capture the knowledge gained about the process of building solutions for a given domain, and encompass knowledge about creating other instances that belong to this class".

As it was explained in section 2.2, five types of theories are identified in the Information Systems discipline, from which the theory for design and action forms part of. (Vaishnavi & Kuechler, 2015, p. 15) state that "a design theory is a set of prescriptive statements and outcome specification from which the implications can be drawn: if a system is constructed according to the (design) theoretical prescription, then that system will behave (or have outputs) as specified in the theory". They also claim that developing such theory may take considerable time and effort from the scientific community. Thus, it is more likely for a design science research project to make incremental contributions to existing (or nascent) design theory in an area.

In this research, the formulation of design principles derived from the continuous evaluation and learning constitutes that contribution. (Bharosa & Janssen, 2015, p. 473) also see principle based design (PBD) as "a specific form of the more general design science research methodology that focuses on extracting principles with regard to the elements of a system without explicitly referring to solutions". These principles are not completely new, rather they relate to some extent to the existing ADR principles. Table 8 presents an overview of the extended principles, indicating to which

ADR principle they contribute to. As it will be further elaborated below, these principles apply to the class of solution that was developed (flexible ICT architectures) but some may apply to other types of artifacts as well.

Table 8. Extended design principles

	Extended principle	**ADR Principle**
A	Incorporate both business and technical level insights at an early stage of the design process.	Principle 1 – Practice-inspired research
B	Utilize projection (or similar) methods when faced with the impossibility to execute the Intervening phase.	Principle 3 – Reciprocal sharing
C	Get "immersed" in the operations of the organization to acquire richer perspectives.	Principle 4 – Mutually influencing roles
D	Keep written records of the design activities for an improved learning process.	Principle 5 – Authentic and continuous evaluation

<u>Principle A</u>. An ICT Architecture incorporates perspectives from many different levels of an organization or system, which can range from a very high-level business needs view to a very detailed technical implementation view. ADR prescribes the *practice-inspired* research as a way to incorporate organizational problems in the search for generalized outcomes. When designing an architecture, one might be tempted to whether take a top-down or a bottom-down approach, where one of the architecture layers is addressed first, continuing with the others. This was also the strategy that was followed in this research project; however, during the first stage of problem formulation, a combined exploration of the business and the "lower" levels proves more useful.

Acquiring business insights is important to define business needs and requirements, which mainly help formulate the problem and shape the research objective. But incorporating general technical insights at an early stage can also help set a better scope for the artifact design: understanding what it could and what it could not do. In this research, interviews with both business (e.g. program managers) and technical people (e.g. application managers) were conducted "from day one", even when the goal of the artifact was not perfectly defined.

<u>Principle B</u>. As it has already been explained, given the scope of this research project, it was not possible to conduct an Intervening phase where the designed artifact could be implemented. The BIE (Building, Intervening, Evaluating) cycle of ADR puts a great emphasis on the learning outcomes that are gained from intervening in the organization and how this helps further shape the designed artifact. Does that mean that is not adequate to employ ADR in a project were only an initial version will be developed?

From the experience gained in this research project, it is valid to say that it is possible. The *reciprocal sharing* ADR principle highlights the influence that the IT artifact and the organizational context execute on each other. In this case, where the influence could only be seen in one direction (how the organizational context shapes the IT artifact), it was necessary to seek for alternative methods. This was done through a scenario analysis, a well-known projection method where alternative future developments are presented. These scenarios allowed to "fantasize" about how different architectures may impact the organization. In this way, it was not necessary to perform an actual

intervention to get some preliminary insights on how the artifact might influence the organizational context.

Principle C. Being ADR a design science framework that draws from Action Research, there is a great focus on the researcher intervening in the context where the research is carried out. The *mutually influencing* roles principle does not limit the researcher on how this intervention should be carried out; however, it does state that researchers should bring in their knowledge of theory and technological advances. Going a step further, I also believe that it is important that the researcher gets involved in some daily operations of the organization, asides bringing external knowledge.

This type of intervention (what I call *immersion*) allowed to get perspectives that would have not been acquired through interviews or analysis of company documents. When participating in project meetings, the researcher can both get and contribute with insights of the work he or she is doing, which may help further shape the artifact. Moreover, even if employees could report outcomes from meetings with (for example) suppliers, it was proven more valuable to get these insights from a closer source. This principle can be applicable to the design of artifacts other than architectures.

Principle D. A design research can be a very extensive process where activities of different nature take place: collecting data, analyzing the context where the artifact will be implemented, leveraging information that can inform the design, among others. Moreover, due to the iterative nature of ADR, it is very likely that the researcher loses track of the exact outcomes of every iteration. ADR prescribes a continuous shaping of the artifact through the principle of *authentic and concurrent evaluation*. In many cases, this evaluation may be implicit, where the researcher "mentally" reflects about the impact of one stage in the remaining stages.

(Keijzer-Broers, 2016) conducted an Action Design Research a service platform for health and wellbeing was developed. Throughout the design process, a logbook of the design activities conducted at every stage was kept. This helped keep a more accurate track of the design process and avoid researcher bias when evaluating the research outcomes. Such logbook was not kept during this research project but it would have been very useful for an optimized formalization of learning. In this last stage, I had problems tracing the efforts conducted throughout the design cycle and extracting the maximum knowledge out of this experience. For that reason, I believe it is important to emphasize in the use of such tools, so that the researcher is aware from the very start of the process of techniques that could be useful for later reflection. This principle can be applicable to the design of artifacts other than architectures.

7 Epilogue

Efficient traffic management is key to maintaining mobility, guaranteeing optimal transport and logistic processes and offering citizens a satisfactory quality of life. Road authorities have an intrinsic motivation to leverage developments in ICT to achieve such efficiency and innovate in the services they offer. With that purpose, Floating Car Data (FCD) has become one of the most attractive technologies in the last couple of decades as an alternative to gather traffic data and gain richer information. However; even when there are numerous projects using FCD in selected cities or areas, none of them has integrated the use of legacy sensors data and FCD. Moreover, even when there is extensive literature on the feasibility of fusing these two sources, these studies have been just experimental and they have not been executed in an actual live setting.

The question thus arises on how road authorities ought to face this challenge; a situation that has been identified at Rijkswaterstaat as well. This is the main driver that motivated this research and which resulted in the formulation of the research objective presented below as a means to address such challenge.

> *Design a flexible ICT architecture that integrates Floating Car Data (FCD) into Rijkswaterstaat's Traffic Management and Information Systems for Automatic Incident Detection (AID) and Traffic Information Provision (TIP) services.*
>
> Research Objective

The main conclusion of this research is that the designed solution architecture provides an attainable solution to the problem encountered at Rijkswaterstaat by incorporating all necessary elements for an integration between legacy data and FCD to happen. Taking an architecture approach is appropriate because it provides a comprehensive view of the changes that need to take place in the organization at different levels (business, information systems and technology) for this to become a reality. According to Antwan Reijnen, solution architect with vast experience in Rijkswaterstaat's traffic management systems, "the architecture has all necessary elements. If we execute projects to realize it, we can certainly say that the architecture will support them and make an implementation possible".

Architecture design is not a simple task, since an appropriate balance between obtaining a complete and detailed picture should be achieved. Designing the presented ICT Architecture was additionally challenging due to the technological, market and organizational uncertainties that surround the implementation of FCD. This was different than a regular architecture design exercise (where efforts are conducted to describe elements and link them together) due to the existence of numerous *black boxes* and the need to use additional tools to "work around them". The idiosyncratic characteristics of Floating Car Data and the ecosystem around it made the design process even more complex, as numerous factors that have a small (or no) impact in the use of traditional sources of data but which do influence FCD implementation had to be explored and considered in the design.

In this final chapter, section 7.1 will present the contributions of this research at both the practical and scientific level, while section 7.2 will provide a recapitulation on the answers to the research

questions, which ultimately led to reach the presented contributions. Section 7.3 will present a reflection on the research process, indicating limitations and improvement points. Finally, section 7.4 will propose recommendations for Rijkswaterstaat, as well as recommendations for future research.

7.1 Research Contributions

7.1.1 Practical Contribution

This project was conducted following a design science research approach, which puts a strong emphasis on the creation of an artifact as the main outcome of a research. The main driver to develop this artifact arose from a problem identified at Rijkswaterstaat, hence it is logical for this research to provide several practical contributions to the organization.

First, up until now, there was no **architectural description** at Rijkswaterstaat for the two services this research focuses on (Automatic Incident Detection and Traffic Information Provisioning). This was a very challenging task since it involved an extensive review of company documents, accompanied with interviews to validate and complete missing gaps. Data was very dispersed and it was difficult to summarize in comprehensive and understandable terms. In many cases, information could not be found in a single set of documents, it was found in very technical and extensive manuals or there was inconsistent information in between documents. Having such clear overview helps the organization better understand the capabilities and limitations of their systems, as well as their interdependencies. This is not only useful for this specific project but also for any activity that requires an understanding of the systems under analysis.

Second, the designed architecture allows to derive an **explicit list of changes** that need to take place at Rijkswaterstaat to make the integration of FCD possible. Integrating FCD for the fulfillment of the AID and TIP services is relevant to Rijkswaterstaat because both services rely on the use of induction loops as a main source of data. FCD would offer the possibility to replace these sensors, potentially saving costs and reducing installation and maintenance efforts. Moreover, future developments on FCD technology have the potential to unlock richer information, making it relevant to have an architecture that can readily incorporate new providers and new functionality. The conducted analysis reveals that such implementation will not be a straightforward process, rather many changes at the business, information systems and technology levels are required (see section 6.4). Moreover, this list also includes **relevant concerns** and raises **awareness on issues** that may arise during implementation, such as the need to control data quality from providers or the challenges that may result due to the need to process increasing amounts of data.

Third, this research makes clear the **design choices** that still need to be made by Rijkswaterstaat before moving forward with the integration of FCD. In the last couple of years, Rijkswaterstaat has been working on projects that test the usability of FCD for various traffic applications and it has been closely working with market parties to assess the feasibility of utilizing this technology in live settings. However, definitive decisions such as the data procurement strategy (i.e. the type of data that should be acquired) and the traffic engineering strategy (i.e. how new methods will be deployed in different types of road) must be taken before starting implementation projects. Even when these

areas are out of the scope of this project, the research has allowed to gain some expertise in them and provide recommendations on what desirable choices might be (see Recommendations for Rijkswaterstaat in section 7.4).

7.1.2 Scientific Contribution

A core outcome that derives from this research is the contribution that it makes to existing literature on the **use of FCD in a real-life setting**. As it was described in the literature review in section 3.4, FCD has already been used in many cities around the world. However, all these projects have been limited to the sole use of FCD and no other data sources. An internet search revealed that it is possible that Bavarian authorities are using FCD from Inrix along with induction loops data. Since no associated literature could be found, it is not clear whether this is just a test or if it is indeed happening in Germany already. Moreover, there is also extensive literature in the science of fusing loop data and FCD but these studies have just been conducted in a laboratory setting. This research project contributes to filling that gap by providing guidance on how to leverage those experimental projects and on how to move forward with the implementation of FCD in an actual setting, where it must coexist with legacy technologies while a full transition occurs.

Furthermore, even when the designed ICT Architecture is targeted to a specific organization, **the derived high-level requirements and the architecture functional blocks** can serve as a framework for other organizations looking to integrate FCD into their traffic management systems. These requirements have been formulated in such a way that other organizations can easily reflect them in their own settings. The architecture blocks, even when focused on the AID and TIP services, offer a logical set of functions that can be used as a first guideline for organizations to adapt them to their specific processes, applications and technologies. Additional outcomes of the design process can be leveraged by these organizations as well. First, the research provides **a set of political, technological, legal and organizational factors** that should be considered when implementing FCD. These factors are derived from an extensive analysis of the characteristics of FCD and the ecosystem where it is placed in (see section 5.2). Second, the research also illustrates **a sample of use cases** defining how to integrate FCD and legacy technologies. These use cases not only indicate how a rollout of the technology could be made in roads with different requirements but they also provide hints on how to move towards a scenario where legacy systems can be retired (see section 6.4).

Another core outcome is the contribution the research provides to design science. Being a relatively new method (2011), this research is one of the few to **apply ADR to the design of ICT Architecture**. On one side, this contributes to assessing how ADR can be put into practice and to determining what its limitations can be. Through this research, it is possible to see that even though ADR provides helpful design guidelines to researchers, it remains at a very high-level and the incorporation from other methods becomes necessary. ADR proposes a set of seven principles that guide the design process. As part of the last stage of ADR (Formalization of learning), an evaluation of how these principles are utilized in this research project is presented (see section 6.5). This is an additional contribution to design science that helps assessing to what extent the ADR principles are applicable and useful in a research project.

On the other side, the lessons learned throughout the design process can contribute to the **ICT Architecture Design** field. According to (Sein et al., 2011), DSR allows to contribute to design theories by generalizing the problem and solution to broader classes of problems and solutions and by deriving design principles from the design research outcomes. In this sense, this research contributes to architectural design theories by laying down the four principles presented in section 6.5: (1) early incorporation of both business and technical perspectives in the design process, (2) utilization of projection methods (e.g. scenario analysis) when implementation of the artifact is not possible, (3) *immersion* in the organization operations to acquire richer perspectives and (4) register of design activities for an improved learning process. These principles are extensions to the ADR principles which can be applied in the ICT Architecture Design field.

7.2 Recap of the Research Questions

In order to reach the formulated research objective in a more practical way, a set of five research questions was formulated in section 2.1. These questions were placed within the research framework presented in section 2.3 (see Figure 3), which was elaborated based on (Sein et al., 2011) Action Design Research and (Verschuren & Hartog, 2005) Design Cycle and served as a guideline for the design process. The answers to these five questions are presented below.

RQ1 – Flexible ICT Architecture	What does the concept of a *flexible ICT architecture* in the context of Rijkswaterstaat's Traffic Management and Information systems mean?

An ICT Architecture is defined as a formal description of a system structure, its components and interrelationships between them, along with a set of design principles that govern its evolution and implementation guidelines that provide direction on how to implement it (see section 3.1). It has been found that choosing an architecture framework with widely known concepts and standard components is useful to make this definition more concrete. (The Open Group, 2011) Architecture Framework (TOGAF) has been selected to describe three different layers that should compose the architecture: Business, Information Systems and Technology. Moreover, a modeling and visualizing approach (ArchiMate, an Architecture Description Language) has been used to effectively communicate the architecture to stakeholders. Flexibility is defined as the ability to readily support a wide variety of hardware, software, communications technology, data, applications, skills and competencies (Byrd & Turner, 2000, p. 172). Moreover, the use of Service Oriented Architecture (SOA) constructs such as loose coupling, autonomy and reusability helps reinforce this definition.

A flexible ICT architecture in the context of Rijkswaterstaat's Traffic Management and Information systems refers to the ability to address the technological, market and organizational uncertainties that surround the implementation of FCD. Some examples include the difficulty to establish fixed penetration rates for FDC, the question whether providers can currently meet service levels or the intrinsic uncertainties of ongoing internal projects at Rijkswaterstaat.

RQ2 – Descriptive or *as-is* **Architecture**	What does the current architecture for the AID and TIP traffic systems at Rijkswaterstaat look like?

An extensive analysis of company documents and interviews with experts has allowed to obtain a detailed description of the various components of the current architecture, describing: (i) the business services, processes and actors involved at the Business Layer, (ii) the necessary data flows and existing applications at the Information Systems Layer, (iii) the supporting infrastructure (e.g. hardware, software or communication networks) in the Technology Layer (see section 4.2 and section 4.3).

The main takeaway from answering this question is that it allows, not only the researcher but also the organization, to obtain a clearer picture about the capabilities of Rijkswaterstaat's systems (i.e. what they can and cannot do) and their interdependencies (i.e. how changing one system may affect another one). More specifically, this question has helped determining that the as-is architecture cannot be characterized as flexible. Some reasons include that the current roadside systems cannot process new types of data (only induction loops data) and applications in the central systems are very rigid, making it difficult to implement new functionality needed to process FCD (see section 4.4). This means that integrating FCD would not be just a matter of creating an interface with data providers, rather many functional and structural changes would be required for it to happen (see RQ5).

RQ3 – Technology Analysis	What are the factors that influence the implementation of FCD for AID and TIP in the context of Rijkswaterstaat's current traffic systems?

Answering this question is particularly relevant for Rijkswaterstaat but also to other organizations planning to integrate FCD on their systems. Even though many of these factors may have already been considered by Rijkswaterstaat at some point, a complete overview of "the whole picture" was not available thus far. This analysis brings attention back to some concerns that have been discussed before and raises awareness about issues that may have been overlooked in the past. This question is partly answered by evaluating the characteristics of FCD with a SWOT analysis and further elaborated by means of an influence map. In this map, two main categories of influencing factors are differentiated: external and internal (see section 5.2 for a full overview).

Among the identified external factors, three subcategories are specified.

  i. Political factors. This includes encouraging policies, such as calls at the European level that encourage private and public parties to innovate in the transport area.
 ii. Technological factors. Examples include the evolution of the car industry towards autonomous cars, the appearance of alternative sensing technologies to collect traffic information, data trends (big data, data fusion and open data) and the development of next generation mobile networks (i.e. 5G).
iii. Legal factors. This mainly relates to existing regulations in The Netherlands which require the collection of traffic intensity and speed for noise regulation purposes and to the need of using privacy standards to anonymize data and guarantee user acceptance for the use of FCD.

Furthermore, two subcategories are identified under internal factors.

i.   Organizational factors. This refers to the existing organizational vision of moving towards new technologies and higher management initiatives such as the "Better informed on the road" program. This also relates to the need for a strategy that allows the migration from new to old technologies, while considering the need for savings imposed by other organization-wide programs.

ii. Internal projects. This factor refers to the development of projects that may have an influence on the integration of FCD for AID and TIP. Examples are other projects working with FCD from which lessons can be learned or projects commissioned to change existing systems that affect the way FCD would be implemented.

RQ4 – Requirements and Principles	What are the design principles and high-level requirements that the ICT architecture integrating FCD for AID and TIP should meet?

The design principles have been selected from a set of existing principles from Rijkswaterstaat's Enterprise Architecture, which are deemed to be relevant for the solution ICT Architecture and which are used as a normative guideline to inform the design. For example, one of the principles indicates that any needed functionality should be implemented reusing existing data, applications or infrastructure. If not available, acquiring standard commercial products or services can be considered. The last option should be to acquire custom made products or services from suppliers. This principle does not set a hard requirement on how to implement new functionality but it does provide an idea on which strategy to follow.

As far as for the requirements, they are expressed in a very high-level to reflect general areas of concern of the context where the ICT Architecture will be implemented. This means that they can be used not only by Rijkswaterstaat but also by other organizations, which can extend them to their own settings. These requirements are derived from both the analysis of the current architecture and the factors influencing the use of FCD. Some requirements that can be highlighted are the need to (at least) fulfill the same AID and TIP service levels (service fulfillment), the need to allow the use of induction loops and FCD in parallel (compatibility) or the need to allow the seamless addition, modification or removal of components (modularity) at the technology, supplier or functional level (see section 6.3).

Additionally, when answering this question, assumptions are also made explicit. These assumptions relate to some of the uncertainties surrounding the implementation of FCD, as well as to the scope of this project. For example, one of the main assumptions is that the quality of acquired FCD will be guaranteed by providers. Information Quality is a very comprehensive topic that has not been touched upon (e.g. what constructs should be used to measure it), thus making this type of assumptions becomes necessary.

RQ5 – Prescriptive or to-be Architecture	What does a flexible ICT architecture that integrates FCD into Rijkswaterstaat's AID and TIP traffic systems look like?

The final research question directly allows to address the research objective, since it refers to the design of the ICT Architecture. The whole research process has allowed to gain useful insights for a future FCD implementation at Rijkswaterstaat: analyzing the current architecture to determine its

strengths and pitfalls, making influencing factors explicit to ensure they are well understood by all involved stakeholders and specifying principles and requirements to guide the design and set clear expectations. This all contributes to the designed solution architecture, which represents a picture of an end desired state that should be reached to achieve FCD integration in Rijkswaterstaat's traffic systems. A comparison between the *as-is* and *to-be* architectures helps determine what changes are required and which components need further specification for a transition to the new architecture to occur. The main outcomes from this analysis can be summarized as follows (see section 6.4 for a detailed overview).

Layer	Required Change
Business	Establish contracts with providers, where Service Level Agreements are made explicit.
	Define parameters for the format FCD will be delivered by providers.
	Devise a mechanism to verify and control providers' data quality.
Information Systems	Transition from legacy to new generation i-WKS. In the i-WKS new functions such as real time speed forwarding and legacy / new systems (TOP / i-TOP) integration should be developed.
	Determine frequency of data necessary to perform data fusion (i.e. are real time speeds needed or is minute based information sufficient?)
	Define actor accountable for the Data Fusion module and determine deployment strategy for this application.
	Develop functions in the central systems needed to integrate FCD, including a congestion detection module, a speed measures calculation module based on new data sources and a business logic module that can harmonize the measures from legacy and new systems.
	Specify standardized interfaces to collect data from providers in close collaboration with market parties.
Technology	Utilize integration middleware in the form of an Enterprise Service Bus to integrate applications, facilitate the exchange of data and make services available to third systems or parties.
	Evaluate to what extent the Enterprise Service Bus technology can process large amounts of real time amounts of data, how resilient it is and to what extent it can scale up.
	Upgrade the network infrastructure to fiber for new generation roadside systems to operate.
	Ensure infrastructure with scalable and low latency hardware, software and network resources, as well as efficient application logic and optimal transfer of information.

Finally, an architecture review conducted by two experts has served as an evaluation tool for the designed ICT Architecture. The input from a program manager and a solution architect proves to be very useful, since insights are obtained at both the business and technical level. The program manager has stated that "the architecture represents a complete picture and it is a good simplification

of the Traffic Management Domain complexity at Rijkswaterstaat". Both reviewers agree that the architecture allows to have a very good overview of the pending concerns or elements that still needed to be addressed for an FCD integration to occur. The solution architect has noticed some points that still need attention in the design and for which a subsequent iteration would be required (see Appendix J). As an addition to the evaluation, the review of the high-level requirements indicates that the main requirement of integrating FCD in the current Traffic Management landscape at Rijkswaterstaat is indeed fulfilled by the designed architecture. More specifically, the architecture clearly indicates how AID can be fulfilled, since this service was the focus during the design. A drawback of the architecture is that the fulfillment of the TIP service is not addressed in detail; however, the architecture does not present any elements that may hinder its realization.

The solution architecture achieves flexibility through the fulfilment of requirements related to compatibility, interoperability, modularity, scalability and reusability. This refers to several aspects such as: (1) the possibility to use various sources of data, including induction loops and different data providers, (2) the possibility for legacy and new systems to operate in parallel and exchange information, (3) the availability of an interface with service providers, (4) the use of integration middleware for application integration and exchange of data and (5) the use of a service oriented architecture approach where new functionality can be deployed in the form of easily modifiable and reusable services.

7.3 Reflection and Limitations

The way this research project was conducted can be divided into three major stages.

The first stage refers to the selection of an appropriate approach to conduct the research, which in this case was **Action Design Research** (ADR), a relatively new design science research method (2011). As it was explained in section 2.2, ADR was selected given its great emphasis on the development of IT artifacts in response to organizational problems. ADR provided a structured mean to guide the design process, while allowing for a sufficient degree of freedom to materialize the research and select convenient methods for data collection. However, being a relatively recent methodology, utilizing ADR was like exploring a new field, where not much practical experience has been gathered. My initial expectation was that I would be able to use ADR as the sole method to guide the design; however, I soon encountered difficulties to apply it in a concrete way.

Even though when ADR provides a set of design principles which are useful to leverage the design process and generate knowledge, they remain at a very high level. I had some struggles defining what the exact steps in the design process should be; thus it was necessary to incorporate (Verschuren & Hartog, 2005) Design Cycle and use elements from TOGAF for better guidance throughout the design. Additionally, a limitation of having chosen this method is that ADR emphasizes on the interweaving of Building, Intervention and Evaluation of the artifact but due to the scope of this project, no intervention was possible. ADR suggests that the IT Artifact and the organizational context should influence each other. In this case, the solution architecture was informed by the organizational environment but it was not possible to truly see the influence of the architecture in the organization. This limits the possibility to see this research as an evaluation of ADR to its full extent, as well as the effectiveness of using ADR as a design framework.

The second stage refers to data collection and it was focused on the processing of significant amounts of information. To be more precise, this refers to the execution of desk research, semi-structured interviews, architecture working sessions and scenario analysis workshops with a twofold purpose: (i) understanding all sides to the formulated problem and describing the current architecture and (ii) obtaining input for the design of the prescriptive architecture.

One of the main trade-offs that had to be made when designing the ICT Architecture was the level of detail that should be conveyed. This is a decision that was not made beforehand, rather it was continuously evaluated throughout the design iterations. When reflecting on the **desk research**, it might be that the some of the analyzed documents were not needed for the design but this was something difficult to judge in advance. It is valid to say that all these documents somehow contributed to better understand the problem by better understanding the organization and its underlying processes and systems. However, if this process were to be started again, it would be recommendable to assess the required level of detail beforehand to make a better estimation of the required desk research efforts. For example, (The Open Group, 2011) provides some guidelines and dimensions for scoping the architecture which could have been used before starting the design process.

As far as for the **semi-structured interviews**, even when the information obtained from the selected interviewees was sufficient to develop the architecture design, an additional possibility could have been to interview some more external people. This might include traffic experts from academia, data and service providers or even the Bavarian road authorities (as the reader may remember, it is possible that they have already integrated legacy sensor data and FCD), who could have provided alternative insights. An architecture concept that was not used in this research was that of an architecture view. These are models that indicate to stakeholders the sections of the architecture they are mostly interested in. Given the scope of this project, a single general architectural view was designed. An exercise that could have been beneficial for the design process would be the outline of other architecture views to be shared with the experts in follow-up interviews. This could help them focus in the elements they know the best and generate reactions and comments useful for further iterations.

It should be mentioned that the **scenario analysis workshops** had not been planned as part of the initial research strategy. After a few initial iterations of the design, a considerable deadlock was encountered. I faced the challenge that there were many decisions that Rijkswaterstaat had not taken and which mostly related to the technology, market and organizational uncertainties surrounding FCD. The workshops emerged as a tool to move the design cycle forward by attempting to counterbalance these uncertainties and to avoid the use of too many *black boxes*.

There were many challenges associated to the workshops. Initially, I planned to conduct a two-hour session; however, during the session, we noticed that understanding the problem and the formulated solutions was not a straightforward task for all attendees and a second session was needed to complete it. This problem probably originates from the fact that the participants had different levels of business and technical knowledge, making it difficult provide a single picture that could be quickly understood by everyone. Another challenge emerged when trying to get everyone together on the same date for the workshop. The idea was to conduct these sessions with experts from several

business units but this proved to be a difficult task given the difference on their agendas. For example, traffic management experts or functional managers could not attend the workshop. Even though all attendees provided useful insights, not having those key profiles had an impact on the outcomes that we reached, since they would have contributed different perspectives. A lesson learned is that the researcher should anticipate this type of impediments and be prepared to timely counteract them. This way, a more adequate selection of the participants could have been done for an improved session.

The <u>third stage</u> was dedicated to the design of the solution architecture itself. A challenge that comes back again in this stage is the determination of an appropriate **level of detail** for the design. A balance must be found between not going too deep into details that the researcher loses focus and not going to a too high level that the design would not be relevant for stakeholders. When designing an ICT Architecture, there is always a design trade-off between reaching a good level of abstraction so that there is a complete picture of the systems under analysis and a sufficient level of detail so that this picture can provide useful insights. As it was mentioned just above, it is difficult to determine beforehand the desired level of abstraction and this is something that is continuously defined throughout the design iterations. It is very likely that too much details were explored during the data collection stage; however, as per the opinion from the architecture reviewers, the designed solution architecture filters out the elements that are not essential and achieves a good balance.

As it was mentioned in the literature review, there is no universally accepted **definition of architecture**. This means that choosing one definition over another already puts some conditions on the elements the architecture will and will not include. In section 3.1, an ICT architecture was defined as a description of a system structure and its components, along with a set of design principles and implementation guidelines. Moreover, the layered definition provided by TOGAF was used to describe the as-is and to-be architectures. This can be considered a limitation to the outcomes of the research, since selecting a different definition would have probably resulted in different findings.

In section 3.1 and section 3.2, we saw that **TOGAF and ArchiMate** were selected for being well-known and widely accepted standards / tools, in addition to the fact that they are used already by Rijkswaterstaat. TOGAF was found to be a relatively easy framework to apply, as it provides a very clear description of what the business, information systems and technology layers should comprise. I also found TOGAF to be very compatible with design science research, since TOGAF ADM (Architecture Development Method) presents something analogue to a design cycle with a great emphasis on an iterability. Nevertheless, TOGAF is a very extensive framework and due to the time limitations of this research, it was not possible to analyze it to its full extension. For example, TOGAF provides guidelines to scope the architecture, to manage stakeholders or to prepare a migration plan, none of which was used in this research.

As far as for ArchiMate, an additional advantage of using it is that it is highly aligned with TOGAF (since it was also developed by The Open Group), making it easier to work with both standards / tools in parallel. However, ArchiMate is not a very intuitive language and it was challenging for me to use, having little experience with it. ArchiMate attempts to be a language that can be used together with any architecture framework, hence it provides a wide variety of architectural building blocks and connections. I expected ArchiMate to provide a graphical representation that I could use to

approach all stakeholders. However, I found this was not the case and for that reason, it was necessary to utilize simplified Visio diagrams during the scenario analysis workshops. I presume that if I were to utilize a different language, I would encounter similar difficulties and that the use of a diverse set of tools is necessary when engaging stakeholders from different areas and levels of the organization.

Finally, an element from the design process that deserves reflection is the **evaluation of the architecture**. As it was seen in section 6.4, an architecture review was conducted with two experts at Rijkswaterstaat, where they provided some general impressions on the design and assessed whether the architecture fulfilled the formulated requirements. Another possibility would have been to conduct a quantitative evaluation or a combination of both approaches. If the architecture review was to be done again, more specific evaluation criteria could be set with numeric indicators for each criterion. For example, an estimation from 1 to 10 on how complete the design is (general assessment) or on to what extent it is modular (individual requirements), accompanied with qualitative comments or feedback. However, for this type of evaluation to make more sense, it would be necessary to engage more than two reviewers. At this point is where a review from an architecture board could have been useful. As a matter of fact, there is an architecture board in Rijkswaterstaat which oversees and makes sure all architecture efforts are coherent. Even when they are not experts in every topic, they can provide valuable insights regarding the design, the architecture quality and the building blocks used. Due to time limitations, it was not possible to organize such a review.

7.4 Recommendations

7.4.1 Recommendations for Rijkswaterstaat

The first recommendation proposed to Rijkswaterstaat refers to the decisions the scenario analysis workshops focused on: what type of data to acquire from providers and how to integrate different sources of data. These decisions are highly dependent on traffic engineering considerations and the establishment of a procurement strategy. These are not the areas of expertise of the researcher and the scope of the research did not include to conduct a study in those areas either. Nevertheless, the insights gained through the workshops and the interviews conducted with experts in different fields, allowed me to reach some conclusions that I would like to bring to Rijkswaterstaat's attention (and which were to some extent included in the architecture in the form of assumptions).

1. Acquire raw speed data from different providers. Technology trends indicate a shift towards external parties or systems increasingly conducting traffic management functions. However, this shift may still take several years to happen. In the meanwhile, Rijkswaterstaat should remain fully accountable for mission critical services, such as AID. Acquiring raw speed data allows road authorities to keep more control over the execution of AID, since traffic logic is conducted *in-house*. Moreover, it is easier to verify the quality of this type of data and compare it among different suppliers (than data that has been further processed, i.e. congestion flags). Finally, raw speed data has the potential to be used for services other than AID.

2. Use Data Fusion as a preferred technique to combine various sources of data. To support the use of FCD, it is necessary to replace legacy WKS by new i-WKS roadside systems. This means that it will be necessary to still use induction loops data in certain roads while a full transition

occurs. For those roads where an incremental installation of i-WKS will occur, it would be recommended to utilize data fusion techniques to also incrementally start removing loops from the road. Off course, an assessment of which providers could offer this data fusion service (or if it can be done *in-house*) is still needed.

The second recommendation relates the changes that need to take place for a full integration of FCD in the current landscape to occur, as described in section 6.4. With those changes in mind, it is possible to come up with a series of steps that should be taken from an architectural point of view, as well as a suggestion for implementation projects.

Regarding the solution architecture:

1. Implement the improvements indicated in Appendix J in a subsequent iteration of the design.
2. Evaluate the designed artifact in an architecture review that engages more participants. These can be the experts who participated in the scenario analysis workshop and Rijkswaterstaat's CIV architecture board.
3. Based on the outcomes of that evaluation, adjust the design and elaborate in the components where possible.
4. Specify implementation guidelines for the architecture by developing various architecture plateaus.
5. Specify a Project Start Architecture (PSA), which would be a "evolution" towards the solution architecture through the formulated architecture plateaus.

Regarding implementation projects:

1. Assign a responsible to take care of changes in a global level, for example a program manager. The feasibility of initiating the required implementation projects would be subject to the development of a corresponding business case, where it should be demonstrated to higher management what the benefits and costs of carrying them out are. Within this program, an overview of these projects should be kept and it should make sure they are aligned to other projects within the organization.
2. Establish a project to conduct a more in-depth analysis of the legacy systems, especially at the central system. This project would allow to detail more technical information about these systems by reviewing existing manuals, performing reverse engineering or engaging experts. With that understanding, it would be easier to determine if and how they could be modified or be made open to new systems and data sources.
3. Set up a project to address the changes needed in the central systems. This would require determining where the functions needed to integrate FCD would be placed (i.e. in existing or new applications) and how the interfaces with providers would be developed, specifying all the associated functional and non-functional requirements and working in collaboration with a third party to execute implementation. This would also imply selecting the supporting hardware and software and determining a procurement strategy for it.
4. There is already an ongoing project for developing and testing a new generation of i-WKS, as well as a project to upgrade the existing network infrastructure. These projects should be closely aligned with the project described above.

A final and general recommendation for Rijkswaterstaat would be to do an extensive analysis of the impact of FCD in all the services of the Traffic Management Domain business services portfolio. This analysis does not need to go into a deep system detail, rather it could be a high-level evaluation of which services would benefit or would be impacted with the integration of FCD.

7.4.2 Recommendations for Future Research

In this research, a design science research approach was adopted, where ADR was used as a base methodology to construct the employed research framework. As it was indicated in section 2.3, it was necessary to incorporate insights from another method to provide some more clarity on the steps that should be followed throughout the design process. ADR provides high-level principles that are general enough to apply to all fields. However, I would suggest ADR researchers to elaborate on the Building phase by adding explicit sub-phases and providing more direction to designers, while keeping its applicability to all classes of artifacts. This would make ADR more appealing to researchers looking to have clear design guidelines and a structured means to contribute to theory. Moreover, it would constitute a unified framework and it would avoid the need to combine ADR with other design science research methods.

In section 2.2, it was mentioned that design science research has not been widely used for the development of architectural artifacts. In this research project, a specific DSR framework was used to structure the design process. Moreover, a contribution to the ICT Architecture Design field was done by indicating some design principles, extended from ADR principles. Further research could be done in this area, where a design science research methodology applied to architecture solutions could be developed. It would be important to closely relate this methodology with existing architecture frameworks (e.g. TOGAF) but in such a way that it gives designers the freedom to choose between any framework.

A final recommendation for future research would be to dedicate efforts to the development of a reference architecture for the use of FCD in traffic management. The designed ICT Architecture for Rijkswaterstaat can serve as the departure point for such reference architecture, which would require a higher level of abstraction to be fully leveraged by any organization. This architecture can be analogue to the existing reference architecture for Cooperative ITS[6] (i.e. DITCM Architecture).

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[6] Cooperative ITS (Cooperative Intelligent Transport Systems) refers to systems that allow vehicles, infrastructure and other road users to communicate with each other.

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Appendix

Appendix A – List of Interviewees

Name	Organization	Role	Date
Antwan Reijnen	RWS CIV	Solution Architect	December 5, 2016 December 14, 2016 January 25, 2017 January 31, 2017 February 8, 2017 March 7, 2017 March 17, 2017 April 4, 2017 April 7, 2017 April 21, 2017
Gerard Avontuur	RWS CIV	Program Manager "Wegkant en Omgeving"	January 26, 2017 February 10, 2017 March 8, 2017 March 16, 2017 March 23, 2017 March 31, 2017 April 21, 2017
Marco Schreuder	RWS WVL	Traffic Engineering Expert	January 18, 2017 February 6, 2017
Johann Visser	RWS VWM	Functional Manager MTM-2	February 3, 2017
Kai Feldkamp	RWS CIV	Smart Mobility Director	February 7, 2017
Serge Hoogendoorn	Civil Engineering, TU Delft	Traffic Engineering Expert	February 10, 2017
Edoardo Felici	NDW	Strategy Manager	February 13, 2017
Karen van Vianen	CIV		February 13, 2017
Petra Prins	CIV	Information Analyst	February 13, 2017
Ronald Warris	CIV		February 14, 2017
André Ingelse	CIV	PCP Manager, CHARM	March 6, 2017
Harry Ooststroom	CIV	Project Manager, PPA	March 6, 2017
Eugene Heijnen	CIV	Application Manager, MONiCA	March 7, 2017
Pim Meij	CIV	Solution Architect, CHARM	March 9, 2017
Fokert Bloembergen	CIV	Project Manager, Talking Traffic	April 5, 2017

Appendix B – ArchiMate notation

Meaning

Value

Product

Object

Representation

Artifact

Service

Process

Function

Interaction

Event

Actor

Role

Component

Collaboration

Interface

provided

required

Node

Device

Network

System software

Communication path

Location

Composition

Aggregation

Assignment

Specialization

Realization

Used by

Access

Association

Triggering

Flow

Junction

Group

Appendix C – Business Services Portfolio

1: Strategisch verkeersmanagement
   1.1 Beleidsinformatie produceren
   1.2 SLA-management
   1.3 Netwerkplanning
	RWS is een uitvoeringsorganisatie en formuleert zelf geen beleid op het gebied van mobiliteit. RWS is wel verantwoordelijk voor het aanleveren van de benodigde gegevens die tot beleid kunnen leiden en de terugvertaling van vastgesteld beleid naar een operationeel niveau. De diensten die dit alles mogelijk maken zijn gegroepeerd binnen het strategisch verkeersmanagement. In het licht van de taakstelling van RWS zijn de diensten in dit gebied gericht op de bijdrage die verkeersmanagement kan leveren aan de landelijke en regionale mobiliteitsdoelstellingen.

2: Tactisch verkeersmanagement
   2.1 Leveren verkeerskundig instrumentarium
   2.2 Prestatiemetingen (PIN's) verwerken
   2.3 OVM voorbereiden
   2.4 Comfortdiensten
	De diensten in het gebied "Tactisch verkeersmanagement" dienen het operationeel verkeersmanagement goed te laten verlopen. De diensten in dit gebied richten zich voornamelijk op de voorbereiding van het operationele proces en de evaluatie van dit proces. Hier vindt dan de doorvertaling plaats van de beoogde verkeersmanagementbijdrage naar de benodigde inzet van verkeersmanagementdiensten (m.a.w. hoe je de beoogde bijdrage realiseert met beschikbare verkeersmanagementdiensten). Dit gebeurt op basis van SLA's en PIN's, zodat desgewenst kan worden bijgestuurd.

3: Operationeel verkeersmanagement
   3.1 Uitstroom optimaliseren
   3.2 Instroom optimaliseren
   3.3 Doorstroming bevorderen
   3.4 Incident Management
   3.5 Vertrektijd beïnvloeden
   3.6 Modaliteit beinvloeden
   3.7 Beprijzen
   3.8 Omleiden
	Als het netwerk beschikbaar is willen we dat netwerk ook optimaal gebruiken zodat de doorstroming op het netwerk maximaal is. We komen dan in het gebied "Operationeel verkeersmanagement" dat boven de beschikbaarheiddiensten is gepositioneerd. Om het netwerk zo goed mogelijk te benutten, in dynamische zin, kun je iets doen aan dat netwerk zelf (capaciteitsmanagement) of aan het verkeer dat daar overheen rijdt (vraagbeïnvloeding).

4: Beschikbaarheidsdiensten
   4.1 Veiligheidsdiensten
   4.2 Brugbediening
   4.3 Tunnelbewaking
   4.4 Schadevoorkomende diensten
   4.5 Milieudiensten
	De aanwezigheid van een fysieke infrastructuur is niet voldoende om ook een netwerk te hebben waar het verkeer (altijd) gebruik van kan maken. Om dit te bereiken worden er beschikbaarheid diensten geleverd; deze diensten zijn randvoorwaardelijk voor het gebruik van het netwerk

5: Infrastructuurdiensten
 	
   5.1 Aanleg
   5.2 Beheer en Onderhoud
	Om verkeer over een netwerk te laten rijden, moet er allereerst een netwerk bestaan. De diensten die hiervoor zorgen zijn gegroepeerd onder de naam "Infrastructuurdiensten". Deze groep bevat onder meer diensten voor de aanleg van het wegennet, en voor het beheer en onderhoud ervan (inclusief het DVM-areaal).

6: IV voor VM en VI
 	
   6.1 Verkeersinformati e produceren
   6.2 VM-informatie produceren
   6.3 Verkeersgegevens leveren
	Deze diensten betreffen de verkeersinformatie-verstrekking aan de buitenwereld, en van informatie aan het interne operationele en tactische VM-proces.

7: Nationale basisinformatie
 	
   7.1 Leveren weggegevens
   7.2 Leveren veiligheidsinformatie
   7.3 Leveren verkeersprestaties
	Deze diensten richten zich op de IV die voornamelijk benodigd is voor het tactisch en strategisch verkeersmanagement. Dit is opgedeeld in informatie over het netwerk zélf, en metingen over het verkeer en haar effecten daaróp.

Appendix E – Factors influencing the use of FCD

External Factors

<u>Political</u>
At the policy level, there might be many factors that encourage or influence the use of FCD or in general technologies to improve transportation systems.

Encouraging Policies. The European Commission opened a $1.9 billion CEF Transport call focused on innovative transport to improve safety and environmental performance, increase efficiency and build cross-border connections. 349 proposals were submitted by February 7th 2017 that included many ITS project, from which a final selection will be made in July 2017 after evaluating them (European Commission, 2017). This kind of policies encourage the improvement of Traffic Management applications and have a positive impact for road authorities like Rijkswaterstaat aiming at moving towards the use of FCD, since more funding is made available to develop innovative projects.

<u>Technological</u>
The development of technologies that can serve the same purposes as FCD or that support it has a great influence on the way FCD should be deployed at a system level for AID and TIP.

Car Industry. According to the predictions of BI Intelligence, around 10 million vehicles with self-driving features (including all levels, from semi-autonomous to full-automated cars) will be on the road by 2020 (Business Insider, 2016). This short-term prediction gives an indication of the very rapid pace the car industry is moving towards a future with fully automated cars, where no human intervention is needed and which is made possible with V2X[7] communication. This major trend opens new possibilities for Traffic Management. At some point in the future, the AID function will start deprecating, since vehicles will be equipped with increasing communication capabilities. The type of information required to fulfill TIP services will also eventually change given the fact that many of the services that make use of such information will also be transformed in this future scenario. Nevertheless, this is a gradual change that will still take several years. In the meantime, Traffic Management systems should be able to prepare and adapt for this evolution.

Alternative Technologies. DAS (Distributed Acoustic Sensing) is an example of a technology that is able to fulfill the same functionality of FCD in a very different way. This technology basically uses already laid fiber along the roadside to detect acoustic events in the vicinity, hence measuring vehicle movement and traffic patterns (such as congestion) in real time (Pinchen, Wu, & Swift-Hoadley, 2014). As it has occurred in many industries, there is always a possibility that a disruptive technology displaces an existing one and changes or completely creates new markets (take the example of how smartphones disrupted the market of cameras, MP3 players and GPS devices). Since FCD is very tied to the development of smart cars and IoT, it seems very likely that this technology will become dominant when it comes to Traffic Management applications. However, it is important to keep other technologies in the radar and make strategic decisions, especially because of the considerable

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[7] V2X refers to V2I (Vehicle to Infrastructure) and V2V (Vehicle to Vehicle Communication)

investments that need to be done for FCD (contracts with service providers, infrastructure for WiFi-P).

Data Trends. Under this category, attention is paid to the fact that with the evolution of connected cars and the ability to obtain data from larger samples of mobile phones, the amount of available information will start increasing dramatically. Big Data, Data Fusion and Open Data are key words here. Traffic Management Systems will need to be scalable enough to be able to process this continuous (FCD could allow for data at any time and point) and richer (FCD could provide more data than speed) information. Techniques will need to be implemented to analyze data from different sources, validate it and integrate it consistently and accurately. Moreover, as a governmental institution, Rijkswaterstaat should make this information openly available for the larger public.

Mobile Networks Development. 5G is the next generation mobile network that aims at handling more data, connecting more devices, reducing latency significantly and bringing new levels of reliability. According to a report from the HIS, "5G will be able to support the needs of all-new markets like the Internet of Things (IoT) and Mission Critical Services (MCS), as well as emerging Augmented Reality (AR) and Virtual Reality (VR) applications" (Mundy, 2017). 5G could represent an alternative for WiFi-P since it would enable new possibilities that are not feasible or practical with 4G and other legacy mobile technologies, such as allowing for fast V2X communications. This is a development that can accelerate the usability of FCD for Traffic Management critical applications such as AID.

Legal

At the legal dimension, it is important to consider regulations or laws that somehow set requirements or limitations to the way information is collected. One concrete example of a regulation that is currently a reality and an example of a more general situation that may have implications for FCD are provided below.

Traffic regulations. In the Netherlands, there are different laws where noise pollution is regulated but for road traffic the law 'Wet geluidhinder' (Wgh) is probably the most important. In this law 'noise zones' are identified as areas along the highways are delimited and where the average noise level over a year is controlled. For this measurement, virtual reference points are set 50 m away from the highway, 100 m away from each other and at a height of 4 m (Rijkswaterstaat, 2010). The data used to calculate the noise level at these points includes (among other) traffic intensity and traffic speed at such points. This regulation sets a requirement on the type and frequency (space wise) data has to be recorded. As described in section 5.1, one of the limitations of FCD is that it cannot provide intensity information, meaning that it would not be able to meet that requirement.

Privacy Standards. When using FCD, privacy challenges related to the utilization of road users' information arise. When collecting data such as vehicle location, speed or route, it is possible to trace users, determine their mobility patterns or driving behavior. For the use of FCD for AID and TIP, these concerns need to be considered and data should be somehow anonymized so that individual users cannot be identified. There are even standards for privacy in the frame of FCD. For example, the international standard ISO 24100 defines personal data as "data which pertains to an individual and can identify a particular individual, and are handled by probe vehicle systems defined in ISO 22837 when collecting probe data via a telecommunication network" (Bessler & Paulin, 2013, p. 25). This type of standards or regulations influence the deployment of services that use FCD.

Internal Factors

<u>Organizational</u>
At the organizational level, there are some drivers that incite the use of FCD for Traffic Management. These drivers have to do with various organizational goals or objectives that may be fulfilled with the help of FCD.

Organizational Vision. In many situations, the drive to move towards new technologies comes from a broad organizational vision that gives direction to projects and brings them together to guarantee they consistently contribute to the realization of a common goal. In 2013, the Dutch Ministry of Infrastructure and the Environment launched the program "Better informed on the road", whose mission is to "realize a smart and substantive consistent mix of information using smartphones, navigation systems and collective information channels on, above and along the road" (Rijkswaterstaat, 2013a). Mission that can only be achieved with the cooperation of the public and private sector. The migration to FCD for AID and TIP fits within this broader organizational context and contributes to the realization of this type of goals.

Budget Constraints. While it is true that the projects developed within Rijkswaterstaat seek to "improve the country's roads and waterways so that people can reach their destinations quickly and safely" (Rijkswaterstaat, 2016b), another important drivers to develop such projects is the achievement of more efficient processes. This also implicates the reduction of costs. As a matter of fact, the Dutch Ministry of Infrastructure and Environment decided to reduce budget shortages for Management and Maintenance through by making more financial means available and by implementing austerity and efficiency measures. This implicates that the budget for the development of systems that utilize cooperative and in-car technologies is limited and that room should be created within the existing budget. This calls for a strategy that can allow for the transition from old to new technologies, while keeping into account the savings needed within this austerity program and the free up of means for funding of the new technology (Rijkswaterstaat, 2013b).

Data Centralization. Another organizational trend within Rijkswaterstaat is the centralization of traffic information, task that is carried out by the NDW (National Data Warehouse for Traffic Information). The NDW is an alliance of nineteen public authorities who work together to consolidate a database of both real-time and historical traffic data. Within the framework of NDW, real-time data from 24000 measurement sites located along 7100 km of national, provincial and municipal roads is collected. This information is made available not only to these nineteen authorities for their own use but also to external parties such as the ANWB (the national motorists' association) or INRIX and other service providers who use it to provide various services to their users (e.g. alert them about congestion or incidents).

The NDW not only collects information from these authorities but it has also entered a framework agreement with fourteen private companies to acquire of real time information. All these organizations provide data collecting services by using mobile devices (e.g. smartphones or in-car navigation systems) or acquiring data directly from the roadside (e.g. induction loops or cameras). "NDW data is available as open data, which means that it is available to third parties for reuse in their applications. For parties that require more services, NDW offers an Agreement on Mutual Data Provision and Services" (NDW, 2016, p. 9).

For the current projects that have been conducted in Rijkswaterstaat, FCD has been directly acquired from service providers but in a future, live implementation, this data would most likely come through NDW.

Projects
One last factor to review when assessing the implementation of FCD for AID and TIP is the ongoing projects within Rijkswaterstaat that have a direct impact on this implementation (e.g. because of the systems that will be affected) or that have an indirect relation with it (e.g. because they also work with FCD for other applications). An overview of those projects is presented below.

PPA (Praktijk Proef Amsterdam). PPA is a large-scale test to experiment with innovations in car and roadside systems technologies in the Amsterdam region. The focus is on the use of alternative sources of data such as FCD and in the development of techniques for *Geïntegreerd Netwerkbreed Verkeersmanagement (GNV)* (Integrated network-wide Traffic Management). The PPA has been divided into three phases (Rijkswaterstaat, 2017a).

In phase 1, in-car systems and roadside systems were tested separately. Already in the literature study conducted in this phase, a gap between the offer and demand of FCD was identified:

- The demand of data for Traffic Management applications is based on the characteristics of induction loops data as a source; FCD has other characteristics that require other specifications from the demand side.
- The offer of FCD has been originated due to applications for traffic information; it is necessary to make some adjustments to make this data appropriate for traffic management purposes.
- Induction loops data is collected via public sources and is made openly available. For FCD, there is an existing market but the revenue model for traffic management applications is still in development, which represents an obstacle to close the gap between offer and demand.

In phase 2, three different tests were carried out that aimed at the integration of innovative in-car and roadside systems. From these tests, probably the most relevant for the scenario under analysis is the PPA West. In this test, four modules with various Traffic Management functionalities were implemented. For three of them FCD from three different providers (TomTom, BeMobile and Here) was used as an input. In all cases this was FCD based on GPS locations, since from previous experience in phase 1, other types of FCD (i.e. based 3G/4G) was not yet accurate enough. The most important outcomes that may concern us from phase 2 are:

- Determination of location. When determining the location and speed of a vehicle with FCD, there's an inaccuracy of minimum 5 m. This means that determining location at the lane level is still a problem with FCD. There are many situations that providers still need to take into consideration. For example, knowing when there's a parking place instead of congestion or a local road next to the highway when slow speeds are detected.
- Delay.
- Sample size. The percentage of vehicles from which FCD can be obtained is approximately 8% for highways and 2-3% for other roads currently. When there is less vehicle intensity (e.g. at night), it takes longer for enough vehicles to pass that can generate FCD, which is a limitation for real-time traffic management.

- Selectivity. In many cases, FCD comes from specific road users (e.g. leased cars, trucks) and this is not always representative for all vehicles. For some applications (e.g. congestion detection) that doesn't represent a problem but for other applications, it may be a limitation.

Finally, phase 3 aims at a full integration based on the results achieved in phase 2 and it has just started in 2017.

C-ITS Corridor (Cooperative ITS Corridor). C-ITS Corridor is an international project initiated by the Dutch Ministry of Infrastructure and the Environment, the German Ministry for Traffic, Construction and City Development and the Austrian Ministry for Traffic, Innovation and Technology. With this project, Road managers from these three countries, working with industrial partners, are taking the first step towards the introduction of cooperative services in Europe. The idea of the project is to initially develop two services: Road Works Warning and Probe Vehicle Data (an additional service, Collision Risk Warning is also being developed in the Netherlands), which will serve as the base to provide more services to users in the future. This project is based on the use of WiFi-P FCD, where cars enabled with WiFi-P modules can communicate with roadside systems, also enabled with this technology.

In the Netherlands, there will be four large demonstrations throughout 2017 on different sections of the Dutch section of the international ITS Corridor.

Talking Traffic. Talking traffic is a partnership between the central government, different regions that take part in the Dutch program '*Beter Benutten*' (a national program to improve the accessibility at roads, water and railways) and several market parties. The main objective of this project is to bring information to the car for different use cases: maximum speeds and speed recommendations, personal and current information about potential dangerous situations and road works in the road, current information about traffic lights and parking information including the reservation of parking places. This project will use the 4G telecommunications network to provide this information to users and it's being conducted in cooperation with 15 market parties including VRI providers (e.g. Swarco), service providers (e.g. KPN) and data providers (e.g. Flitsmeister).

An important highlight from this project is that one of the envisioned use cases requires the speed signs generated from AID to provide them to users in the car. For this, they're currently using the speed signs that are made available through the ESB.

FCD – BeMobile. This is a concrete project that makes use of FCD from the service provider BeMobile to fulfill the AID service. In the second half of 2016, a real-time pilot was conducted with GPS FCD from users of the Flitsmeister app, where traffic signs (50 and 70 speed signs) generated by BeMobile using this data were compared with signs generated via information from induction loops. BeMobile signs were displayed live via a prototype of i-WKS in an MSI in the Rijkswaterstaat's Innovation Center (Helmond). Information came from three test road segments from the A1L, A27L and A58L (ModelIT, 2017).

The evaluation of this pilot was conducted by an independent party (ModelIT) and it included comparing the AID status generated by both systems, as well as the availability of the system in time. Speed measures were also generated by BeMobile (Central AID) but assessing them was not on the

scope of the evaluation, as neither was the communication of BeMobile systems with Rijkswaterstaat's system. The overall results from a visual inspection of the data sets were:

- When comparing the locations of the AID intervals generated from loops vs. FCD, they are aligned for an aggregated inspection. Only when the data sets are examined closer, there are differences in the times AID turns on and off. However, these differences are small when compared with the length of the AID intervals.
- In most cases, AID with FCD is activated a little later than in MTM but this occurs (also in most cases) before the moment congestion reaches the upstream detector point. There are also intervals where AID with FCD is active and it is not active in MTM (or the other way around). However, this does not have a large impact on the overall picture because such intervals are very short. The spacial error in most cases is smaller than the distance between MSI portals.
- Whether AID with FCD can replace AID with induction loops cannot be determined based on the conducted visual inspection because it does not provide any numerical *onderbouwing*.

From the numerical analysis conducted, the following conclusions were drawn:

- False alarm probability (probability that an FCD interval overlaps with at least one MTM interval). When expressed as a percentage of the time, the false alarm probability was never larger than 1.4% for all three road segments. Thus, it can be judged to be "good".
- Detection probability (probability that a MTM interval overlaps via one or more FCD intervals). When expressed as a percentage of the time, the detection probability was above 20% for the A1L and A57L. For the A58L, this was 12% from the intervals. In short, this means that FCD was 20% or 12% effective with reference to MTM.
- Reaction time to activate (average time between the moment AID in MTM activates and the moment that the first overlapping FC interval activates). The average reaction time was found to be between 3 to 16 seconds, which is considered acceptable.
- Distribution of reaction time. In the A1L and A57L, a reasonable distribution of the reaction times was found. This translates to a less consistent user experience. This distribution is certainly more important than the reaction time itself, since the reaction time can be sorted out by locating the sight of FCD further downstream.

The final conclusions included the fact that none of the analyses conducted justifies an unambiguous conclusion about the applicability of this data. The results fluctuated considerably per road segment and traffic profile. Moreover, it was recommended to improve the utilized FCD algorithm in the aspects "detection of local incidents" and to a lesser extent the "distribution of reaction times" (ModelIT, 2017).

Figure 18. Demonstration of speed signs generated from loops next to FCD from BeMobile

FCD – Vodafone/Ericsson. In the second half of 2016, another pilot was started to be able to execute AID by means of FCD. In this case (unlike with BeMobile, where GPS FCD was used), 3G/4G FCD coming from users of the Vodafone network was used. At the end of 2016, Vodafone had not been able to generate accurate enough vehicle speeds. For this reason, Vodafone was not able to calculate traffic signs to be compared with those generated from induction loops data (Rijkswaterstaat, 2017b).

At the time this report has been published, Vodafone has been working on improving the algorithm they use to determine average speed per carriageway, using NDW data as a comparison point. For the moment, they have one-minute data and they have been able to reduce space resolution by measuring in spaces of 100 m. With their current technique, it would not be possible to gather sufficient data at night or weekends but they believe this situation can improve with time. Additionally, they will start evaluating how accurately they could detect a congestion by comparing their data with log files from MTM-2.

i-WKS. This is a very relevant project that will impact the way FCD for AID and TIP is implemented. In 2014 Rijkswaterstaat decided to develop a new version of WKS due to several reasons: (i) currently control and maintenance have to be done locally in the OS, (ii) WKS 1.3 is not prepared to integrate cooperative technologies, (iii) hardware and software are built together as a "black box" creating vendor lock in and (iv) in general it is an expensive and technically complex model (Rijkswaterstaat, 2017b, p. 8).

Since many of the current WKS would soon approach its end of life, a decision was taken to develop what it is known as i-WKS, a flexible system that would allow to adapt the way AID and other functions are carried out. For this new version, (i) software and hardware have been separated, (ii) using components with standard IP technology and (iii) experimenting with alternative sensors (i.e. FCD).

In 2016 already some demonstrations were conducted, including a WKS Light prototype connected to MSIs displaying information coming from induction loops next to information coming from FCD (BeMobile) in the Innovation Centre (Helmond). By mid-2017, the WKS Light project should already

deliver specifications for this new WKS version, a new software (that allows to use alternative sensors), a hardware prototype and a procurement strategy. Since the concept from WKS-Light is quite different to the previous versions (e.g. WKS 1.3), the roll out will occur in small steps. The initial idea would be to install 20 WKS-Light in the last quarter of 2017.

i-Infra. As mentioned in section 4.2, there are currently 5700 WKS in the Netherlands, from which 2500 are UDP WKS connected to a TCP/IP fiber network. Moreover, the new WKS-Light version will also require to be connected to this glass infrastructure. Rijkswaterstaat has around 3500 km of glass fiber (managed by KPN) and around 3500 km of copper lines (managed by VODK partners). By 2015, 600 km from the network were already plug & play, which comprises the glass fiber infrastructure, nodes and connection possibilities. Rijkswaterstaat has decided to invest €100 million to expand the current network and make it plug & play (Rijkswaterstaat, 2015c, p. 11). This project has a direct impact on the locations where i-WKS could be installed and where FCD could be used.
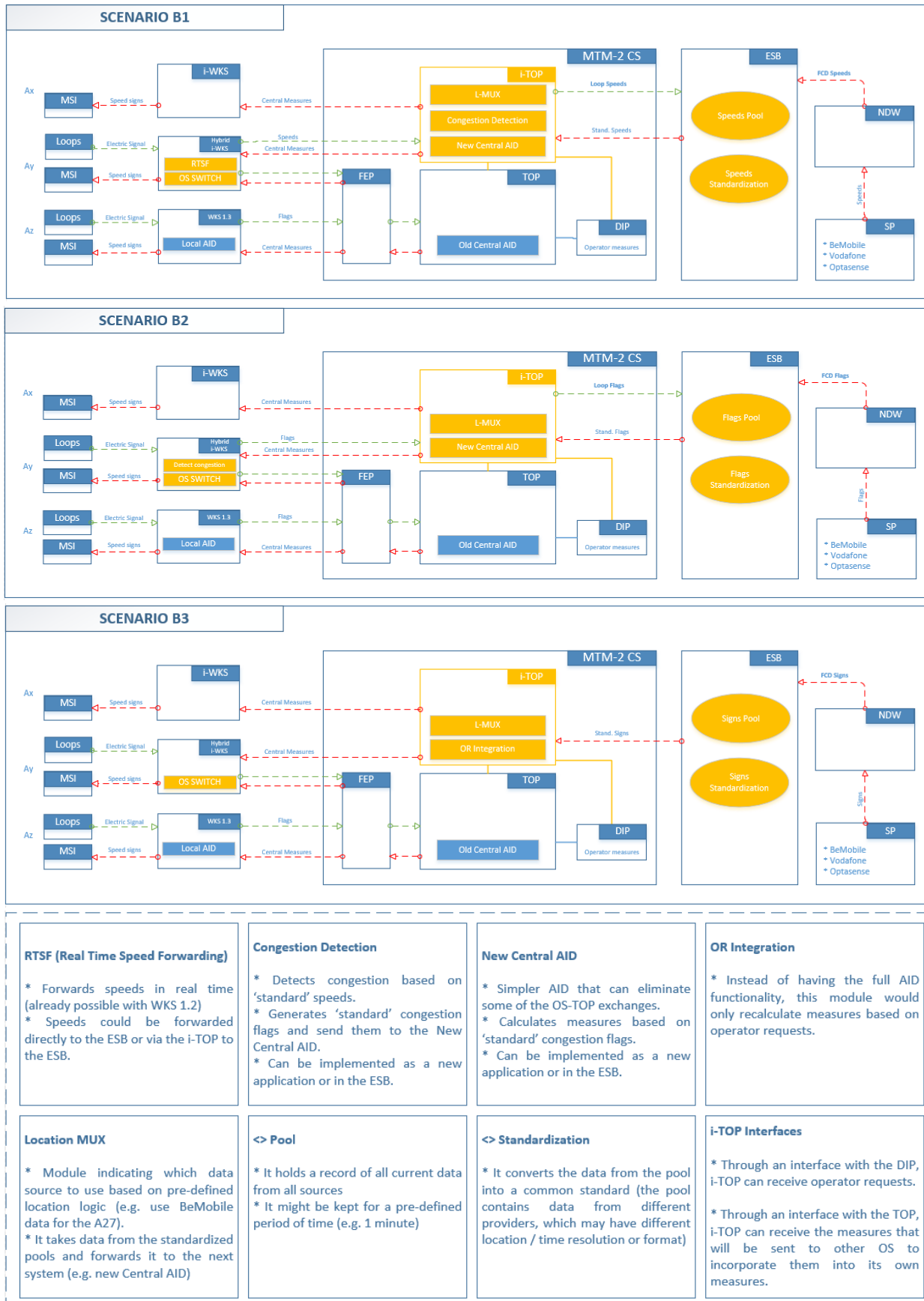
CHARM. A relevant project under development is the replacement of legacy traffic management systems for a new generation Advanced Traffic Management Software (AMTS). This project is called CHARM and it's a collaborative program between Highways England and Rijkswaterstaat, where an ATMS system from the Austrian provider Kapsch TraffiCom called DYNAC will be implemented both in England and the Netherlands. This new system will modernize and consolidate many traffic management services, optimizing traffic operations and improving user experience (Rijkswaterstaat, 2016a).

The software is highly configurable, allowing for the deployment of various traffic applications. MTM-2 is partially in scope of CHARM within Rijkswaterstaat, more precisely, all MTM-2 functionality should be implemented in this new system, except for the FEP. MONiCA is full in scope of CHARM and it will have interfaces to non-CHARM systems. This means that this new development should be taken into consideration when integrating FCD in the current landscape, since supporting systems are also changing.

Additionally, CHARM, on its PCP (Pre-Commercial Procurement) phase, will test six innovative traffic modules on the ATMS. Two of these projects have to do with the detection and prediction of incidents, where market parties seek to combine data from various sources such as induction loops, radar, FCD, Can Bus and even unstructured data coming from Social Media or Emergency services websites.

Appendix F – Scenario Analysis Workshop Diagrams

SCENARIO B1

SCENARIO B2

SCENARIO B3

RTSF (Real Time Speed Forwarding)

* Forwards speeds in real time (already possible with WKS 1.2)
* Speeds could be forwarded directly to the ESB or via the i-TOP to the ESB.

Congestion Detection

* Detects congestion based on 'standard' speeds.
* Generates 'standard' congestion flags and send them to the New Central AID.
* Can be implemented as a new application or in the ESB.

New Central AID

* Simpler AID that can eliminate some of the OS-TOP exchanges.
* Calculates measures based on 'standard' congestion flags.
* Can be implemented as a new application or in the ESB.

OR Integration

* Instead of having the full AID functionality, this module would only recalculate measures based on operator requests.

Location MUX

* Module indicating which data source to use based on pre-defined location logic (e.g. use BeMobile data for the A27).
* It takes data from the standardized pools and forwards it to the next system (e.g. new Central AID)

<> Pool

* It holds a record of all current data from all sources
* It might be kept for a pre-defined period of time (e.g. 1 minute)

<> Standardization

* It converts the data from the pool into a common standard (the pool contains data from different providers, which may have different location / time resolution or format)

i-TOP Interfaces

* Through an interface with the DIP, i-TOP can receive operator requests.

* Through an interface with the TOP, i-TOP can receive the measures that will be sent to other OS to incorporate them into its own measures.

SCENARIO C1

SCENARIO C2

SCENARIO C3

RTSF (Real Time Speed Forwarding)

* Forwards speeds in real time (already possible with WKS 1.2)
* Speeds could be forwarded directly to the ESB or via the i-TOP to the ESB.

Congestion Detection

* Detects congestion based on 'standard' speeds.
* Generates 'standard' congestion flags and send them to the New Central AID.
* Can be implemented as a new application or in the ESB.

New Central AID

* Simpler AID that can eliminate some of the OS-TOP exchanges.
* Calculates measures based on 'standard' congestion flags.
* Can be implemented as a new application or in the ESB.

OR Integration

* Instead of having the full AID functionality, this module would only recalculate measures based on operator requests.

Time MUX

* Module indicating which data source to use based on pre-defined time logic (e.g. use BeMobile data between 7-9).
* It takes data from the standardized pools and forwards it to the next system (e.g. new Central AID)
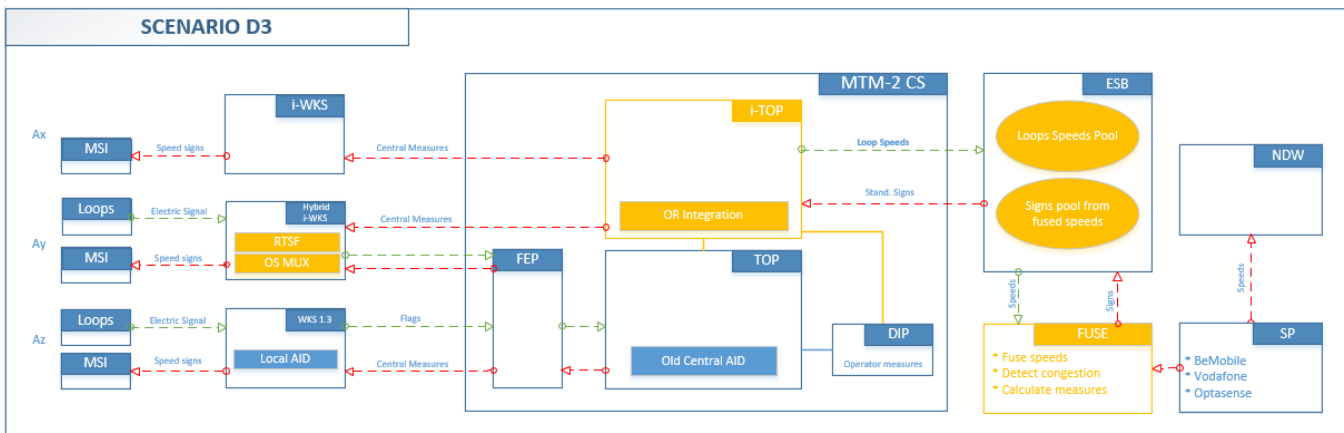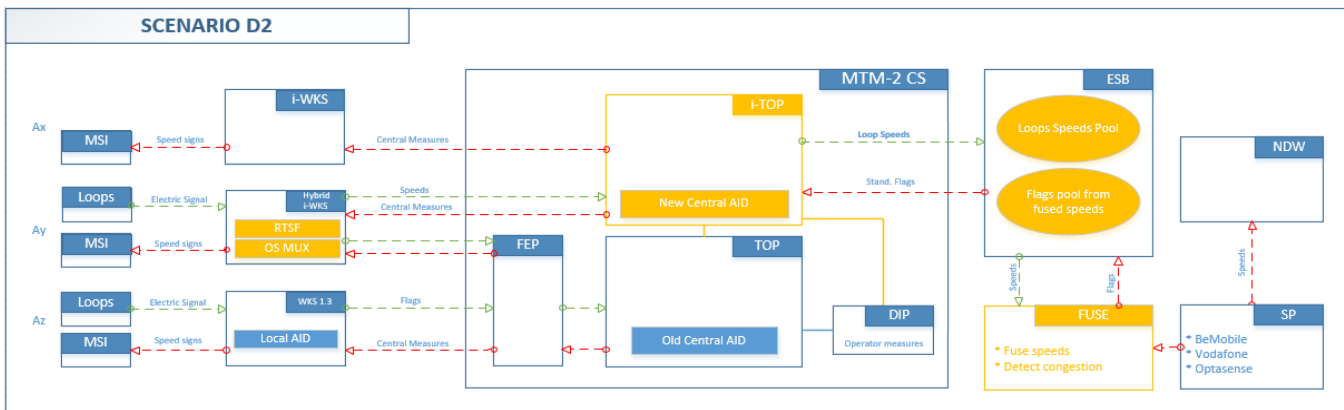
<> Pool

* It holds a record of all current data from all sources
* It might be kept for a pre-defined period of time (e.g. 1 minute)

<> Standardization

* It converts the data from the pool into a common standard (the pool contains data from different providers, which may have different location / time resolution or format)

i-TOP Interfaces

* Through an interface with the DIP, i-TOP can receive operator requests.

* Through an interface with the TOP, i-TOP can receive the measures that will be sent to other OS to incorporate them into its own measures.

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SCENARIO D1

SCENARIO D2

SCENARIO D3

RTSF (Real Time Speed Forwarding)

* Forwards speeds in real time (already possible with WKS 1.2)
* Speeds could be forwarded directly to the ESB or via the i-TOP to the ESB.

Congestion Detection

* Detects congestion based on 'standard' speeds.
* Generates 'standard' congestion flags and send them to the New Central AID.
* Can be implemented as a new application or in the ESB.

New Central AID

* Simpler AID that can eliminate some of the OS-TOP exchanges.
* Calculates measures based on 'standard' congestion flags.
* Can be implemented as a new application or in the ESB.

OR Integration

* Instead of having the full AID functionality, this module would only recalculate measures based on operator requests.

FUSE

* Module that fuses speed data from various sources. It allows to remove loops from certain locations and "fill the gaps" with FCD.

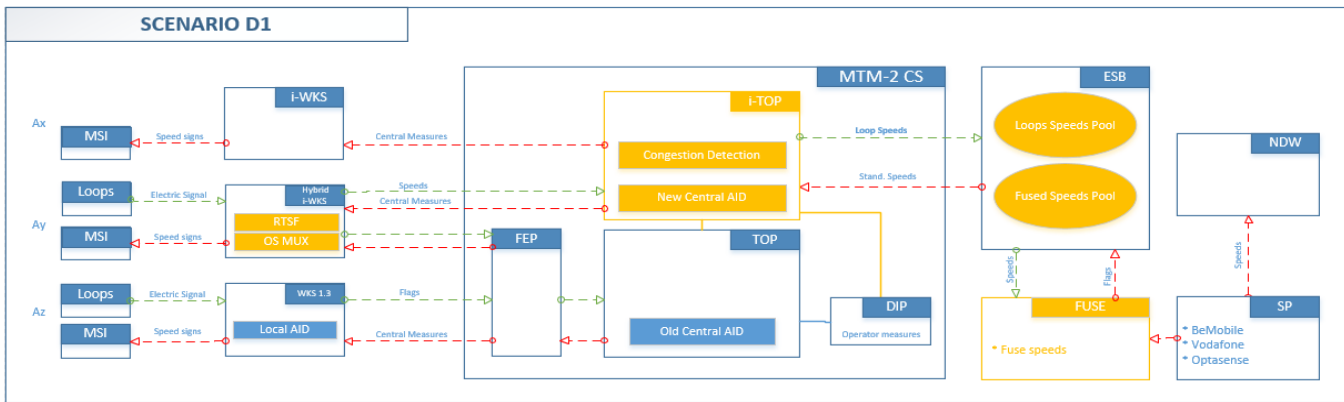* This fused data would need to follow the CS standard.

<> Pool

* It holds a record of all current data from all sources
* It might be kept for a pre-defined period of time (e.g. 1 minute)

<> Standardization

* It converts the data from the pool into a common standard (the pool contains data from different providers, which may have different location / time resolution or format)

i-TOP Interfaces

* Through an interface with the DIP, i-TOP can receive operator requests.

* Through an interface with the TOP, i-TOP can receive the measures that will be sent to other OS to incorporate them into its own measures.

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Appendix G – Scenario Analysis Workshop Guiding Questions

<u>General Questions</u>

- What are the advantages of this scenario?
- What are the disadvantages of this scenario?
- What are the main differentiating points of this scenario when compared to the other two?
- What are possible use cases for this scenario?

<u>System and Implementation Complexity</u>

- What do you think about the mission critical character of AID and the control RWS should have over it?
- How complex is to implement these changes in the RS and CS? What else would be required? (i.e. install i-WKS in all road segments vs. only installing a few i-WKS for this scenario)
- Which services would make sense to locate in the ESB and which not?

<u>Procurement Strategy</u>

- Does acquiring certain type of data match NDW's strategy or is coherent with other projects?
- Is it better to use NDW as an intermediary or to have a direct interface with the providers?
- Does it make sense to make this type of investment? (i.e. acquire data from 3 different providers) Is it possible that new providers or technologies become available and we may want to invest in them?

<u>Commercial Feasibility</u>

- Are these stable or reliable providers? (BeMobile, Vodafone, Optasense)
- Is the data they offer enough to perform AID?
- Would it represent different costs to acquire speeds, flags or signs?

Appendix H – Rijkswaterstaat Enterprise Architecture Principles

<u>Business</u>

Name	Statement
EP-1	We werken als één landelijk opererende organisatie
EP-2	We voeren de kerntaken uit met eigen mensen
EP-3	Wij stemmen bij de uitvoering van onze taken af met onze stakeholders
EP-4	Taken, verantwoordelijkheden en bevoegdheden zijn duidelijk, eenduidig vastgelegd en bekend
EP-5	De "Regio" focust op de netwerkgebruikers en op de bestuurlijke partners, de "Landelijke uitvoering" focust op efficiëntie en standaardisatie
EP-6	Samenwerken met anderen moet leiden tot verbetering van ons functioneren
EP-7	Verandering moet bijdragen aan effectiviteit en efficiëntie
EP-8	Beveiliging is integraal opgenomen in het ontwerp van processen
EP-9	Informatie dient primair voor onze sturing en taakuitvoering
EP-10	Eerst "hergebruik", dan "kopen", dan "laten maken"

<u>Information</u>

Name	Statement
IP-1	Informatie dient primair voor onze sturing en taakuivoering
IP-2	Geïntegreerde netwerkinformatie
IP-3	Toegankelijk en gerbuiksvriendelijk
IP-4	RWS voert regie op informatie
IP-5	Levenscyclysbenadering

<u>Data</u>

Name	Statement
GP-1	Gegevens voldoen aan de wet
GP-2	Gegevens volgens standaarden
GP-3	Gegevens onder governance
GP-4	Gegevens zijn geclassificeerd
GP-5	Gegevens zijn toegankelijk
GP-6	Gegevens voor organisatiedoelen
GP-7	Gegevens hergebruik vóór inwinnen
GP-8	Gegevens zijn toekomstvast
GP-9	Gegevensstructuur is geborgd
GP-10	Gegevenskwaliteit is geborgd
GP-11	Gegevens zijn koppelbaar
GP-12	RWS voorziet haar gegevens van metadata

<u>Application</u>

Name	Statement
AP-1	Koppelen van industriële automatisering en administratieve automatisering alleen met voldoende beveiliging
AP-2	Applicaties worden ontworpen voor optimale samenwerking met partners

AP-3	RWS gebruikt standaarden
AP-4	Gegevens worden eenmalig ingewonnen en beheerd, en meervoudig gebruikt
AP-5	Vernieuwing en groot onderhoud vinden plaats onder architectuur
AP-6	Nieuwe applicaties bieden herbruikbare functionaliteit aan op basis van services
AP-7	Nieuwe applicaties die algemeen gebruikt worden, bieden een webbased user interface
AP-8	Data is los van de applicatie beschikbaar
AP-9	Hergebruik vóór kopen vóór maken
AP-10	Standaard pakketten gebruiken zoals geleverd

Technology

Name	Statement
TIP-1	De technische infrastructuur van RWS is gericht op interoperabiliteit
TIP-2	De technische infrastructuur van RWS ondersteunt rijksbrede samenwerking in publieke- en private netwerken
TIP-3	RWS richt zich op de kerntaken
TIP-4	De RWS infrastructuur is flexibel, schaalbaar en efficiënt
TIP-5	RWS meet kwaliteit en maakt management informatie inzichtelijk

Industrial Automatization

Name	Statement
IAP-1	Netwerkresultaat is geborgd
IAP-2	RWS streeft naar uniforme bediening en dienstverlening naar de (vaar)weggebruiker en standaardasiering van de infrastructuur
IAP-3	RWS werkt vanuit één RWS architectuur gericht op de gehele werkende keten
IAP-4	Bij aanleg en assetmanagement van Industriële Automatisering in de infrastructuur past RWS lifecycle management toe
IAP-5	Kwaliteit van inkoop is geborgd
IAP-6	IA wordt gerealiseerd en aangepast en gewijzigd me aantoonbare toetsing op de juiste keuzes in relatie tot de eisen, de Industriële Automatiseringkaders -en standaards.
IAP-7	Veiligheid is geborgd
IAP-8	In gebruik, aanleg, beheer en onderhoud van IA in RWS infrastructuur wordt de fysieke en digitale beveiliging voldoende geborgd en gehandeld volgens (cyber) security beleid
IAP-9	Goed portfoliomanagement en voldoende georganiseerde kennis, expertise en capaciteit zijn hierbij onontbeerlijk

Security

Name	Statement
SP-1	Beveiliging op basis van risicoafweging
SP-2	Beveiliging is uit diverse lagen opgebouwd
SP-3	Beveiliging zo dicht mogelijk bij te beveiligen asset
SP-4	Beveiliging is ongecompliceerd (simpel)
SP-5	Beveiliging is makkelijk in gebruik
SP-6	Beveiligingsincidentdetectie is geborgd
SP-7	Incidentresponse is geborgd en geoefend
SP-8	Een IA objecy is aanyoonbaar beveiligd

Appendix I – Rijkswaterstaat Traffic Management Vision

Name	Statement
VVM-1	Rijkswaterstaat kiest ervoor de verkeersmanagementtaak op te pakken vanuit zijn 'systeemverantwoordelijkheid'.
VVM-2	Rijkswaterstaat kiest nadrukkelijk voor continueren en mogelijk intensiveren van de samenwerking ('partnering') met zowel overheden als private partijen, met als doel het benutten van elkaar kracht/expertise, en het versterken van het innovatief vermogen van VM.
VVM-3	Netwerkbreed VM ('van deur tot deur') is het vertrekpunt in het denken van RWS. Dit vraagt om regionale samenwerking, waarbij RWS vanuit zijn systeemverantwoordelijkheid het landelijke perspectief inbrengt.
VVM-4	RWS kiest voor ondersteuning van alle weggebruikers, zowel personen- als vrachtverkeer.
VVM-5	De RWS verkeerscentrales vervullen een sleutelrol in de dagelijkse uitvoering van VM.
VVM-6	Rijkswaterstaat positioneert het glasvezelnetwerk als een 4e netwerk dat kan dienen als een 'backbone' voor de ontwikkeling van een slimme infrastructuur en data uitwisseling ten behoeve van een geïntegreerd vervoersysteem.
VVM-7	Rijkswaterstaat kiest voor coöperatieve diensten en systemen gecombineerd met gecoördineerd netwerkbreed VM. Rijkswaterstaat kiest voor het gebruik van informatieverstrekking via wegkantgebonden systemen, naast alternatieven in-car, zo-lang deze voldoende aantoonbare toegevoegde waarde hebben.
VVM-8	RWS neemt een proactieve, samenwerkingsgerichte houding aan richting zijn omgeving. Dit betekent dat RWS en de RWS-ers.
VVM-9	RWS kiest ervoor om bij crisis en/of calamiteiten met een bovenregionale impact op te treden als landelijke verkeersmanager voor het gehele wegennet, met erkenning van die rol door andere netwerkbeheerders.
VVM-10	RWS kiest voor zichtbaarheid en transparantie door actieve communicatie.

Appendix J – Improvements needed in the Solution Architecture

<u>Business Process</u>
- Separate the last step, *combine all signs requests*, into different levels of traffic signs combination (at the roadside system level, central level and MTM-FCD level) for clarification.
- Link the *calculate and distribute congestion measures* and the *combine all signs requests* (or derived sub-processes from previous step) to lower layers.

<u>Underlying Data Services</u>
- Separate the *RWS Traffic Data Services* into two categories: basic traffic information (minute-based v, i, c and real time speeds) and congestion information.
- Link these services to the corresponding business processes.
- Differentiate the services that allow to provide basic traffic information and congestion information, also for the *data fusion services*.

<u>ESB Services</u>
- Indicate the possibility to offer other services such as providing speed or intensity information.
- Elaborate on the limitations of the current *(MTM) Signs Service* and the need to convert it into a service that contains more contextual information.

<u>Applications</u>
- Include the RTSF function in the Legacy WKS and specify that a small percentage can fulfill it.
- Do not specify the functions in the Provider Application.
- Make sure to make the correct linkage between the Data Fusion Application and the separated services in the Underlying Data Services section of the Business Architecture.
- Make a better specification of the functions at the TOP and i-TOP, including changing some naming (e.g. Distribute AID Measures → Deploy AID Measures) and subdividing the functions.