Uncovering causes of financial setbacks in bridge renovation & replacement

Enhancing project delivery for public commissioners

MOT2910: Master Thesis Project

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Uncovering causes of financial setbacks in bridge renovation & replacement

Enhancing project delivery for public commissioners

by

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Preface

With this thesis, I conclude my master's degree in Management of Technology at TU Delft. It has been an academic journey of several months in which I have immersed myself into an issue that will shape the future of the Netherlands, as maintaining our famously high-quality infrastructure will become a matter of growing concern. I hope that this research serves as a comprehensive source of knowledge to those who want to explore the practical reality of infrastructure renewal and R&R projects. Practitioners involved in these projects may benefit from the results of this research, as it pinpoints why this type of project is considered to be challenging, and different than traditional greenfield construction projects.

I want to express my gratitude towards my graduation committee at the TU Delft, for providing continuous support and interesting conversations which have contributed to the progression of this research. To prof. dr. ir. P.H.A.J.M. van Gelder, I want to thank you for your time during our meetings, as your cheerful support and in-depth recommendations strengthened my efforts. To dr. M. Leijten, for your critical insights and illustrating real-life examples, provided from both your abundant academical and practical knowledge, anchoring the research into the real-world context. To ir. M. de Rooij as my company supervisor, providing guidance along all steps of the way, acting as a true mentor with sharp assessment and allowing me to improve on my results. It was a pleasure to work with you all, and I am grateful for a committee that holds such differentiated knowledge on the topic of my research.

I also want to thank my peers at Horvat & Partners, which offered me the opportunity to work on this topic. Their support and contributions have allowed for an in-depth examination of infrastructure renewal, substantiated by their abundant experience. Furthermore, I am grateful to all the individuals that have contributed to my research through participating in the interviews, sharing their insights and helping to ground the results into practice. Your openness and willingness to participate laid the foundation for true understanding.

Lastly, I want to thank those who are close to me, as your unwavering encouragement and belief in my work has brought me focus and motivation through this journey.

J.J. Mathôt
Delft, December 2025

Summary

The public infrastructure manager Rijkswaterstaat (RWS) faces challenges in effectively preparing and tendering projects for renovation and replacement (R&R) of bridges in the Primary Highway Network (*Hoofdwegennet, HWN*) and Primary Waterway Network (*Hoofdvaarwegennet, HVWN*). The project delivery framework for R&R projects, the "R&R Approach," has shown limitations for identifying the full scope of and accurately estimate costs in R&R projects, resulting in financial setbacks, project delays, and heightened risks to the long-term functioning of critical infrastructure.

The main aim of this thesis has been to identify the primary complexities in bridge renewal that cause financial setbacks and what mechanism underlie them, so that the causes of scope change and inaccuracy in the cost estimation can be mitigated through enhancement of the project delivery framework. For this purpose, the following main research question has been established: How can RWS enhance the project delivery framework for R&R projects involving bridges within the HWN and HVWN, by specifically targeting the complexities and uncertainties faced in scope identification and cost estimation? As a result of the complexities and uncertainties encountered within R&R, RWS faces challenges in scope identification and cost estimation, which has resulted in financial setbacks. A financial setbacks encompasses the moment in a project when it emerges that the actual costs incurred are higher than anticipated, which may happen for a variety of reasons.

To answer the main research question, a study has been conducted to determine what project delivery frameworks are used by RWS, what complexity and uncertainty is present in R&R projects, and how their manifestation has led to financial setbacks. The results of these steps have been utilized to design recommendations to improve organizational performance and enhance the project delivery framework for R&R projects. The first part of this research established that the R&R Approach is the project delivery framework for R&R projects at RWS.

Through a series of semi-structured interviews held among seven respondents, insights into complexity, uncertainty, and the overall approach to infrastructure renewal projects were acquired. These individuals originated from a multiple organizations, such as contractors (planning and cost experts), RWS (PM teams, cost pool), and the Ministry of I&W (policymakers), which are all currently working on RWS R&R projects. These practitioners, have elaborated upon the challenges they encounter, which has allowed for a structural categorization of complexities and underlying uncertainty through the theoretical framework developed in the literature study within this thesis.

Under this framework, complexities were categorized into the technical, social, financial, legal, organizational, or time category. Subsequently, a further distinction was made in each category, stating whether it involves a detail or a dynamic complexity. Dynamic organizational complexities dominate R&R projects, which can be concluded from the fact that these were found to be most prominent out of all the complexities identified as shown in Figure 1.

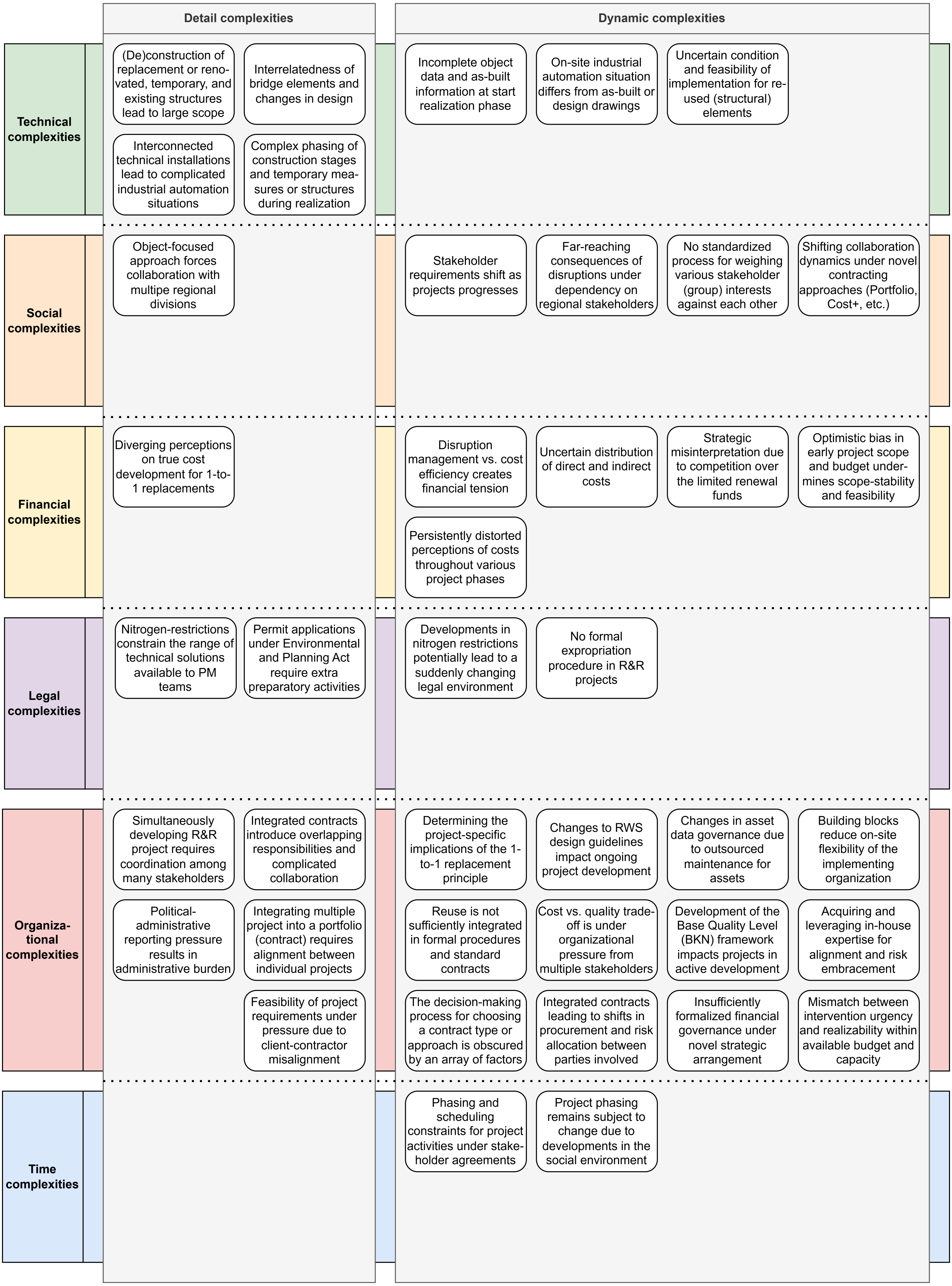

Figure 1: An overview of the complexities identified in the practitioner interviews.

The previous stage of the research, resulted in the overview of a large number of complexities as highlighted above. In the continuation of this research, it has been chosen that a selected number of these complexities were to be focused on and analyzed in-depth, thereby uncovering their underlying mechanisms. This selection has taken place based on the findings of the case study, which is elaborated upon the in coming paragraph. Nevertheless, it must be stated that the complexities not included in the subsequent in-depth analysis are to be ignored, as their identification and description provides detailed insight in the practical reality of R&R projects, and may be critical to other R&R projects.

The results of this initial stage have been grounded into practice through developing single case study, which has illustrated complexities and uncertainty through practical examples. The project selected to serve as the case, was the R&R project Civil Structures A44. This project encompasses the replacement of one movable bridge and three viaducts, which are a part of the A44 highway. The case study resulted in a set of five complexities, which were identified by the PM team of this project as the primary causes of financial setbacks in the case study project, and underwent an in-depth analysis to uncover which mechanisms underlie them. Through this examination, it was found that each complexity resulted from two underlying mechanisms. These result are shown in Figure 2.

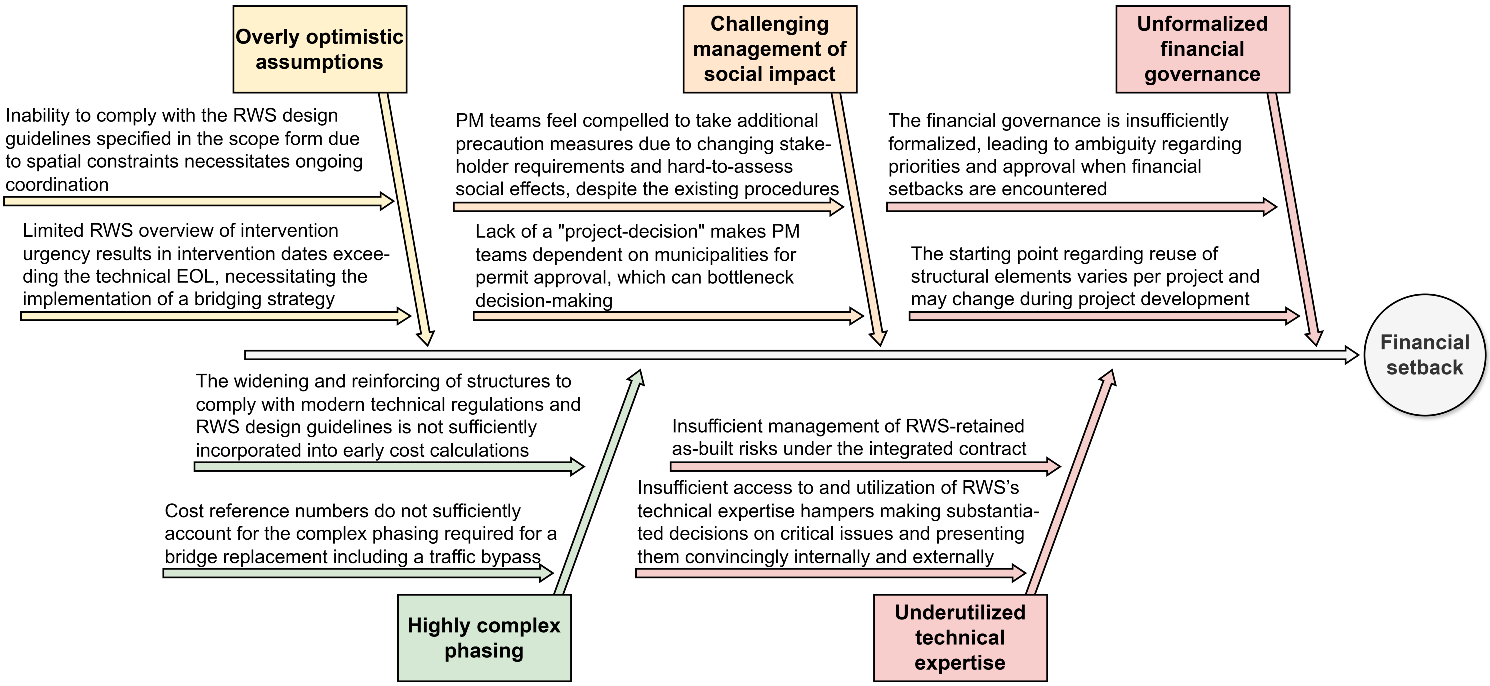

Figure 2: Cause-and-effect diagram of the primary complexities leading to financial setbacks and their underlying mechanisms in the case project.

The research has been concluded by ten recommendations to improve scope identification and cost estimation, with some of these recommendations implemented in an enhanced version of the project delivery framework as shown in Figure 3. An important note for these recommendations is that financial setbacks in R&R projects stem from initial presumptions, that do not hold in practice as these do not include critical scope inherent to bridge renewal. Key examples of this scope are reused structural elements (foundations, girders), traffic bypasses, and temporary measures for safeguarding structural integrity or traffic safety. Additionally, cost elements critical for accurately estimating the project costs (in early stages before the project enters active development), are insufficiently accounted for. Examples of these cost elements include the bridging strategy, complex construction phasing, and the temporary situation prior to and during the realization phase.

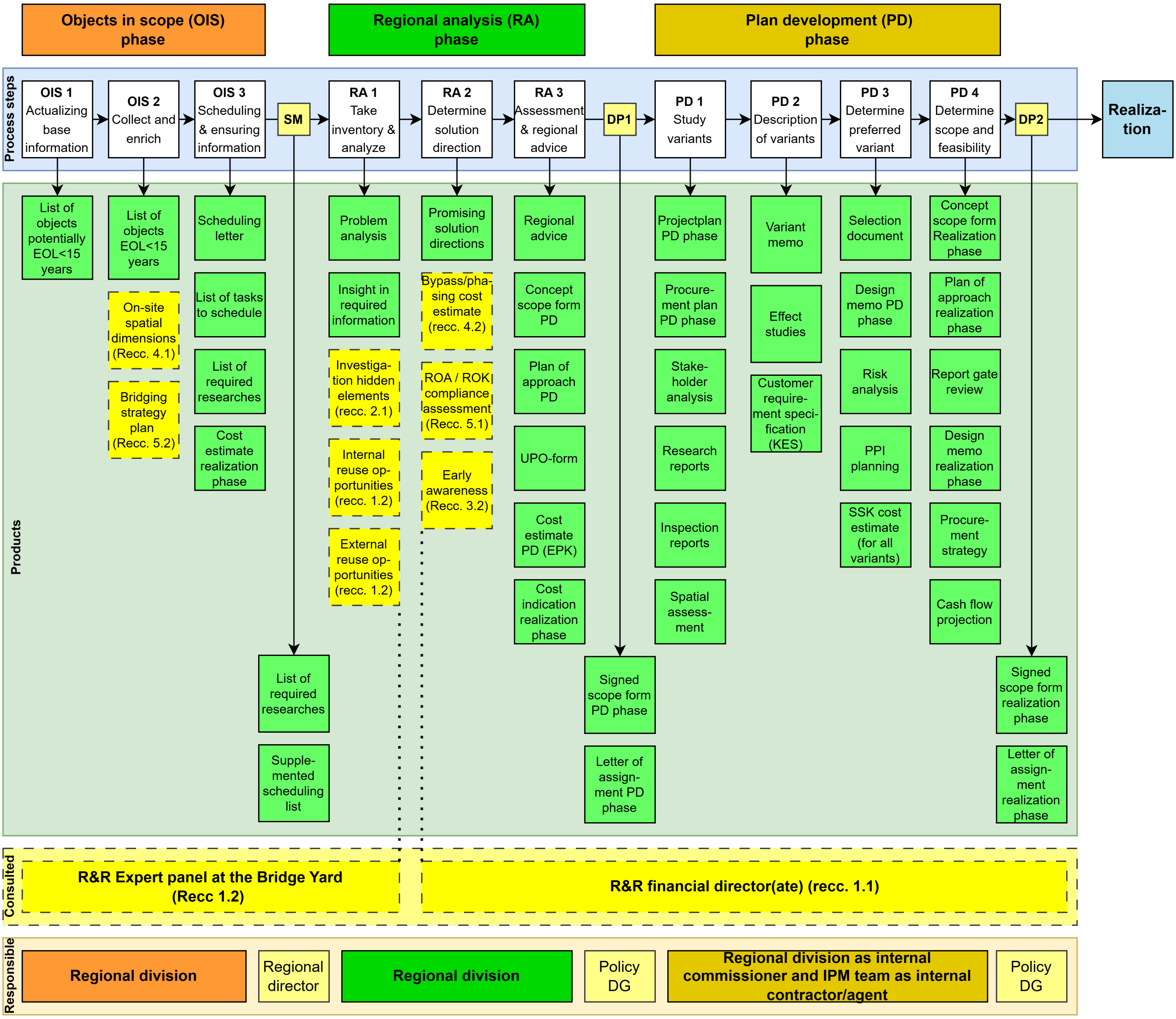

Figure 3: The enhanced R&R Approach. The striped yellow blocks are recommended processes/products to improve the project delivery framework.

When reflecting upon this research, it must stated that the research knows a limited generalizability, as a single case study had to be employed, as confidentially restrictions prevented access to RWS project cost data. Nevertheless, the results provide in-depth insights, which are grounded in practice. Therefore, this study holds theoretical and practical value, through filling a gap in the existing literature, and providing real-life illustrations of the challenging nature of infrastructure renewal. Future research should expand the scope to other asset types, and include a wider range of stakeholders, such as contractors and policymakers. Finally, a quantitative analysis of cost data may validate the findings. With infrastructure renewal becoming a matter of growing concern in the coming decades, it is expected that data availability will increase, offering opportunities for further research.

In conclusion, RWS can enhance the R&R Approach project delivery framework through including several steps that identify critical scope which is inherent to bridge renewal, and improve the overall cost estimation methodology by conducting research that established cost driving scope in the (early) cost estimates. With these recommendations, RWS can enhance the R&R Approach and surrounding procedures, strengthening project delivery.

Contents

List of Figures

List of Tables

Nomenclature

This table has been added to provide clarity regarding the various Dutch terms and their abbreviations, as well as for English abbreviations.

- **1-to-1 replacement:** Like-for-like replacement (*1-op-1 vervanging*).
- **AM:** Asset Management.
- **BKN**: Base Quality Level (*Basiskwaliteitsniveau*).
- **CFO:** Chief Financial Officer.
- **COO:** Chief Operations Officer.
- **DDF:** Double Diamond Framework.
- **DG:** Directorate-General (*Directoraat-Generaal*).
- **DP:** Decision point (*Beslismoment*).
- **EOL:** End-of-life.
- **EOV:** Operations, Maintenance, and Renewal (*Eploitatie, Onderhoud en Vernieuwing*).
- **GPO:** Large Projects and Maintenance (*Grote Projecten en Onderhoud*).
- **HVWN:** Primary Waterway Network (*Hoofdvaarwegennet*).
- **HWN:** Primary Highway Network (*Hoofdwegennet*).
- **(Ministry of) I&W:** (Ministry of) Infrastructure and Water Management (*Infrastructuur & Waterstaat*).
- **KES:** Customer requirement specification (*Klanteneisenspecificatie, KES*).
- **LIP:** Large Infrastructure Project.
- **M&M:** Management & Maintenance (*Beheer & Onderhoud*).
- **MIRT:** Multi-Year program for Infrastructure, Spatial Planning, and Transport (*Meerjarenplan Infrastructuur, Ruimte en Transport*).
- **OIS:** Objects in scope (*Objecten in beeld*).
- **PD:** Plan Development (*Planuitwerking*).
- **PPO:** Projects, Programs, and Maintenance (*Projecten, Programma's en Onderhoud*).
- **RA:** Regional analysis (*Regioanalyse*).
- **RE:** (If needed; not present—ignored)
- **ROA:** Design guideline for highways (*Richtlijn Ontwerp Autosnelwegen*).
- **ROK:** Design guideline for civil structures (*Richtlijn Ontwerp Kunstwerken*).
- **RV:** Guideline for waterway design (*Richtlijn Vaarwegen*).
- **R&R:** Renovation & Replacement.
- **RWS:** Rijkswaterstaat.
- **SM:** Scheduling moment (*Agenderingsmoment*).
- **TOE:** Technical, Organizational, and External.

1 Introduction

The introduction of this thesis elaborates on the nature, design, and necessity of this research. The context is provided in Section 1.1, followed by the problem statement Section 1.2. From this statement, the consequent aim of this research has been derived in Section 1.3. The fundaments of the research have been established in the research framework in Section 1.4 and the corresponding research questions in Section 1.5. The practical and academic value are provided in Sections 1.6 and 1.7. This chapter is finalized by an introduction to the company which has provided the topic of this research in Section 1.8, and a reading instruction Section 1.9.

1.1. Context

Globally, the Netherlands stands out for its remarkable success in reshaping landscapes and maximizing land-use efficiency. From building dykes and flood barriers to protect low-lying lands against flooding, reclaiming land from the sea through creating polders, and and for this thesis research most important: building a great number of civil structures to increase the accessibility of the country. Highways, waterways, and railroads, in combination with a multitude of tunnels, overpasses, aqueducts and bridges form an intricate network of infrastructure. It leads to the Netherlands having high-quality, national transportation networks. As of recently, Dutch infrastructure was ranked as the fourth best globally (Schwab, 2018). The total value of this infrastructure has been estimated at € 347 bn. (TNO, 2023).

Renovation & replacement (R&R), known in Dutch as 'Vervanging & Renovatie' (V&R) or as 'de vervangingsopgave' (the renewal challenge), refers to the systematic efforts by Dutch infrastructure managers to renew their assets through either renovation or replacement of structures. These initiatives address the critical need to maintain the functionality, safety, and longevity of existing infrastructure as it reaches its technical end-of-life (EOL). A substantial portion of the Dutch infrastructure has been built in the 1960's and 1970's and is now nearing the end of its technical and/or economical lifespan, urging its managers to start R&R of these assets. Additionally, the infrastructure is being used by heavier and more intense traffic than anticipated at the time of construction (Snijder & Hesselink, 2017; TNO, 2021).

While experience with constructing new infrastructure is abundant, large-scale R&R projects have proven to be complex and risky. Recent news highlight the cost overruns, delays, and failed tendering procedures that occur within R&R projects. A prominent example of the latter, is the abrupt halt of the Van Brienenoord Bridge (in the A16 highway) R&R project tender. For infrastructure, renewal measures such as replacement or renovation are far reaching. These measures have a significant impact on the surrounding area and availability of the (water)way network, typically requiring large investments and preparation with a long lead-in time (TNO, 2021).

In the Netherlands, the main road, waterway, and rail networks are owned by the Dutch State. The National Highway Network (*Hoofdwegennet, HWN*) and the National Primary Waterway Network (*Hoofdvaarwegennet, HVWN*) are operated and maintained by Rijkswaterstaat (RWS), which is the executive agency of the Ministry of Infrastructure and Water Management (*Infrastructuur en Waterstaat, I&W*. The main rail network is operated and maintained by ProRail, which is a private legal entity with a public task. Hence, both of these organizations can be categorized as public infrastructure managers. These two entities are among the largest commissioning parties in the Dutch infrastructure sector, awarding a substantial share of the Dutch infrastructure budget.

The main task of an infrastructure manager is to ensure that their transportation networks (and thus the assets within) operate in line with their own policies and objectives. Timely and safe renovation or replacement of assets is an important link in the maintenance cycle of these networks. To ensure this, the infrastructure manager outsources various tasks to market parties (e.g. contractors and engineering firms). When tendering large-scale interventions, often bundled into an R&R project, it is the responsibility of the infrastructure manager to: i) Tender a contract that includes activities aligned with the organization's policies/objectives, ii) award that contract through a fair, predictable, and transparent procurement process, and iii) ensure sufficient competition to receive a competitive offer.

However, research conducted by Flyvbjerg et al. (2003) shows that in term of costs, transport infrastructure does not always performs as promised, with substantial cost escalations rather being the rule than the exception. In R&R projects additional hurdles are present, complicating processes in a way not encountered before in when constructing new infrastructure. When preparing the renewal of structures, preparatory research must often be performed to determine which materials, structural elements, and construction techniques were used to construct the existing asset, as there often is a lack of clear as-built documentation.

To save costs and contribute to a circular economy, it is often preferred to re-use structural elements of the existing structure, such foundations or steel and concrete girders. This does, however, introduce uncertainty regarding the exact condition of the element. To determine the exact condition of an element, additional inspections or research is required. In some cases, inspection can only be performed by (partially) deconstructing the object. This causes the re-use of structural elements to be a risky part of R&R projects. Moreover, digitization and sustainability developments contribute to an increase in the number of project requirements, adding workload and complexity to projects.

Finally, traditional risk allocation between RWS and contractors has come under pressure. Large-scale R&R interventions are considered to be risky, potentially carrying severe financial consequences to a contractor if risks materialize. The current practices in risk allocation in which contractors assume substantial amounts of risk, are perceived as unfair. This development, in combination with low profits in infrastructure construction and a competing supply of project in the energy transition and residential construction, leads contractors to be more selective in choosing their projects.

1.2. Problem statement

The public infrastructure manager RWS engages in activities to plan, estimate costs in, and tender R&R projects for bridges in the HWN and HVWN during preparation phase of the project. In recent times, R&R projects have proven to be unpredictable and uncertain, highlighting their complex and costly nature compared to the construction of new infrastructure, that is, network expansion projects. The current project delivery framework is not yet fully aligned with R&R projects, resulting in financial setbacks. A financial setback is defined as an unexpected event that negatively impacts the financial situation of the project. This leads to the following problem statement:

Public infrastructure manager RWS faces challenges in effectively preparing and executing projects for the renovation and replacement of bridges in the HWN and HVWN. The existing approach has shown limitations for identifying the full project scope and accurately estimating costs in R&R projects, resulting in financial setbacks, project delays, and heightened risks to the long-term functioning of critical infrastructure.

1.3. Research aim

This thesis explores the key challenges faced by RWS in their approach and decision-making process when executing R&R projects for bridges in the HWN and HVWN. Through the exploration of the complexities that underlie these challenges, a foundation will be created for further analysis of financial setbacks. The complexities causing financial setbacks will be managed through incorporating best practices and mitigation measures in the project delivery framework used in R&R projects, optimizing it for bridge renewal. In summary, the aim of this thesis is:

Identify the key complexities that lead to financial setbacks in R&R projects for bridges in the HWN and HVWN, and define what mechanisms cause project scope changes and inaccuracy in cost estimation, so that the R&R project delivery framework used by RWS can be optimized.

1.4. Research framework

For this thesis, a research framework has been developed consisting of multiple research methods. Collectively, these methods analyze various key elements of the process that RWS uses for infrastructure renewal.

1.4.1. Methods

The mixed methods frameworks offers an integral research approach that will be able to address the main research question with a level of detail that the separate research methods cannot do independently. Each of these methods is further elaborated upon in the sections where the respective research question is discussed. The methods are as follows:

1. Literature study
2. Qualitative analysis (semi-structured interviews)
3. Case study
4. Double Diamond Framework (framework enhancement)

1.4.2. Research flow diagram

A visualization of the research steps in this study is given in Figure 1.1

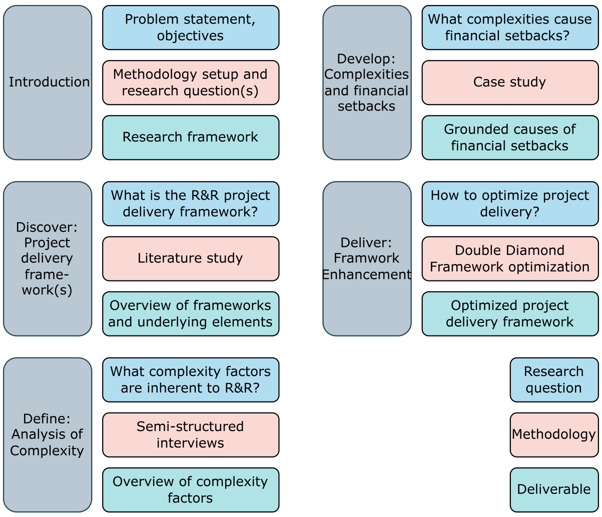

Figure 1.1: Research flow diagram.

1.5. Research questions

The main research question embodies the question which must be answered to achieve the goal of this study. This has been formulated as:

How can RWS enhance the project delivery framework for R&R projects involving bridges within the HWN and HVWN, by specifically targeting the challenges faced in project scope identification and cost estimation?

To answer the main research question, four underlying research questions have been formulated. Each question is addressed through an appropriate research research method, chosen to match the type of information that is to be collected.

Research question 1: What are the prevailing project delivery frameworks used in R&R projects for bridges in the Dutch HWN and HVWN by governmental infrastructure managers and to what extent do they support effective project delivery in terms of project scope definition and cost estimation?

This first question analyzes the prevailing framework(s) utilized by RWS in R&R projects. By conducting a structured breakdown, the various components of the framework incorporated into the framework(s) will be analyzed. The foundation provided through this initial analysis will be utilized to make an assessment of its effectivity in supporting project delivery organization in overall management, project scope definition and cost estimation.

A literature study has been conducted to retrieve information, forming an initial overview of RWS project delivery frameworks. Additionally, in-depth information will be provided by RWS, to fully establish the project delivery framework used in R&R projects. This is necessary as public sources primarily provide outdated and conflicting versions of the various frameworks used in infrastructure renewal.

Research question 2: What challenges do practitioners encounter in R&R projects for bridges in the HWN and HVWN, and how can the complexities and uncertainties from which they result be categorized?

The second research question supports the identification of complexities that are specifically present in R&R projects. To offer a structured approach for this section, a literature study is to be conducted, establishing a framework for identifying and categorizing complexity and uncertainty. This framework will then be employed to provide a structured breakdown of the challenges encountered by practitioners in R&R projects.

These challenges are to be retrieved from semi-structured interviews, held among practitioners involved in infrastructure renewal projects. The interviewees will be recruited by through a convenience sampling approach. Consequently, samples will not be systematically selected but rather emerge pragmatically based on accessibility and availability. This approach reflects the required accessibility and relevance needed for the topic of this study.

Research question 3: Which complexities are primarily responsible for causing financial setbacks, and what mechanisms underlie these effects?

For the third question of this research, a single case study will be conducted. This case study will encompass an in-depth examination of an exemplary R&R project. Based on this case, an overview complexities must be compiled, thereby determining which are most influential in causing financial setbacks. Through this process, the complexities defined earlier in this study are grounded into practice. Each complexity will therefore be supported by evidence from the case project, allowing for a analysis of what mechanism underlie them. The case study is selected as the research instrument for this question, as it is particularly useful to employ when there is a need to obtain an in-depth appreciation of an issue, event or phenomenon of interest, in its natural real-life context (Crowe et al., 2011).

Interviews are one of the most important sources of data for case research and should always be included if the opportunity exists (Ozcan et al., 2017). Therefore, an in-depth interview will be held to support the case study. This interview, among other subsequent interaction with selected members of the PM team of the case project, will provide a continuous source of information.

Research question 4: What measures can be included in the prevailing project delivery framework so that project scope identification and cost estimation is enhanced for R&R projects encompassing bridges?

The final research question addresses the process of designing enhancement measures that can be implemented in the project delivery framework for R&R projects. Through implementation of these measures, the framework must be enhanced to increase the effectivity of management for complexities encountered in projects. The choice for enhancement stems from the fact that a framework has already been developed, which is currently utilized by RWS. As a consequence, it is not desirable to construct new project delivery framework from the ground up.

The Double Diamond Framework (DDF) has been chosen to guide the enhancement process throughout this study. This framework offers an systematic approach to constructing new frameworks, but also to optimize existing ones, as is the case here. The British Design Councils' Double Diamond approach reflects the emphasis on problem definition in the design process. It has been noted that Civil engineering design methods do not yet explicitly include such approaches (Keusters et al., 2021). Therefore, it is an valuable addition to the research framework.

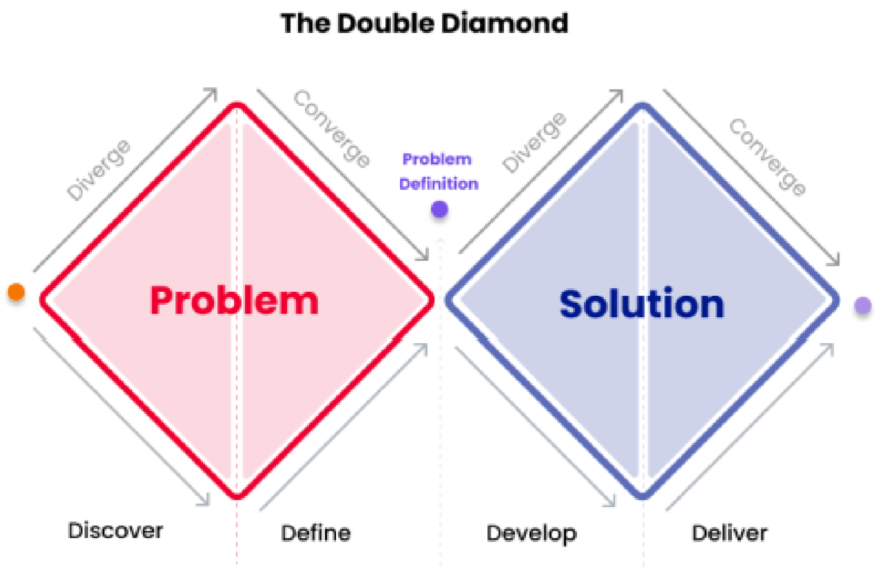

Figure 1.2: Visualization of the Double Diamond Framework. Retrieved from: www.hi-interactive.com

The problem phase is divided into two parts. First, the problem is "discovered," providing insights into the current situation of R&R bridge projects. This phase is embodied by the first research question. Secondly, the project scope is "defined", resulting in an overview of the challenges and complexities faced. This will be achieved through answering the second and third research questions. The solution phase consists of the development and delivery of the optimized framework.

1.6. Practical value

If the challenges and complexities encountered in R&R projects continue to cause financial setbacks, then effective and timely intervention when structures reach their technical EOL will be hindered. Consequently, critical infrastructure may potentially be put under severe restrictions or completely be closed off for traffic. As of now, numerous bridges throughout the Netherlands face postponed intervention, posing significant impact to road and waterway users (Rijkswaterstaat, 2023a).

An increasing number of assets approaches their technical EOL, indicating that a peak in the total number of R&R projects is arriving in the foreseeable future. With RWS's organizational resources already under pressure the backlog of (postponed) R&R projects is growing, under a development of decreasing interest from market parties to engage in large-scale, high-risk projects (Department of Infrastructure and Water Management, 2022). These developments continue to call for an improvement of project delivery for infrastructure renewal projects.

1.7. Academic value

Management-of-Technology is a broad program that covers technical disciplines within a multitude of sectors. This study provides an integral approach to framework enhancement, operating in a technical environment that encompasses various stakeholders, processes, and high-complexity technical disciplines.

The academic value of this study is provided through advancement in various areas related to infrastructure renewal. It will provide insight into the practical reality of R&R projects, for which information is not widely available. Furthermore, the complexity framework will allow for a structured breakdown for the challenges and underlying complexities encountered in the renewal of bridges. The project scope for this study has been set on bridges, but the developed knowledge extends beyond this specific type of structure.

1.8. Introduction of company: Horvat & Partners

This research topic was provided by the Delft-based consultancy firm Horvat & Partners. Horvat & Partners specializes in infrastructure projects, the public commissioning parties of these projects, and their asset management systems. Horvat & Partners supports public clients in the infrastructure sector with audits, evaluations, and advisory services to help them achieve their intended results (Horvat, 2025).

1.9. Thesis outline

This section elaborates on the structure of this research, which is also visualized in Figure 1.3. In this study, Chapters 2 and 3 collect the information required for the first research question. Subsequently, Chapter 4 lays the foundation for the identification of complexities and uncertainty in Chapter 5, required for the second research question. This is followed by the case study in Chapter 6, which identified the primary causes of financial setbacks, which is the objective of the third research question. The mitigation measures designed for the aforementioned complexities, thereby answer the fourth research question, are provided in Chapter 7. The research is finalized by a reflection on the results in the Discussion, and concluded by an answer to the research questions and main question in the Conclusion.

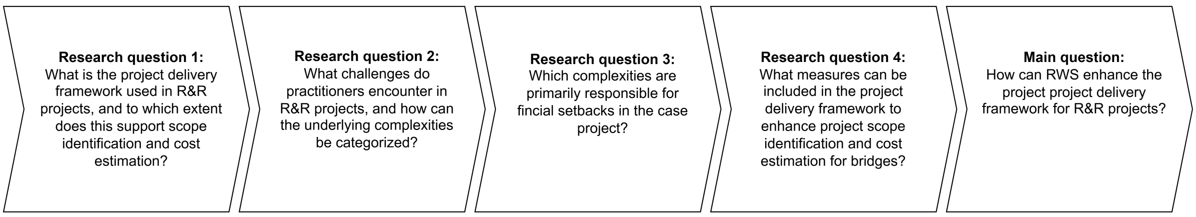

Figure 1.3: Visualization of the thesis outline.

Part I

Discover

2

Theoretical background of infrastructure renewal

Large-scale R&R projects are becoming increasingly prominent in the Dutch infrastructure sector. As it is still a topic of rising interest, information regarding infrastructure renewal in the Netherlands is still limited. To provide insight into the theoretical background of infrastructure renewal in the Netherlands, various key concepts are contextualized. The governmental department governing Dutch infrastructure is discussed in Section 2.1, along with how its executive agency executes the developed infrastructure renewal policy in Section 2.2. Furthermore, the three different main categories of bridges in the RWS asset base are presented in Section 2.5. The expected costs, included in the cost prognosis developed by RWS for the renewal of their entire asset base, is discussed in Section 2.4. The chapter is concluded by a summary and conclusion in Section 2.6.

2.1. Ministry of Infrastructure & Water Management

The Ministry of I&W is the governmental department tasked developing infrastructure-related policy in the Netherlands. It knows a branched-out organizational structure, divided into various specialized units. To organizational structure has been illustrated in Figure 2.1.

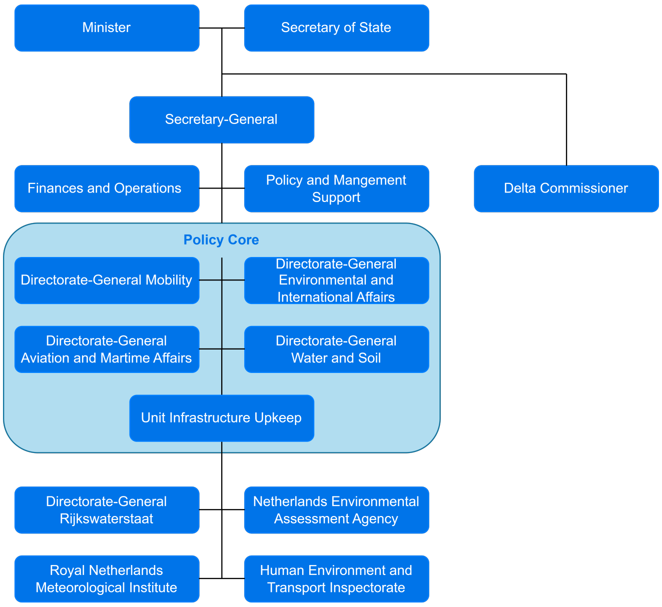

Figure 2.1: Organizational diagram of the Ministry of Infrastructure and Water Management.

2.1.1. The Policy Core

Infrastructure policy is developed by the Policy Core (*Beleidskern*) within the Ministry of I&W. Within the Policy Core, a further distinction can be made between several Policy Directorates-General (*Directoraat-generaal, DG*). A Policy DG is a major division focused on a specific area of policy. It is headed by a Director-General, a senior civil servant who reports directly to the Secretary-General of the Ministry. As of now, the DGs are (Ministry of Infrastructure and Water Management, 2025):

- **DG Mobility:** Develops policy in the areas of roads, traffic safety, public transport and rail, cycling, and sustainable mobility.
- **DG Environment and International Affairs:** Develops policy to ensure a clean, safe, healthy and sustainable living environment. The DG focuses on a circular economy, air quality, environmental safety, and the prevention of environmental risks.
- **DG Water and Soil**: Develops policy in the areas of water management and safety, climate adaptation, water projects in specific regions, and the integrated management of water and soil.
- **DG Aviation and Maritime Affairs:** Develops policy on maritime affairs and aviation.

In 2023, a new division has been added to the Policy Core of the Ministry: the Unit Infrastructure Maintenace (*Unit Instandhouding)*. The unit has been instated to improve alignment between the various policy DGs and RWS, through creating a standardized interface. Moreover, the Unit Infrastructure Maintenace will act as the system owner of the networks managed by Rijkswaterstaat, formulating maintenance and renewal policy and streamlining the processes between de different Policy DGs (Ministry of Infrastructure and Water Management, 2024).

2.1.2. Rijkswaterstaat

In the Netherlands, in total, there are 377 entities that manage public infrastructure. The national infrastructure managers, RWS and ProRail, work alongside 12 provinces, 342 municipalities, and 21 water boards (democratically elected authorities, responsible for water management), to manage approximately 141,000 km of roads, 5,700 km of waterways, 7,000 km of railways, and tens of thousands of structures such as bridges, viaducts, tunnels, locks, weirs, and pumping stations (TNO, 2023). Out of all organizations managing infrastructure, Rijkswaterstaat is the largest, both in terms of budget and number of objects managed.

As previously mentioned, RWS is the executive agency of the Ministry of I&W, meaning it is responsible for executing the policies related to infrastructure and the public area in the Netherlands. It is a large organization, employing approximately 10.000 people. RWS has been tasked with developing a safe, livable, and accessible Netherlands (Rijkswaterstaat, 2025h). These goals are achieved through the management and development of the two networks and and one system that RWS is responsible for:

- **HWN:** Consist primarily of the national highways and other primary roads.
- **HVWN:** Comprises the principal navigable rivers, canals, and other shipping routes under national management.
- **HWS:** Refers to the nationally managed hydraulic infrastructure in the Netherlands, including the Delta Works (system of flood barriers).

Managing these networks simultaneously amounts to an immense and complex undertaking, especially under various threats of current times: aging infrastructure, climate change, extreme weather, rising sea levels, and global tensions. Additionally, efforts are being made to comply with social expectations such as sustainability, circularity, and development of nature. The scale and complexity of the networks involved, combined with their national importance, makes the tasks of RWS both critical and highly demanding. Their role is not only to manage assets, but also to safeguard the resilience and future-readiness of the Netherlands' vital infrastructure systems.

Since achieving these goals requires specialized efforts in various geographically dispersed areas throughout the Netherlands, RWS has been divided number of divisions. The regional divisions, often referred to as 'regions' (*regio's)*, are responsible for the management and maintenance of infrastructure within specific territories. These territories consist of roughly one to two Dutch provinces. For example, North Netherlands consists of the provinces of Groningen and Friesland, while West-Netherlands-South encompasses roughly the province of South-Holland. In infrastructure renewal, regional divisions identify the structures in need of intervention, and execute the preparatory phases of R&R projects. The role and responsibility of these regions in the project is therefore referred to as ”internal commissioner.”

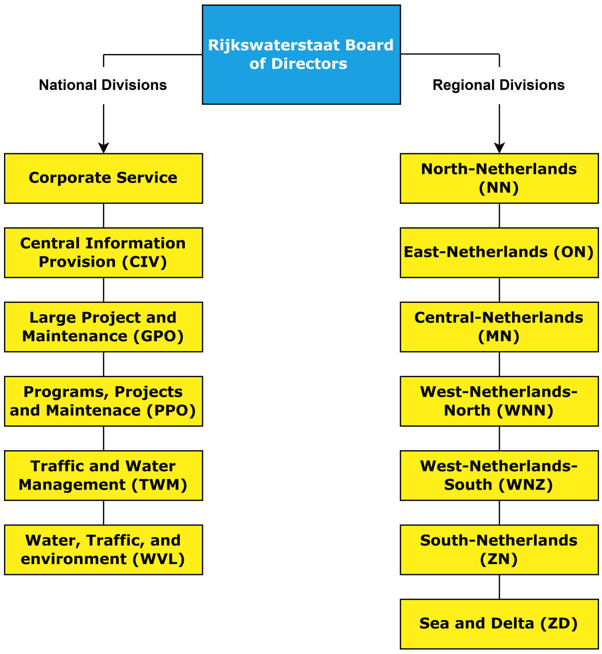

Figure 2.2: Organizational diagram of Rijkswaterstaat (Rijkswaterstaat, 2025h).

Besides the regional divisions, RWS also encompasses several national divisions. National divisions are not bound to a specific geographic area, but rather a predetermined set of tasks, thus fulfilling a specific functionality within the organization. After finalization of the preparatory phases, R&R projects are handed over from a regional division to a national division, which then acts as the ”internal contractor.” The national divisions most prominent in infrastructure renewal are:

- **Large Projects and Maintenace (*Grote Projecten en Onderhoud, GPO*):** The GPO division responsible for the realization of large and complex infrastructure projects, as well as the management and maintenance of existing networks and assets at the national level.
- **Programs, Projects, and Maintenance (*Projecten, Programma's en Onderhoud, PPO*):** The PPO division manages and executes regional programs and projects, focusing on the daily operation, maintenance, and renewal of infrastructure within the different RWS regions.

2.2. Infrastructure renewal at RWS

Today's modern transportation infrastructure relies, to a large extent, on structures that were built during the 20th century. However, a continuously growing number of structures is expected to reach the end of their service life in the coming decades. Therefore, it is inevitable that some bridges will fail to comply with the safety requirements in the present regulations and should, formally, be strengthened or replaced (Nyman et al., 2023).

Traditionally, the primary focus of RWS was to construct new infrastructure, expanding and increasing the capacity of the transportation networks. In recent times, organizational focus has been shifting away from this network improvement, as the increasing age of RWS's asset base means that efforts must now be concentrated on maintaining existing infrastructure.

2.2.1. Defining R&R

When an asset has reached the end of its service life, and its functionality cannot be maintained through regular maintenance anymore, then large-scale intervention is needed. Within infrastructure renewal, there exist two main pathways for intervention:

- **Renovation:** major overhaul of the asset which often sees the replacement of several critical parts, while maintaining the majority of existing structural elements. For steel bridges, renovation can also include local strengthening, through adding a reinforcing substructure (Snijder & Hesselink, 2017).
- **Replacement:** A new structure is built, typically in close proximity to the existing structure. The existing structure is demolished after the replacement structure is finalized.

The main objective of an R&R project is to restore the functionality of a structure. However, in some cases, this functionality may also be increased through the intervention, or similarly be decreased if deemed necessary. An example of the latter is provided by bridges that were initially movable, modified in the intervention to become fixed (Rijkswaterstaat, 2024c).

2.2.2. Intervention after reaching end-of-life

RWS is forced to undertake intervention when assets reach their EOL. Within EOL, van der Vlist et al. (2016) distinguishes between technical and functional EOL, while acknowledging that these relate closely. The author provides that functional EOL is reached when the functionality requirements of the asset change, for example when it must handle a traffic intensity not anticipated at the time of construction, leading to excessive wear. The functionality required in terms of capacity is larger than the object can handle, thus indicating its functional EOL (van der Vlist et al., 2016). In the Netherlands, most bridges reach their EOL functional before other reasons (Mooren et al., 2023).

Technical EOL is based on the performance level set at the time of construction. When serious technical deficiencies occur, the performance of a bridge and its components can reach a minimum acceptable level and therefore their technical EOL according to Hartmann and Bakker (2023). Additionally, the authors state that outdated technologies or the unavailability of spare parts are ground for declaring technical EOL. Assets that are close to or have reached their technical EOL, often face strict inspection regimes, emergency repairs, and have a high vulnerability to collapse. Inspections, calculations, and degradation models form the base assessment method for declaring technical EO of an asset.

Besides reaching EOL due to functional or technical reasons, economical EOL offers a different perspective. Despite being still operable, and thus not having reached technical EOL, the cost of keeping the asset in operation outweighs the benefits. At a certain point in time, it might no longer financially viable to keep the bridge or its components operational, meaning that replacing them becomes an economically attractive alternative (Mooren et al., 2023). At this point, the asset has reached economic EOL. A life-cycle cost analysis forms the primary instrument for declaring this type of EOL. As a consequence, substantial amounts of data are required for accurate determination.

Although these rules are explicitly defined and categorized as the technical, functional, and economic EOL in official documents at RWS, the rules are found to be high-level, human-interpreted, overlapping, and fragmented across various forms of documentation (Bektas & Ozer, 2023). Information specifications per rule are not always well defined and interrelations of shared issues are not yet formally established. This reality forces RWS experts to focus solely on technical aging, excluding the other rules while assessing the EOL of an object (Bektas & Ozer, 2023).

The narrow focus potentially leads to missed opportunities to optimize infrastructure, as the EOL is a logical moment to change functionality of an asset, as doing this earlier or later poses a large risk for capital destruction (van der Vlist et al., 2016). This again emphasizes the importance of accurately determining EOL. However, data management challenges hinder effective assessment. De Raat (2023) states that objects are lacking data, such as a year of construction, spatial dimensions, or a cost model. Even if data is present, it poses a different set of challenges. Bektas and Ozer (2023) noticed large amounts of data is collected by RWS and the regional asset managers. A challenge embedded in these vast amounts is that it might prove conflicting or knows a complex structure, meaning it takes cumbersome efforts from experts in order to obtain relevant datasets. As a consequence the aforementioned point, the EOL of an asset is often declared based on a combinations of factors, including technical condition, changes in use, and shifting requirements and regulations (Klanker & Uijtewaal, 2017).

2.2.3. R&R and other domains

A demarcated terminology is used to describe different sets of activities that are related to the management of infrastructure. According to Tillema and Lange (2016) these are:

- **Management & Maintenance (M&M):** Measures planned at the time of the infrastructure being commissioned to ensure that asset performs its intended function throughout the expected service life. M&M encompasses a large number of regular, relatively small-scale activities.
- **Renovation & Replacement (R&R):** R&R takes place for infrastructure assets where safety and/or functionality can no longer be assured through regular M&M due to the assets reaching the end of their service life. These involve relatively infrequent interventions and significant investments.
- **Network expansion:** While R&R focuses on maintaining the safety or functionality of the existing network, network expansion adds new or additional functionality (network expansion), through the construction of new civil structures.

2.2.4. The growing need for R&R projects

While the construction of new infrastructure continues, the task of renewing the existing infrastructure is demanding increased attention from policy makers and infrastructure managers. According to Rijkswaterstaat (2024c), the Minister of Infrastructure and Water Management announced a shift in financial resource allocation in March 2023: from new construction to asset maintenance, particularly for bridges, viaducts, waterways, and roads. Concerns over bridges stem from the fact that many bridges are close to or have already reached their expected technical EOL, as is shown in Figure 2.3.

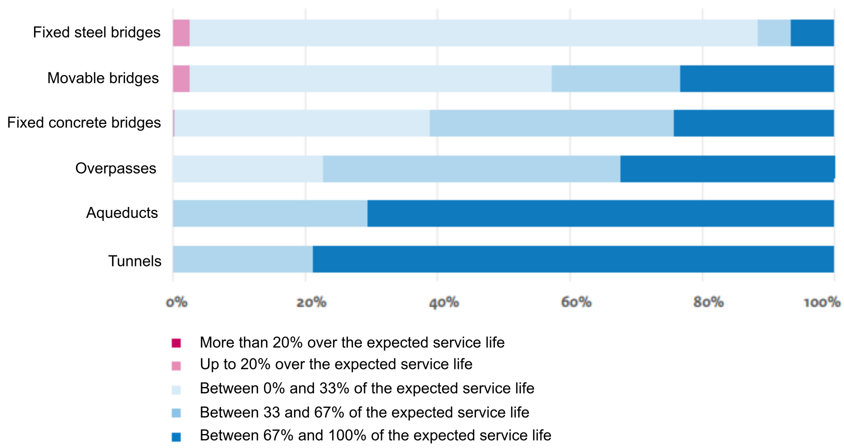

Figure 2.3: Expected remaining or exceeded service life of various asset types, retrieved from Rijkswaterstaat (2024c)

The aggregation of structures reaching their technical EOL, presents an immense workload to RWS. The workload has been allowed to grow in recent years, as the organization's production capacity, which is RWS's capacity to develop and execute projects, does not match the rate at which structures are reaching their technical EOL. This is supported by Figure 2.4, which show a clear discrepancy between the budgets allocated for infrastructure renewal, and which portion of that budget has actually been utilized to realize renew structures. This continuous under-utilization (*onderuitputting*) poses a structural problem to RWS.

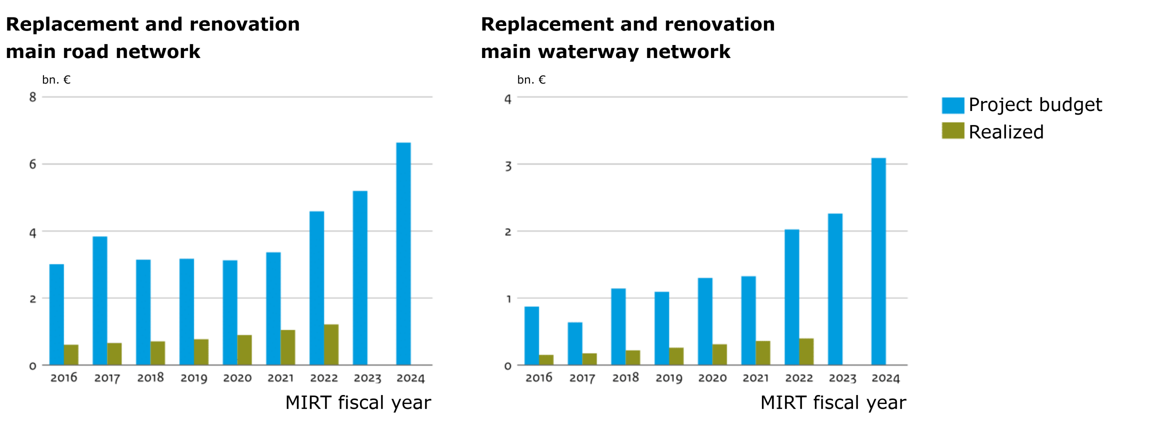

Figure 2.4: Available and realized project budget of R&R projects in MIRT. (Note: the figure shows funds for infrastructure renewal originating from MIRT budgets, which is no longer the case as they are now financed separately). Retrieved from: www.clo.nl

2.3. Examples of recent R&R projects

In recent years, a number of R&R projects has been carried out by RWS. These projects display various challenges and opportunities typical to this type of project. To illustrate some examples of effective practices, and the potential challenges and setbacks encountered in R&R projects, four examples of R&R projects have been provided.

2.3.1. Effective practices

A prime example of a (preparatory) R&R project that utilized an effective approach, is the intervention at the Suurhoff Bridge (*Suurhoffbrug*). Due to an increase in truck traffic in the port area of Rotterdam, the bridge was subjected to high loads and traffic intensities. Therefore, RWS chose to install a temporary bridge next to the existing structure, so that traffic can be divided to reduce the excessive degradation of the original bridge. This temporary situation, with two bridges besides each other, will remain unchanged until the definitive intervention after 2030, in which the complex as a whole will be replaced by a single new structure (Rijkswaterstaat, 2024a). The approach consisted of installing a temporary bridge which was prefabricated at a different location, allowing for an intervention with minimal traffic disruption. Moreover, the design of the temporary bridge allows for it to be moved and reused in future R&R projects (NSP, 2024).

Figure 2.5: The original Suurhoff Bridge (blue) and the temporary bridge (white), installed to reduce traffic on the original structure. Retrieved from: www.hollandia.biz

Another R&R project that showcases a well-performed bridge replacement can also be found in the port area of Rotterdam, at the Botlek Bridge (*Botlekbrug*). At this location, a replacement bridge has been built parallel to the existing bridge. This approached allowed for continued road and railway traffic during construction, with only significant disruption experienced by large vessels unable to pass without opening the bridge (Rijkswaterstaat, 2025a). Parts for the replacement structure were produced in Germany and transported to the Netherlands, were they were welded together. The assembled bridge sections were then transported per ship, which allowed for a float-in installation on-site (Ballast Nedam, 2025).

Figure 2.6: The old Botlek Bridge (blue) and the replacement bridge (white). Retrieved from: www.brielsnieuwsland.nl

2.3.2. Challenges and setbacks

A prominent example of the challenging nature of large-scale R&R projects can be found at the Van Brienenoord Bridge (*Van Brienenoordbrug*), the busiest bridge in the HWN with over 250.000 vehicles passing daily. RWS estimated that the intervention scheduled for this bridge, which encompassed the replacement of the east arch (1965) and the renovation of the younger western arch (1990), could be achieved for approximately € 700 mln. The project had already been postponed multiple times and during its tender in 2022, it emerged that there was only a single interested party willing to execute the project for a substantially higher price (Ponton Bouwconsultantcy & Horvat & Partners, 2024). After these developments, the project costs were adjusted to approximately € 1.5 to 2 bn., resulting in a major financial setback (Rijkswaterstaat, 2025d).

Figure 2.7: The east (left) and west (right) arches of the Van Brienenoord Bridge. Retrieved from: www.capelle.ijsselenlekstreek.nl

Another bridge renewal project which has faced difficulties, is the Haringvliet Bridge (*Haringvlietbrug*). In 2023, the bridge deck, technical installations, and drives of the movable section were replaced, which was followed by a series of technical malfunctions. The resulting traffic disruption was significant, necessitating commuters to take long detour routes or in some cases wait for several hours. These problems sparked outrage among regional stakeholders (Rijkswaterstaat, 2023c). As of 2025, RWS announced that another closure (6 to 12 months) will be in order after 2030. In this period, the fixed steel bridge sections will be replaced, as they are subject to fatigue damage (Rijkswaterstaat, 2025g). This will again seriously affect the accessibility of the region, fueling the perception of continuous and severe traffic disruption.

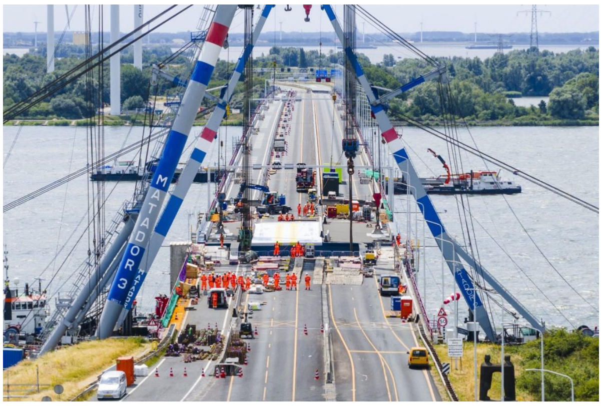

Figure 2.8: Hoisting of the replacement bridge deck of the Haringvliet Bridge. Retrieved from: www.infrasite.nl

2.4. Infrastructure renewal cost prognosis

For the entire R&R project-program, i.e., the infrastructure renewal challenge at hand, several versions of the projected costs have been produced. The most recent version of the budget projected to be required for the R&R program have been provided by the Multi-Year Plan Infrastructure Maintenance (Ministry of Infrastructure and Water Management, 2025). The previous insight was offered by the Prognosis Report R&R (Rijkswaterstaat, 2022). The different projections, their substantiation, and a comparative analysis are discussed in this section.

2.4.1. Prognosis report

To validate the budgetary needs of the transportation networks RWS manages, the R&R Prognosis Report was published (Rijkswaterstaat, 2022). The research conducted within this document set out to determine the magnitude of the approaching renewal workload. The main function of the report is to provide a cost estimate, establishing how much funds must be allocated to maintain infrastructure in the RWS asset base. The cost prognosis presented is a rough-order-estimate, as it is not feasible to conduct an in-depth analysis of the tens of thousands structures under RWS management. The methodology utilized is described as (Rijkswaterstaat, 2022):

> The replacement costs per asset were calculated using cost models applied for construction estimates. The underlying assumption is '1-to-1 replacement,' (*1-op-1 vervanging*) i.e., substitution with a new asset providing the same functionality. [In other words, functionality will not be upgraded, for example by expanding traffic capacity such as through adding additional driving lanes]. For most assets, replacement values were linked to general parameters such as the surface area of a bridge or viaduct [combined with material unit prices]. For assets with complex installations, more detailed cost models were used to determine replacement values individually. For these assets, additional R&R measures were defined for partial replacements (i.e., minor and major renovations). The cost estimates for these measures were derived from the construction cost estimates by identifying the relevant components in these estimates, from which percentage factors for the type of R&R intervention were established.

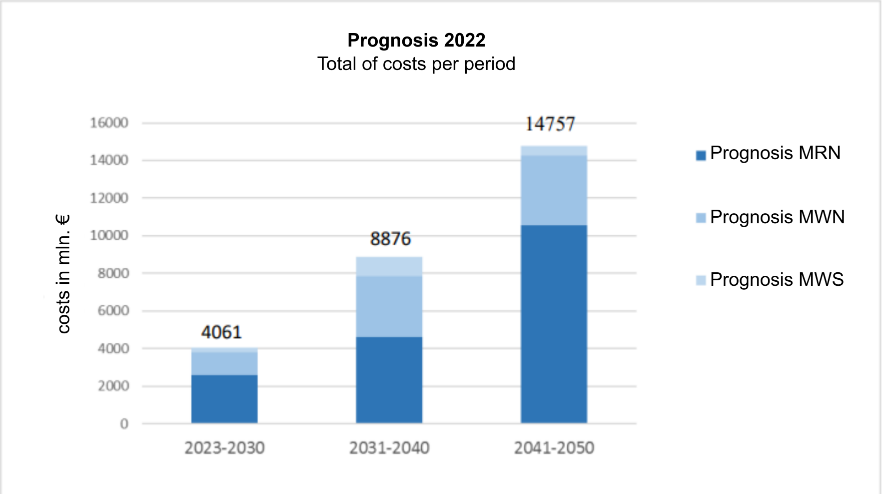

Figure 2.9: Prognosis of cost for renewal per transportation network (Rijkswaterstaat, 2022).

In this report, unlike in the succeeding Multi-Year Plan Infrastructure Maintenance (Ministry of Infrastructure and Water Management, 2025), an insight is provided into budgets that RWS estimates to be required for the renewal per specific bridge type. This has been structured for both of the transportation networks that encompass bridges, the HWN (Table 2.1) and the HVWN (Table 2.2).

HWN:	**2023-2030**	**2031-2040**	**2041-2050**	**Total of bridge type**
Fixed steel bridges	€ 374.8	€ 510.5	€ 210.5	€ 1095.8
Concrete bridges & viaducts	€ 564.8	€ 1381.1	€ 3206.5	€ 5152.4
Movable bridges	€ 115.0	€ 536.8	€ 3140.6	€ 3792.4
Total of period	€ 1054.6	€ 2428.4	€ 6557.6	€ 10,040.6

Table 2.1: Estimated renewal costs (mln. €) for bridges in the HWN (Rijkswaterstaat, 2022).

HVWN:	**2023-2030**	**2031-2040**	**2041-2050**	**Total of bridge type**
Fixed steel bridges	€ 374.3	€ 385.9	€ 0.0	€ 760.2
Concrete bridges	€ 151.5	€ 224.6	€ 164.4	€ 540.5
Movable bridges	€ 231.8	€ 1160.0	€ 1052.8	€ 2444.6
Total of period	€ 757.6	€ 1770.5	€ 1217.2	€ 3745.3

Table 2.2: Estimated renewal costs (mln. €) for bridges in the HVWN (Rijkswaterstaat, 2022).

2.4.2. Multi-year plan infrastructure Maintenance

Recently, the Multi-Year Plan for Infrastructure Maintenance (Ministry of Infrastructure and Water Management, 2025) was published, presenting information on renewal budgets and the governance of R&R projects. The plan provides crucial insights into the funds estimated to be required to keep Dutch infrastructure under the management of RWS's management. The costs presented include those associated with Exploitation, Maintenance, and Renewal (*Exploitatie, Onderhoud en Vernieuwing, EOV*). It is important to note that these figures do not solely represent renewal costs, but also include expenditures related to exploitation and (regular) maintenance. The underlying calculations have been validated by

Netherlands Court of Audit (*Algemene Rekenkamer)*. Based on these estimates, it can be concluded that the Ministry of I&W will be confronted with major budgetary deficits in the coming decades.

Network:	**Total**	**HWN**	**HVWN**	**HWS**
Total budget requirement 2024-2038	€ 75.3	€ 11.1	€ 43.3	€ 20.9
Available budget 2024-2038	€ 40.9	€ 7.8	€ 22.8	€ 10.3
Cost differential	€ 34.5	€ 3.4	€ 20.5	€ 10.6

Table 2.3: Estimated EOV costs (€ bln.) for the RWS asset base (Ministry of Infrastructure and Water Management, 2025).

2.5. Bridge types

RWS oversees the management of a large number of bridges and viaducts, either incorporated in the HWN or HVWN. The number of specific types of bridges included in both of these networks can be found in Table 2.4.

Network:	**HWN**	**HWVN**	**Total**
Fixed steel	34	88	122
Concrete bridge	704	150	854
Viaduct (concrete)	2937	0	2937
Movable	54	113	167

Table 2.4: Number of bridges in the RWS asset base in 2022 (Ministry of Infrastructure and Water Management, 2022).

2.5.1. Fixed steel bridges

Fixed steel bridges are designed to carry high loads over long spans, primarily because steel offers an excellent strength to weight ratio which allows for the construction of long and slender structures. The main causes of structural performance degradation and collapse in steel bridges are fatigue, corrosion, and bolt loosening (Cui et al., 2024).

During their long-time service, steel bridges are subjected to a dual degradation mechanism, wherein corrosion and fatigue damage interact to compromise structural integrity. Corrosion induces the thinning of the steel cross-section, thereby reducing its load bearing capacity while fatigue damage manifests through the progressive propagation of micro-cracks under cyclic loading, ultimately leading to structural failure (Huang et al., 2025).

Additionally, modern bridges are designed differently than shortly after the Second World War, when traffic loads were moderate and traffic intensity were lower than nowadays. As a consequence, they were designed for static and fatigue loading less severe than has been present during their lifetime, in some cases leading to (fatigue) damage (Snijder & Hesselink, 2017).

Figure 2.10: The Bridge over the Lek. Retrieved from: www.schuttevaer.nl

2.5.2. Concrete bridges and viaducts

Reinforced concrete bridges are vital components of modern transportation networks, essential for ensuring safe and uninterrupted traffic flow. However, their long-term integrity is compromised by a range of deterioration processes that can lead to significant structural and functional failures (Ganiev & Muradov, 2025). Under the demarcation of RWS, concrete bridges and viaducts are incorporated into an overarching category. Concrete bridges and viaducts are the most common structure in the RWS asset base, therefore also requiring the largest budget for their renewal.

The HWN includes more than 3,500 concrete bridges and viaducts. In the last decades, the average age of the structures has increased (lack of renewal) and at the same time the use has intensified. Moreover, in the coming years, fewer structures will be built and the existing structures will be used longer (Nicolai et al., 2017). As a consequence, adequate maintenance and timely large-scale intervention at the EOL becomes increasingly important for these structures, that often encompass critical reinforced and prestressed concrete elements.

Concrete elements may suffer damage due to corrosion of steel reinforcement, which may occur if the passive oxide layer protecting it is compromised through mechanisms such as carbonization or corrosion, with the latter being less predictable and usually proceeding faster (National Road Authority (Ireland), 2014). Other common mechanisms that cause deterioration of concrete structures include freeze-thaw cycles, chemical attack, foundations scour, fatigue and overloading, and progressive collapse (Ganiev & Muradov, 2025).

Figure 2.11: A concrete bridge during an inspection. Retrieved from: www.wagemaker.nl

2.5.3. Movable bridges

Movable bridges are designed and constructed to change its position to permit the passage of vessels and boats in the waterway. A variety of design types exist within movable bridges: i) Bascule bridges, ii) swing bridges, iii) vertical lifting bridges, iv) and other specialized types of movable bridges (Metwally, 2015). Movable bridges typically consist of a movable bridge deck, along with other sections that are fixed. The different sections may be constructed using varying materials, with concrete often used in fixed sections and steel as the primary material for the movable section. The use of different construction materials within the structure leads to it being classified as a composite bridge (Al-Darzi & Chen, 2006).

In addition to the deterioration mechanisms that affect steel and concrete as mentioned in the previous sections which will also affect these materials in movable bridges, there are others to consider. Movable bridges are unique structures, from the perspective that they represent the integration of conventional structural components with mechanical systems, electrical power, and control systems (Catbas et al., 2013). These installation are also subject to deterioration. For example, stress cycles occurring in the bridge opening mechanism during opening/closure operations, can lead to (fatigue) damage in parts such as gears or axles (Maljaars & Steenbergen, 2012).

In recent years, the total number of movable bridges in the Netherlands has decreased. This development is a result of decisions to permanently close some bridges due to safety risks, or because they have been replaced by fixed bridges with increased clearance (Ministerie van Infrastructuur en Waterstaat, 2023).

Figure 2.12: The Eiland Bridge. Retrieved from: www.heeswijk.nl

2.6. Chapter summary and conclusion

R&R projects are becoming increasingly prominent in the infrastructure sector. As a growing number of bridges are expected to reach their EOL in the next decades, a peak in workload is expected for RWS. Keeping the Dutch infrastructure operational therefore prove challenging. Additionally, the Netherlands Court of Audit estimates that, without the allocation of additional funds to infrastructure, only approximately half of the funds required to maintain infrastructure is currently available.

To conclude this chapter, it can be stated that RWS faces an extensive and urgent R&R task. The increasing renewal demand, combined with budgetary deficits, and governance complexities, emphasize the necessity for a structured, fit-for-purpose methodology for the delivery of R&R projects. The findings of this chapter therefore establish the relevance of this research, and contribute to knowledge regarding project delivery in bridge renewal.

3

Project delivery frameworks at Rijkswaterstaat

Project delivery consists of various activities that take place for preparing, developing, and executing infrastructure projects. It consists of key operations such as scheduling activities to form a planning, estimating costs of project elements, developing designs, managing risks, and many more. The Ministry of I&W and its executive agency RWS have developed project delivery frameworks, which assemble these various activities into a linked process. This chapter starts with the MIRT framework in Section 3.1, which is the main methodology used in infrastructure construction (network expansion projects). Consequently, the R&R Approach, used for project delivery in infrastructure renewal, is discussed in Section 3.2. For this framework, an examination has taken place regarding practical applicability in Section 3.3. The chapter is concluded with a summary of its contents, followed by the chapter conclusion in Section 3.4.

3.1. The MIRT framework

Infrastructure construction requires significant budgets, long-term planning, engineering, and construction efforts for realization. In the Netherlands, infrastructure projects for the HWN and HVWN are commissioned by the Ministry of I&W. RWS, in its role as executive agency, is tasked with executing projects in accordance with infrastructure policy set by the Ministry. This implies that RWS is responsible for the preparation and development of infrastructure projects through various activities, so that the project can be put out to the market for realization by a contractor or consortium.

3.1.1. The origins of MIRT

To improve the project performance of construction projects for infrastructure, commissioning parties have developed a sophisticated project delivery framework: the Multi-Year Program for Infrastructure, Spatial Planning, and Transport (*Meerjarenprogramma Infrastructuur, Ruimte en Transport, MIRT*).

3.1.2. The process

The MIRT framework consists of four distinct phases, each encompassing a set of underlying activities, and always concluded by a decision point (formal go/no-go moment) (Department of Infrastructure & Water Management, 2022). The MIRT guidelines prescribe the information that must, at a minimum, be mapped out for each phase of the MIRT process through various planning, engineering, and researching activities (Department of Infrastructure & Water Management, 2022). An important guiding principle in MIRT is the bandwidth on the cost estimate. The bandwidth on the total costs estimated reflect the uncertainty margin, i.e., the expected range of actual costs. This margin must be reduced in the subsequent MIRT phases, as a result of scope identification and risk management.

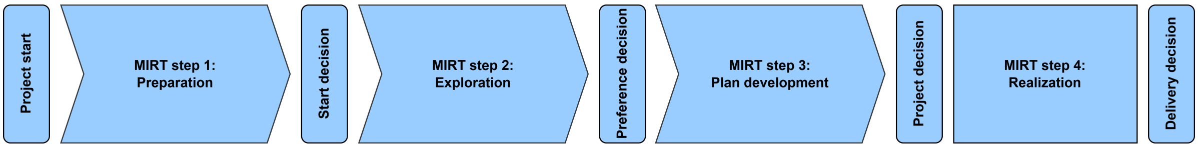

Figure 3.1: The MIRT project delivery framework (Ministery of Infrastructure and Water Management, 2011).

- **MIRT preparation:** The preparation phase focuses on identifying public tasks. It encourages the national government en regional stakeholders to cooperate through researching and concretizing these tasks. The resulting information is compiled into a document known as the "start document."
- ***Start decision:*** Based on the start document, the competent authority will decide if the project gets a green light for further development. At this stage, an initial, high-level indication of the required budget is developed.
- **MIRT exploration:** The exploration phase focuses on developing a sustainable "preferred decision." This is achieved by conducting a comprehensive problem analysis, and establishing a broad inventory of potential solutions.
- ***Preference decision:*** Upon completion of the exploration phase, an explicit assessment is made whether or not the project should continue into the "Plan Development" (PD) phase. The preference decision can either be positive (go) or negative (no go). To receive a go, at least one of the design alternatives must meet the established prerequisites. The uncertainty margin of the cost estimate is limited to a maximum of 25% at the preference decision (Ministery of Infrastructure and Water Management, 2011).
- **MIRT plan development:** The PD phase encompasses activities such as the identification of project scope, establishing the implementation timeline, determining the financing method, and outlining the market approach (tendering procedure).
- ***Project decision:*** This decision point reviews the results of the PD phase, after which the competent authority decides if the project may proceed for realization. At this stage, a decision to discontinue the project is still possible. As the design becomes more detailed, the cost estimate is refined to ensure a uncertainty margin between 10-15%.
- **MIRT realization:** During the realization phase, the design plans are executed in alignment with the prerequisites agreed upon during the PD phase.
- ***Delivery decision:*** The "delivery decision" is made by the Director-General of RWS, who carries final responsibility for the agency's projects. This decision formally grant discharge to the project members involved, thereby releasing them form further responsibility. The responsibility for the asset is subsequently transferred to a designated entity, who ensures its management throughout the operational lifetime. In line with this process, an overview of the actual costs incurred is produced.

3.2. The R&R Approach

The R&R Approach (*V&R Aanpak*) is the project delivery framework used in R&R projects. In recent years, RWS has dedicated significant efforts into the development of this framework. This section discusses the origins and the various underlying process steps of the framework.

3.2.1. Initial version

Since 2000, the large-scale renewal of Dutch infrastructure has grown in prominence within the infrastructure sector. As a consequence, RWS developed a project delivery framework tailored to the specific needs of R&R projects. This framework is derived from MIRT, offering a familiar but streamlined process to prepare, develop, and execute R&R projects. A detailed description of the initial version of the R&R Approach can be found in Appendix B.

3.2.2. Overall process

The current process embodied by the R&R Approach, and now applied in renewal projects, as shown in Figure 3.2. It illustrates the different phases of an object's renewal and the corresponding R&R project, as it progresses over time.

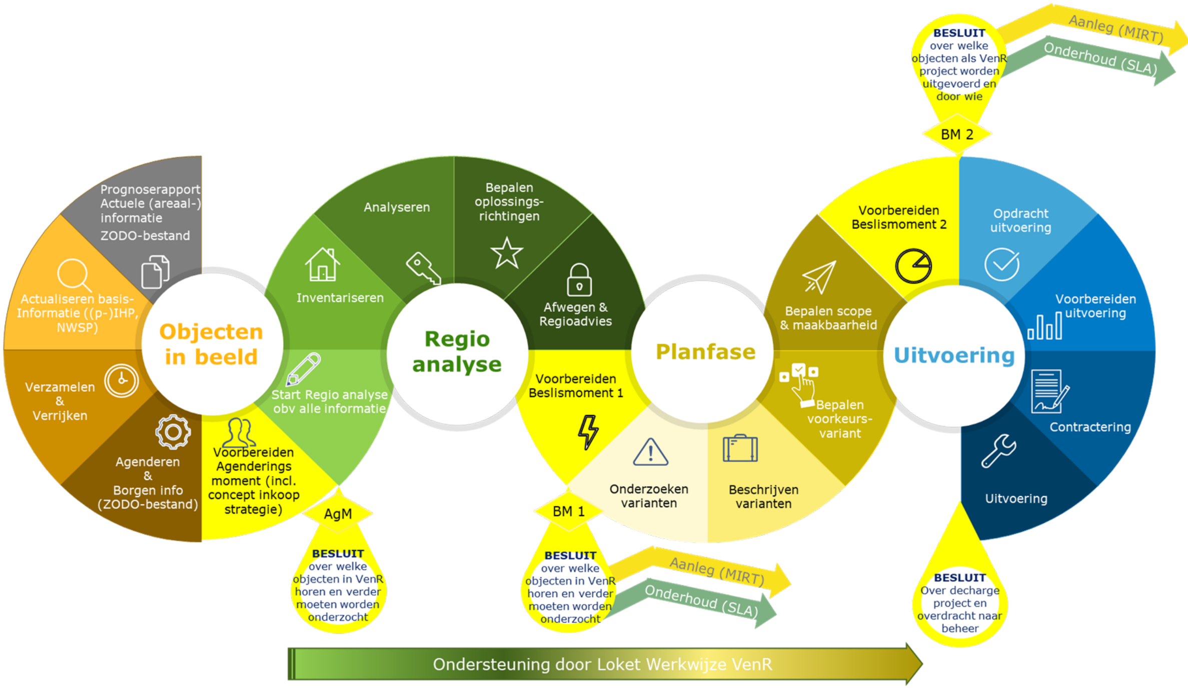

Figure 3.2: The renewal process at RWS (*Dutch*). (Rijkswaterstaat, internal document, 2023)

This overall perception of the process has been consolidated in the R&R Process Chain, as displayed in Figure 3.3. This tool essentially represents the current R&R Approach. Each step or block in the process results in one or more products, thereby establishing a foundation for the next step or decision point. For each block, its respective information sources, guiding principles, communication schemes, and other supporting tools are provided.

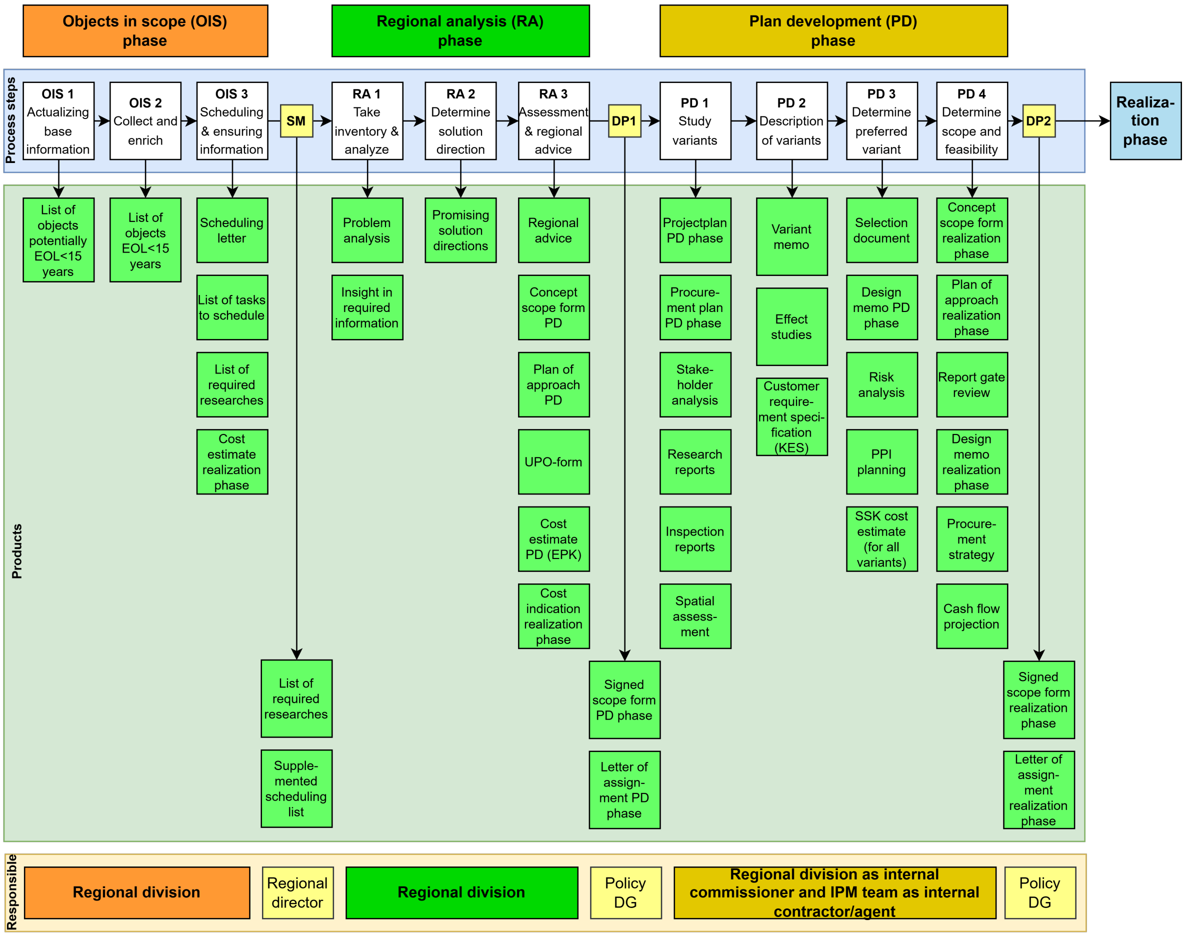

Figure 3.3: The R&R Approach (Rijkswaterstaat, internal document, 2023).

The R&R Approach consist of three distinct preparatory phases, after which the project will be realized. This realization phase is not included within the R&R Approach, as the execution of projects is carried out under the MIRT framework. The three phases within the R&R Approach are discussed in the sections below.

3.2.3. Objects in scope phase

The Objects In Scope (OIS) phase is to update and refine the understanding of the R&R task at hand, in order to establish the budget, project-programming, and schedule.

- **OIS 1: Actualizing base information:** The first step in the process chain is to actualize the base information. The actual condition of the asset forms a fundamental starting point in every R&R project, as it determines whether intervention is necessary and within which time frame it should be executed. This step results in an overview of objects that are potentially within 15 years of their technical EOL.
- **OIS 2: Collect & enrich:** In the subsequent step, the initial overview of objects potentially within 15 years of their technical EOL are further examined to validate which objects actually fall under this threshold, thereby establishing a definitive overview. It provides guidance on what further researches and inspections may be necessary.
- **OIS 3: Scheduling & guaranteeing information:** The main purpose of this step is to announce and schedule the subsequent "regional analysis" for the objects that will reach their technical EOL within 15 years. Moreover, a list must be provided of the additional researches that must be conducted, and a preliminary indication of the project cost must be established. The uncertainty margin of the cost estimate at this stage is approximately 50%.

- **SM:** In the first decision point, the Scheduling Moment (SM), three key actors collectively decide the time period in which the project will be scheduled. These actors include the regional division (based on the geographic location of the asset), the national programmer (strategic coordinator of large-scale, nationwide initiatives), and the Ministry of I&W.

3.2.4. Regional analysis phase

The Regional Analysis (RA) phase involves determining and providing a substantiated assessment of feasible solution directions. This forms the foundation of the "regional advice."

- **RA 1:** The first step provides a description of the task: Necessity, background, function of the object within the network, urgency of intervention, and the regional context. Furthermore, the starting points provided by policymakers (Ministry of I&W), and the laws and regulations are established. An overview is provided, indicating which information must be collected for the Regional Analysis and Decision Point 1.
- **RA 2:** The potential solution directions and boundary conditions are established. These are presented within the context of cost, performance, and risk, in order to gain insight into which options may prove promising for solving the problem. The possible alternatives are:
  - No intervention (M&M).
  - Life-extending measures (M&M).
  - Renovation (R&R).
  - 1-to-1 replacement with identical functionality (R&R).
  - 1-to-1 replacement with a limited functionality upgrade (R&R).
  - Complex replacement or a new, different type of structure (MIRT).

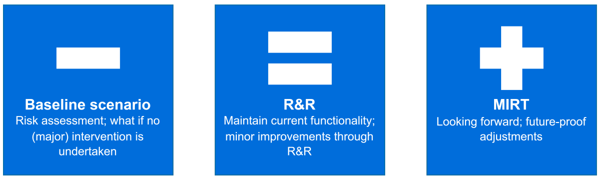

Figure 3.4: Possible solution directions for intervention (Rijkswaterstaat, internal document, 2023)

- **RA 3:** The number of solution directions is reduced, consolidating them into regional advice regarding the necessity of the intervention and the chosen methodology.
- **DP1:** Decision Point 1 (DP1) establishes the project assignment, starting points, program risks, and agreements made on budgets and schedule as discussed with the policymakers from the Ministry of I&W. The project scope of the subsequent phase for (potential design variants), the available budget, and de milestones are defined.

3.2.5. Plan development phase

The PD phase aims to develop and substantively assess the design variants of the object(s), thereby consolidating them into a preferred variant for the next decision point.

- **PD1:** Research is conducted to obtain a complete overview of the challenge at hand and the possible solution directions identified in the RA phase, ensuring an comprehensive information profile is available to further developed the design variants.
- **PD2:** The information gathered and the results of the research are used to refine the design variants to a level at which they address the majority of requirements and wishes identified earlier. One or more potentially promising design variants are further elaborated upon in the variant memo.
- **PD3:** The "preferred design alternative" is discussed to establish support from all stakeholders.
- **PD4:** This step must produce a detailed preferred design variant for the next decision point. The project scope and estimated costs for the realization of this variant are technically finalized.

- **DP2:** In Decision Point 2 (DP 2), the choice is made on how to further approach the project. The project scope is made definitive.

3.2.6. Realization (MIRT)
In the final phase of the project, the plans developed for renewal of the asset must be executed. The realization encompasses the physical activities for renovation or replacement of the existing structure. In essence, there is no difference between the realization phase in the R&R Approach or the MIRT framework.

3.3. Evaluation of the R&R Approach
The R&R Approach has been evaluated in recent years. In these assessments, various elements of the project delivery framework have been examined, thereby analyzing its real-life applicability and effectiveness in supporting RWS in their infrastructure renewal efforts. The R&R Approach is of pivotal importance for the PM teams of RWS that plan, develop, and execute the R&R projects, as it is their primary tool for fundamental activities such as project scope identification and cost estimation.

3.3.1. Structure
In a recent report, PwC and Rebel (2020) observed that several elements of the R&R Approach are not sufficiently formalized. The project scope is not clearly defined, and renewal projects take place through various programs, as some fall under the M&M umbrella, while other proceed under R&R. Conclusively, PwC and Rebel (2020) stated that the R&R Approach has not reached the same level of maturity as the MIRT project delivery framework.

Projects executed under have MIRT different phasing than R&R projects. A main point of interest is the reduced number of decision points. Whereas each project phase in MIRT is concluded by a decision point, totaling four, essentially embodying the formal go/no-go moments, the R&R Approach has only two decision points. Decision points perform a critical role in project delivery frameworks, as they enforce an assessment of the activities conducted and the products delivered in the phase prior to the decision point. As a result, they safeguard the overall performance of the project.

3.3.2. Link to asset management
At RWS, asset management (AM) encompasses maintenance, replacement, and renovation of infrastructure. However, an integral approach to incorporate all of these different activities in the AM process is currently lacking (Improven, 2021). Moreover, the AM process at RWS also includes network improvements, expansions, and service provisions directly related to networks, such as traffic information, incident management, winter maintenance, and traffic control. To address challenges and improve control, RWS aims to align their AM practices with the ISO 55001 AM standard (Rijkswaterstaat, 2025b). In its ambitions, RWS explicitly states that R&R activities will be incorporated in the AM process.

Frolov et al. (2009) has found that, historically, AM has had a narrow focus, primarily on the reliability and maintainability of assets, rather than on their renewal when they reach the EOL. van der Vlist et al. (2016) conclude that AM is defined as risk-driven management and maintenance during the life cycle of the asset, in which the role of large-scale R&R is not clearly stated. Conclusively, the general notion can be developed that the large-scale R&R of infrastructure is a very contemporary development, and that AM has yet to fully incorporate large-scale interventions.

3.4. Chapter summary and conclusion
This chapter presents the two main project delivery currently used by RWS when executing infrastructure projects. The MIRT project delivery framework has been developed for greenfield construction projects. In contrast, the R&R Approach project delivery framework presents, although it has been derived from MIRT, a different structure to align more with the specific needs of R&R projects. The initial versions of the R&R Approach lacked a clear project scope and structure, but have been gradually developed over time. As of now, the R&R Approach forms an essential foundation for the execution of R&R projects.

This chapter illustrates the project delivery framework used in RWS R&R projects. In its current form, there are doubts over the position of the R&R Approach, i.e., infrastructure renewal, in the overall AM process. Additionally, the structure of the framework is perceived to be opaque. These findings regarding the overall effectiveness of the framework present the necessity for further developments. In conclusion, the framework must be enhanced, but where this enhancement must take place specifically, will be determined the next chapters.

4 Development of the theoretical framework

Renewing infrastructure has proven challenging to practitioners in the infrastructure sector. The conditions under which these projects are prepared, developed, and executed are often referred to as uncertain and complex. However, before substantiated recommendations for enhancement of the project delivery framework can be made, it is of pivotal importance to determine the complexities and uncertainties that are at play in R&R projects. Therefore, a literature study has identified literature on complexity, which has been analyzed and synthesized in Section 4.1. A similar approach has been conducted in Section 4.2 for literature regarding uncertainty. The findings of the literature study have been operationalized in Sections 4.3, providing the framework for the identification and categorization of complexity and uncertainty in the next chapter. The chapter is concluded by a summary and conclusion for its contents in Section 4.4.

4.1. Complexity literature review

Complexity is widely used term among academics and practitioners, used to describe the nature of a project. Since this term is used to describe various aspects of projects, ambiguity is bound to it. In order for this research to identify complexity, uncertainty, and the subsequent challenges, a literature review has been conducted.

4.1.1. Complexity frameworks

Several authors have defined complexity in their researches. The first definition included in this review, is the one presented by Baccarini (1996). The author proposes that project complexity can be defined as consisting of many varied interrelated parts, and can be operationalized in terms of differentiation and interdependency. Furthermore, it is explained that differentiation is bound the number of varied elements, e.g., tasks, specialists, or components; and that interdependence (or connectivity), must be perceived as the degree of interrelatedness between these elements.

Another perspective is offered by Williams (1999, 2002), speaking on project complexity as consisting of structural complexity and uncertainty. In this model, structural complexity, encompasses the number of elements and the interdependence of these elements within a system. Subsequently, the author presents uncertainty as consisting of uncertainty in goals and uncertainty in methods.

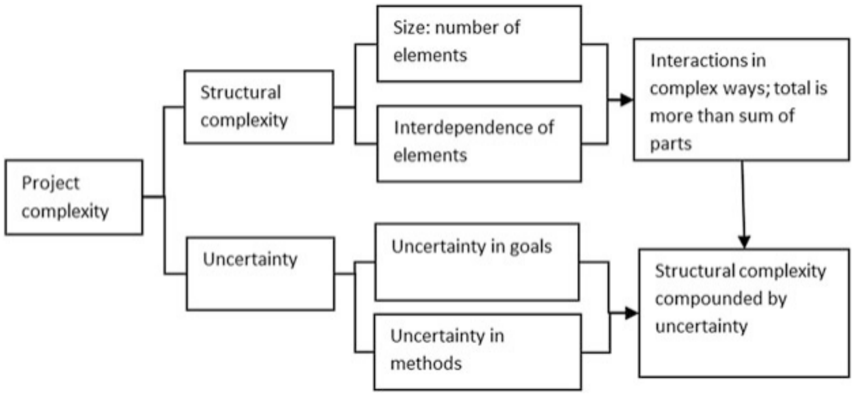

Figure 4.1: Overview of complexity by Williams (2002), as cited in Schwindt and Zimmermann (2015)

The work by Dunović et al. (2014) has also been included in the review, in which the authors shape the perception that project complexity consist of three elements. The authors have analyzed the findings of several earlier studies, which had already defined project complexity in large infrastructure projects (LIPs) as consisting of two parts: structural complexity and uncertainty. Adhering to this starting point Dunović et al. (2014), have expanded the definition by introducing constraints as the third part of project complexity. Practitioners consulted for the research provided that this element is a dominant part of complexity, even more so than structural complexity or uncertainty in LIPs. It leads the authors to the conclusion that project complexity is structural complexity (the inherent complexity of many interconnected parts), compounded by uncertainty (unpredictability of future events), and increased by constraints (limitations on resources and option).

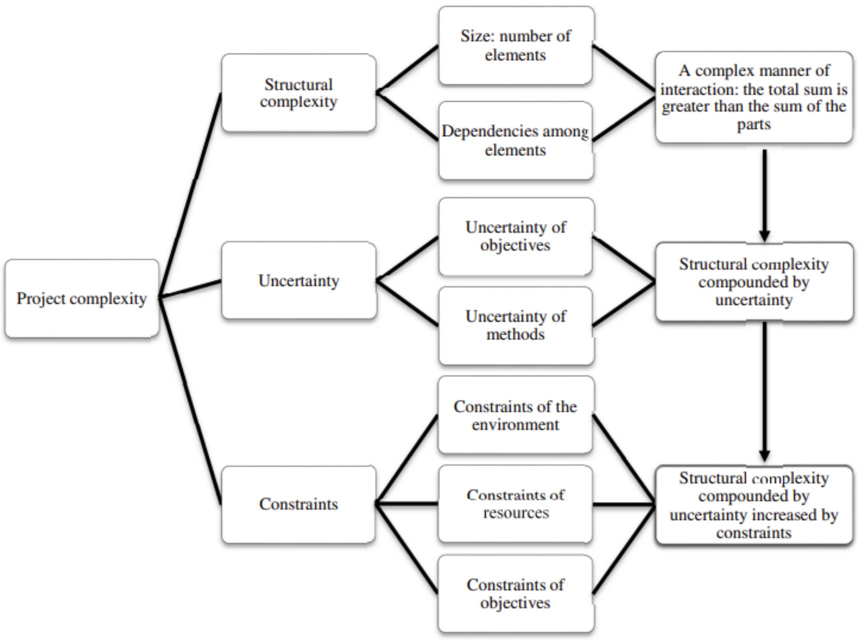

Figure 4.2: Complexity framework as established by Dunović et al. (2014)

The paper by Bosch-Rekveldt et al. (2018) was initially identified as a relevant paper, but after review it could be concluded that it primarily serves as a contextual foundation. It did however, refer to a framework for categorizing complexity: the TOE framework by Bosch-Rekveldt et al. (2011). It categorizes complexity elements as provided by researchers in their preceding researches. This categorization takes place through sorting the complexity elements in one of three categories: technical, organizational, or environmental. The end goal of this categorization is to aid the choice for an appropriate management approach of project complexity for large engineering projects. It consists of 50 complexity elements, which have not been reduced to capture the richness of project complexity (Bosch-Rekveldt et al., 2011).

The elements were included under the criteria of both having a source in both practice and literature, or being named in two independent literature sources, or from at least three interviews covering at least two cases. Through adhering to this approach, the authors have grounded their results into practice.

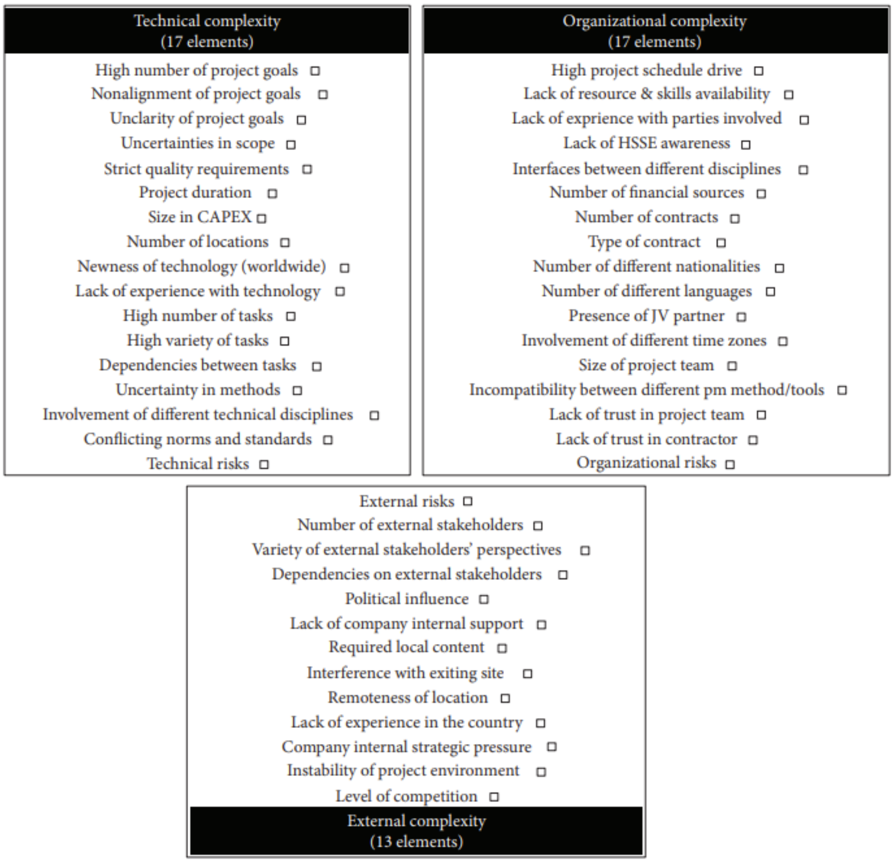

Figure 4.3: Complexity elements as provided in the TOE framework(Bosch-Rekveldt et al., 2011).

The final framework in the literature review is provided by Hertogh and Westerveld (2009). In their research, the authors provide a framework for categorizing project complexity from a practitioners point of view. This framework, shown in Figure 4.4, distinguishes six categories of complexities: technical, social, financial, legal, organizational, and time. Moreover, the authors concluded that the proposed framework is recognized by practitioners.

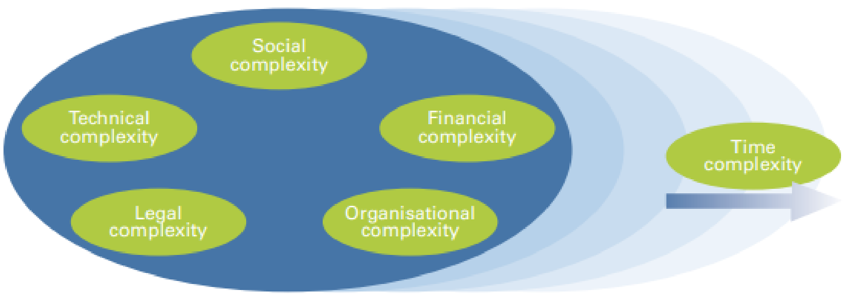

Figure 4.4: The six complexity categories (Hertogh & Westerveld, 2009).

Within each category, Hertogh and Westerveld (2009), a subsequent distinction is made between detail and dynamic complexity. Detail complexity is presented as many components with a high degree of interrelatedness in the stakeholder network, product, or activities. Dynamic complexity is characterized by the potential to evolve over time, through self organization and co-evolution, but also by the limited understanding and predictability. This approach combines the views of practitioners (six types of complexity) with the scientific view (detail and dynamic complexity). It allows for both of these perspectives to complement each other, aiding managers in determining an adequate management approach.

4.1.2. Synthesis

The first framework by Baccarini (1996) provided an initial distinction within project complexity, providing that it can be operationalized in term of differentiation and and interdependence of the elements within a system. Williams (1999, 2002) continues by combining differentiation and interdependence into structural complexity. Furthermore, the author introduces uncertainty as a underlying element of complexity. A third and final addition has been made to this framework by Dunović et al. (2014), both to the underlying elements and the structure in which they are connected. The authors introduce constraints as a novel element of complexity. They conclude their research by stating the structural complexity, compounded by uncertainty, and increased by constraints drives the overall project complexity.

These framework mainly focus of defining project complexity itself through stating what elements are inherent to it. Although the experiences of practitioners have been included in these researches, the frameworks hold a predominantly academical perception. Dunović et al. (2014) conclude their paper by stating two possible conclusions, due to the small correlation between the overall perception of project complexity and specific types of complexity: Either the practitioner’s way of perceiving complexity needs to be updated with an additional element, or the the proposed perception of complexity is not a valid way for research project complexity. Judging by these findings, it seems that there is a discrepancy between the practical and academic view on complexity.

The other two frameworks are better anchored into practice. The TOE (Technical, Organizational, External) framework provided by (Bosch-Rekveldt et al., 2011) categorizes a limited number of complexity types, totaling to three. However, each category knows a rich variety of underlying complexity elements. In contrast, the framework established by Hertogh and Westerveld (2009) knows a total of six categories. The structure of this framework explicitly incorporates financial and legal complexities, in contrast to the TOE framework, which does not. Additionally, Hertogh and Westerveld, 2009 provide a further dissection of complexities classifying them as a detail or dynamic complexity.

4.1.3. Results

As a consequence of the elaborate categories provided by Hertogh and Westerveld (2009), and the detailed structure of the overall framework, it will be used as the foundation for further research in this study. It will serve as the foundation to analyze how different complexities manifest within bridge-related R&R projects. Furthermore, using a common categorization provides consistency in the findings of the research, allowing for focus of the approach when designing their management practices.

4.2. Uncertainty literature review

Infrastructure design and retrofit decisions include a number of conflicting decision criteria, multiple decision makers, and various sources of uncertainty (Shahtaheri et al., 2021). Similarly to project complexity, a similar ambiguity envelopes uncertainty, with risk and opportunity being closely related, but still remaining distinct concepts. As Ward and Chapman (2011) provide, opportunity, uncertainty, and risk are a ”tricky trio”, in the sense that they are linked concepts and any attempt to formally restrict the definition of one of these three words can cripple the practical interpretation and pursuit of all of them, and impose a significant handicap on project management as a whole. Therefore, understanding and managing uncertainty allows for the clarification of both opportunity and risk, with pursuing opportunities being a typical starting point for improving corporate performance (Ward & Chapman, 2011).

4.2.1. Risk and opportunity

Out of the trio of concepts, risks is probably best known concept the project management context. It is a main focus point in every project, for which numerous tools and methodologies have been developed for its management. However, the definition of risk is not without dispute, as can be deviated from the following. Traditionally, many practitioners perceive risks as negative. This view is shared by Ward and Chapman (2011), who provide that risks can be defined as possible unfavorable outcomes.

In contrast, PMI (2013) argues that a risk is an uncertain event or condition that, if it occurs, either has a positive or a negative effect on one or more project objectives. From these conflicting views, it can be derived that nature of the uncertain events forms the center of discussion: are they strictly negative or does it also include positive outcomes? Other authors included in the literature review share the perception of a risk as an exclusively negative phenomenon (Hubbard, 2009; Ramesh & Browning, 2014). Furthermore, Hubbard (2009) elaborates on the formal definition of risk, stating that it is a potential loss, disaster, or other undesirable event measured with probabilities assigned to losses of various magnitudes. It aligns with that presented by Toma et al. (2012), who address that risk refers to situations in which probabilities targets can be identified for possible results, i.e., quantification.

4.2.2. Known, unknown, and unknowable

Among practitioners in the Dutch infrastructure sector, the 'known unknowns' (*voorzien onvoorzien*) and 'unknowns unknowns' (*onvoorzien onvoorzien*) terminology is often used to describe uncertainties. This arises the question, to which extent this aligns with relevant literature. Hoseini et al. (2020) state that, in the context of projects, known unknowns are the events that can be identified and may or may not occur in a project. Unknown unknowns are, in contrast, unforeseeable situations within the scope of the project. Ramesh and Browning (2014) argue that known unknowns are uncertainties of which the PM team is aware and to which the techniques of conventional risk and opportunity management can be applied. Unknown unknowns are described by the authors as unrecognized uncertainties of which the PM is unaware. Additionally, Ward and Chapman (2011) state that known unknowns are identified conditions which are sources of uncertainty because associated assumptions will not hold exactly, and that unknown unknowns, are assumptions or sources of uncertainty which have not been identified.

Another, expanded framework for categorizing uncertainty is offered by Diebold et al. (2010) and Ganegoda and Evans (2014). Within this framework, the 'knowledge-as-measurement' paradigm is described as:

- **The known:** Refers to a situation where the probability distribution is completely specified.
- **The unknown:** Refers to a situation where probabilities cannot be assigned to at least some events. Events are known but probabilities are not.
- **The unknowable:** Refers to a situation where even the events cannot be identified in advance, neither events nor probabilities are known. Once they occur, they enter the domain of the unknown.

4.2.3. Aleatory and epistemic uncertainty

Another common distinction is between aleatory and epistemic uncertainty. Hariri-Ardebili et al. (2018) acknowledge that design of infrastructure is affected by these two main uncertainty sources. Especially in the field of AM, or any other field were (statistical) models are used to simulate reality, these concepts are encountered. AM systems help public works agencies decide when and how to maintain and rehabilitate infrastructure facilities in a cost-effective manner (Kuhn & Madanat, 2006).

Aleatoric uncertainty is described by Ilg et al. (2017) and Kiureghian and Ditlevsen (2009) as what is presumed to be the intrinsic randomness of a phenomenon, Ward and Chapman (2011) explain the concept as predictable variability or randomness. Baccarini and Love (2014) describes it as variability, which relates to the uncertainty of the size of variables parameters; e.g., costs of project elements. Epistemic uncertainty is one that is presumed as being caused by lack of knowledge (or data) (Ilg et al., 2017; Kiureghian & Ditlevsen, 2009). This lack of knowledge also prevent predictability, as noted by Ward and Chapman (2011).

Illustrating these categories of uncertainty within the context of AM, Ferrario et al. (2015) acknowledges as the transitions between different states of damage occur stochastically (aleatory uncertainty). Epistemic uncertainty affects the associated transition probabilities due to insufficient knowledge and information on the components' degradation behavior. Garavaglia and Sgambi (2015) expands on this by acknowledging that epistemic uncertainty can be reduced through the attainment of more information and includes modeling choice and error. However, Durango-Cohen (2004) warns that the complexity, costs and time required to collect reliable datasets may not be ignored, limiting the effectiveness of the model-based approaches. Finally, despite the fact that the quality of data can be improved by developing more advanced inspection methods and deterioration models, it remains impossible to eliminate entirely the uncertainty associated with MR&R decision-making (Kuhn & Madanat, 2005).

4.2.4. Synthesis

With the literature review concluded, a synthesis of the various distinctions within uncertainty, risk, and opportunity is presented. The distinction between risk and opportunity is discussed initially, as risk is a disputed concept. What is, and what is not considered to be a risk, varies throughout the literature examined. However, the majority of authors perceive risk as exclusively negative (Hubbard, 2009; Ramesh & Browning, 2014; Ward & Chapman, 2011), as opposed to some (PMI, 2013), who adhere to a neutral standpoint in which it included both threats (negative outcomes) and opportunities (positive outcomes). Furthermore, some authors conclude that risks must also be quantifiable: its probability of occurrence and effect are to be known by the decision-maker (Hubbard, 2009; Toma et al., 2012). If this information is not present, the authors classify the events as an uncertainty.

A common notion, regardless of the exact standpoint, is that identifying both risk and opportunity is critical. Ward and Chapman (2011) state it as a starting point for improving corporate performance. The importance of identifying opportunities, besides to risks, is also illustrated from a simple experiment of thought. If for every risk that occurs the project performance is negatively impacted, then it will be difficult to achieve the initial performance targets set. If no opportunities are included, projects performance can only decrease under potential events.

Other demarcations of uncertainty, such as known unknowns and unknown unknowns, are respectively described as identifiable events that can occur and unforeseeable situations (Hoseini et al., 2020; Ramesh & Browning, 2014; Ward & Chapman, 2011). Another demarcation structure, divides uncertainties into what is known (identified and quantifiable), what is unknown (identified but not quantifiable), and what is unknowable (not identified thus impossible to quantify) (Diebold et al., 2010; Ganegoda & Evans, 2014). In the last category an interesting remark is made: after occurrence, a situation becomes unknown, but not longer as unknowable (Diebold et al., 2010). The same principle applies to the unknown uncertainties, which can be quantified after a sufficient number of occurrences.

A distinction between sources of uncertainty is found in aleatory and epistemic uncertainty. Aleatory uncertainty is described as intrinsic randomness (Ilg et al., 2017; Kiureghian & Ditlevsen, 2009), or variability (Baccarini & Love, 2014; Ward & Chapman, 2011). A common notion shared by these author is that the uncertainty is considered inherent. It can be measured, e.g., through determining the maximum and minimal value of a parameter, thus establishing its range. However, as it is caused by the randomness of the phenomena itself, it cannot be reduced. With regard to AM of infrastructure, an illustrating example of aleatory uncertainty is provided by Ferrario et al. (2015), stating that transitions between states of damage is typical stochastic behavior.

In contrast, epistemic uncertainty is considered to be caused by a lack of knowledge (Ilg et al., 2017; Kiureghian & Ditlevsen, 2009), which prevents it from being predictable (Ward & Chapman, 2011). Knowledge can be increased, through engaging in various activities, such as research, collaboration between experts, etc. Reducing uncertainty is a welcome development in most cases, but doing so might require significant efforts, which is something cannot be ignored (Durango-Cohen, 2004).

4.2.5. Results

Many authors have shared their perception on uncertainty. What remains important, through reflecting upon the nature of this thesis research, is that the perception proposed is applicable in practice. In other words, the input of practitioners must resonate with the theoretical foundation laid in this chapter. Now a general starting point is taken, with the establishment of risks as exclusively negative, and opportunities as exclusively positive.

In terms of categorizing uncertainty, the epistemic and aleatory demarcation will be adhered to, focusing on displaying the pivotal properties of the uncertainty. It clearly states what measures can be undertaken in efforts for their management, and which cannot, making the practical application of this structure clear.

4.3. Complexity framework operationalization

With the literature review finalized, the results have been integrated into a two layered framework. The first layer categorizes complexities into one of six categories, including whether it encompasses detail or dynamic complexity. The second layer provides a tools for classifying the uncertainties, risks, and opportunities.

4.3.1. Categorizing complexities

The foundation of this framework lies within structuring the distinction between the several types of complexity that may be present in R&R projects. Six categories of complexities have been established: technical, social, financial, organizational, legal, and time. Furthermore, each type has been provided with its respective subcategories: detail or dynamic complexity. For all of the detail and dynamic complexities in their overarching complexity category, examples have been provided by Hertogh and Westerveld (2009), and expanded upon by Dunović et al. (2014). Their collective findings have been consolidated in Table 4.1, presenting an overview of possible complexities as identified in literature.

Complexity category	Detail complexity	Dynamic complexity
Technical	• Mega sized products (project scope) • Many relationships between parts of the product	• Unproven technology • Technical uncertainty
Social	• Large number of stakeholders • Many relationships/connections	• Different meanings and perceptions • Changes of interest over time • Changes in co-operation • Conflict of interest • Major impact on the environment
Financial	• Difficulty in calculating cost for all sub-elements of the product • Costs and benefits are difficult to calculate and are not equally divided • Perception of the development of costs which differs from calculations	• Changing market conditions • Different perceptions about definitions and agreements • Strategic misinterpretation • Optimistic/pessimistic bias • 'Cascade of distortion' effect
Legal	• Large number of consents and permits needed which are often related • Comprehensive legislation and policies have a significant impact on the content and process	• Changing, non-existent and conflicting laws • People need space for execution of activities (look for holes as extra space)
Organizational	• Large number of involved organizations • Numerous working processes that interfere • Large number of contracts with numerous interfaces	• Researchers are part of the system • Find and keep motivated people adequate to the challenge • Large number of decisions with uncertain best solution • Future developments impacts the organization that delivers the project
Time	• Planning of separate activities and their relationships	• Long time frame with continuous developments • No sequential (step-by-step) process of implementation • Planning has to deal with numerous uncertain and ambiguous processes

Table 4.1: Complexity categories with detail and dynamic manifestations (Dunović et al., 2014; Hertogh & Westerveld, 2009)

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4.3.2. Detail and dynamic complexity

Two (sub)types of complexity that are key to LIPs are the detail and dynamic complexity (Hertogh & Westerveld, 2009). It are these two dimensions that allow for a connection between practitioners' views (six complexity types) and scientific views (detail and dynamic).

Detail complexity

The detail complexity refers to the many components with a high degree of interrelatedness that system may inhibit. The structure in which the project elements are ordered provide the firs insight into this complexity. The full perception can only be grasped through also examining the relationships they share. More relationships do not necessarily mean more complexity. While sounding counterintuitive, the relationships in questions might be organized in a hierarchy, enable for loose couplings, provide a backup pathway. It leads Hertogh and Westerveld (2009) to the following notions on complexity :

- The relationships should be intricate.
- The length of the description that will describe the system determines complexity.
- More relations will not necessarily lead to more complexity.

Dynamic complexity

Dynamic complexity knows two main characteristics. The first characteristic offers a perspective from the systems point of view. It show the potential to evolve over time through self organization and co-evolution. It leads to the following notions (Hertogh & Westerveld, 2009):

- Emergent events may be of great importance - importance of coincidences.
- Sensitivity of minimal changes in initial conditions - historical path dependency.
- Complex adaptive systems, as found in LIPs, evolve and have the ability to improve.
- Complexity in terms of ambiguity is connected to the conflicting preferences of stakeholders.
- Shifting preferences of stakeholders which trigger changes in the stakeholder system often originate from dissatisfaction.
- Shifts in preference of stakeholders are related to external factors and internal developments.
- Changes in system state can be visible in all three main sub-systems found within LIPs: the stakeholder network, final product (infrastructure facility) and activities.

The second perspective is from that of a decision-maker, who has to manage under the conditions set by the nature of a project. Dynamic complexity poses limited understanding and predictability within a process. It leads to the following notions (Hertogh & Westerveld, 2009):

- the ”A causes B” rationality is diffuse, there is skepticism about long range planning.
- Uncertainty on decisions and bounded rationality.

4.4. Chapter summary and conclusion

This chapter has established a framework fit for identifying and categorizing complexities and uncertainties that present themselves in R&R projects. The frameworks categorizes complexities into one of six categories, which subsequently encompasses two underlying subcategories.

In conclusion, these frameworks have been selected on the basis of their alignment with practitioner perceptions. As a result, the framework is applicable in practice, allowing for a distinct categorization of all complexity and uncertainty that underlie their challenges.

Part II

Define

5

Challenges and complexities in bridge renewal projects

This chapter presents the complexities, including their underlying uncertainty (if present), that has been identified in the practitioner interviews. The full in-depth analysis which conducts a structured breakdown of the challenges retrieved from the interviews can be found in Appendix C. The identified complexities are structured per category, and then further divided into either a detail or a dynamic complexity. Therefore, the chapter starts with the technical complexities in Section 5.1, followed by the social complexities in Section 5.2, and the financial complexities in Section 5.3. Subsequently, the legal complexities are discussed in Section 5.4, the organization complexities in Section 5.5, and the time complexities in Section 5.6. The chapter is concluded by an overview of all complexities in Section 5.7 , and a chapter summary and conclusion in Section 5.8.

5.1. Technical complexities

This section provides an overview of the technical complexities identified in the practitioner interviews.

5.1.1. Detail complexities

Out of the technical complexities, the following belong to the detail complexity subcategory:

- **(De)construction of replacement or renovated, temporary, and existing structures lead to large project project scope**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large-scale product (detail technical complexity).
  - **Description:** Within R&R projects, the project scope is large as it encompasses the renovation or the replacement of an entire bridge, which potentially also includes the surrounding complex. Furthermore, comprehensive measures are required to establish a temporary situation which allows for execution of the project in a safe manner where traffic flows are maintained. As a consequence, the project scope consists of many elements, all critical to ensure effective and safe functionality of the asset after the intervention.
  - **Uncertainty source:** No uncertainty present.
- **Interrelatedness of bridge elements and changes in design**
  - **Categorization according to complexity categorization framework (Table 4.1):** Many connections among parts of the product (detail technical complexity).
  - **Description:** Elements of the design are severely interrelated, meaning that a change in one part immediately affects others. Design changes mandated by modern design guidelines, i.e., the upgrades to designs required for compliance with technical regulations or guidelines, affect the design as a whole. The interdependence makes the system complicated,

as intricate relationships dominate the system.

  - **Uncertainty source:** No uncertainty present.

- **Interconnected technical installations lead to complicated industrial automation situations**
  - **Categorization according to complexity categorization framework (Table 4.1):** Many connections among parts of the product (detail technical complexity).
  - **Description:** Technical installations of bridges are interwoven with many subsystems of the surrounding complex or other structures. A failure or mismatch in one technical installation, e.g., a building block, can pose significant consequences to others.
  - **Uncertainty source:** No uncertainty present.
- **Complex phasing of construction stages and temporary measures or structures during realization**
  - **Categorization according to complexity categorization framework (Table 4.1):** Many relationships between part of the product (detail technical complexity).
  - **Description:** In facilitating a temporary situation for ensuring safe construction and continuity of traffic, a variety of measures must often be included so that a traffic bypass may be constructed. It drives a phasing of construction stages, in which alternating stages of construction and demolition are employed during intervention. Additionally, temporary measures or structures are required prior to and during the realization phase, such as weight limits, reinforcement structures, temporary bridges, and others to ensure safe traffic continuation. Developing an appropriate phasing strategy for R&R projects requires significant efforts by PM teams, but ultimately, it can be fully planned.
  - **Uncertainty source:** No uncertainty present.

5.1.2. Dynamic

Out of the technical complexities, the following belong to the dynamic complexity subcategory:

- **Incomplete object data and as-built information at start realization phase**
  - **Categorization according to complexity categorization framework (Table 4.1):** Technical uncertainty (dynamic technical complexity).
  - **Description:** There is technical uncertainty regarding the configuration and condition of objects in R&R projects. Asset data is often missing or incomplete, with as-built drawings lacking maintenance throughout the service life of the object. This is in part due to lacking data, which can be reduced through inspections and research efforts (epistemic), but also due to the natural deterioration of elements, which cannot be accurately determined at all times (aleatory).
  - **Uncertainty source:** Epistemic and aleatory.
- **On-site industrial automation situation differs from as-built or design drawing**
  - **Categorization according to complexity categorization framework (Table 4.1):** Technical uncertainty (dynamic technical complexity).
  - **Description:** Changing requirements and local adaptations of building blocks introduce epistemic uncertainty, since full compliance needs or software mismatches often only appear during implementation. Some uncertainties are known, but unforeseen uncertainties might also present themselves during on-site installation.
  - **Uncertainty source:** Epistemic
- **Uncertain condition and feasibility of implementation for reused (structural) elements**
  - **Categorization according to complexity categorization framework (Table 4.1):** Technical uncertainty (dynamic technical complexity).

- **Description:** There is technical uncertainty regarding the condition of structural elements, as a result of difficult assessment of their expected remaining service life. Therefore, guaranteeing service life becomes difficult, and establishing the true condition of a structural elements is not without cumbersome effort. The uncertainty originates from both aleatory uncertainty (continuously changing element state) and epistemic uncertainty (lack of information due to insufficient formalization of research).
- **Uncertainty source:** Aleatory and epistemic.

5.2. Social complexities

This section provides an overview of the social complexities identified from the practitioner interviews.

5.2.1. Detail complexities

Out of the technical complexities, the following belong to the detail complexity subcategory:

- **Object-focused approach forces collaboration with multiple regional divisions**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of stakeholders (detail social complexity).
  - **Description:** The shift towards object-focused workflows in R&R projects, i.e., incorporating objects project into a single portfolio-project, provides the PM team responsible for these portfolios with novel a stakeholder network. Instead of working within one region and thus having one RWS regional division as a stakeholder, spatially fragmented objects incorporated into a portfolio-project may result in multiple regional divisions being a stakeholder. PM teams must collaborate with multiple regional divisions, which all represent unique environments and local stakeholders. This complicates the overall stakeholder management, as more actors and relationships must now be accounted for.
  - **Uncertainty source:** No uncertainty present.

5.2.2. Dynamic complexities

Out of the social complexities, the following belong to the dynamic complexity subcategory:

- **Stakeholder requirements shift as projects progresses**
  - **Categorization according to complexity categorization framework (Table 4.1):** Changing stakeholder requirements (dynamic social complexity).
  - **Description:** Regional stakeholders may introduce new or changed requirements as an R&R project progresses. When the realization phase draws near, it often emerges that additional measures are requested to alleviate negative side-effects of the project. In order to sustain overall stakeholder and political-administrative support for the project, it is of pivotal important to manage these stakeholder requirements adequately. Failing to do so may result in opposition, thereby inevitably hampering project performance. The development described here pose epistemic uncertainty, as it arises from the incomplete knowledge regarding the future position of stakeholder demands.
  - **Uncertainty source:** Epistemic.
- **Far-reaching consequences of disruptions under dependency on regional stakeholders**
  - **Categorization according to complexity categorization framework (Table 4.1):** Major impact on the environment (dynamic social complexity).
  - **Description:** The social impact of traffic disruption and the measures taken to mitigate this require careful consideration by PM teams. However, not al demands made by stakeholders are feasible, as they may require a disproportionate allocation of funds. In the tension that arises from this, issues may lead to reputational damage, or possibly political-administrative scrutinization. Additionally, PM teams are highly dependent on the approval of permits, granted predominantly by municipalities. As a result, project feasibility and planning depends on these entities. Conclusively, the overall opposition that may arise from not adequately

managing regional stakeholders is difficult to fully estimate, as this is continuously developing as the project progresses. This uncertainty is epistemic as it can be reduced through coordination efforts among local stakeholders, but this will require significant efforts while risking potential shifts in preferences.

  - **Uncertainty source:** Epistemic.

- **No standardized process for weighing various stakeholder (group) interests against each other**
  - **Categorization according to complexity categorization framework (Table 4.1):** Different meanings and perceptions (dynamic social complexity).
  - **Description:** Every stakeholder present in an R&R project defines ”minimizing disruptions” differently. It depends on whether preference is given to road users, maritime vessels, or construction teams. The conflicting perceptions make it difficult for a PM team to weigh interest against each other, requiring significant efforts to balance these in the decision-making process. While a guiding framework for reducing traffic disruption is available, a project-specific approach still remains required to determine stakeholder priority. The uncertainty this poses is epistemic, as preferences and solutions can be explored through negotiation, but currently requires efforts.
  - **Uncertainty source:** Epistemic.
- **Shifting collaboration dynamics under novel contracting approaches (Portfolio, Cost+, etc.)**
  - **Categorization according to complexity categorization framework (Table 4.1):** Changes in co-operation (dynamic social complexity).
  - **Description:** The adoption of novel contracting approaches, such as Cost+ and portfolio contracts, fundamentally alters the dynamics of cooperation between Rijkswaterstaat and contractors. Where traditional contracts emphasized transactional relationships, these new approaches encourage a transparent and trust-based approach, in which shared financial incentives must increase project performance during long-term collaboration. At the same time, they increase RWS’s dependency on market parties. This reinforces the need for internal expertise, to balance out market power. This evolving mode of cooperation introduces dynamic social complexity, as collaboration forms are not stable but shift over time in response to developments within projects and market dynamics. The uncertainty regarding this novel collaboration is epistemic as it results from the inability to fully anticipate the resulting project performance, as this may only be obtained through experiences following application within projects.
  - **Uncertainty source:** Epistemic.

5.3. Financial complexities

This section provides an overview of the financial complexities identified from the practitioner interviews.

5.3.1. Detail complexities

Out of the financial complexities, the following belong to the detail complexity subcategory:

- **Diverging perceptions on true cost development for 1-to-1 replacements**
  - **Categorization according to complexity categorization framework (Table 4.1):** Perception of cost developments differs from calculations (detail financial complexity).
  - **Description:** Stakeholder expectations for cost developments differ from actual developments. The development of costs can be perceived in various ways, depending on the role and knowledge of specific stakeholders, with practitioners and executives sharing no common perception. RWS practitioners are aware of the complex and uncertain nature of R&R projects, and thereby the costs associated, but this is not shared among all members of the organization and Ministry of I&W. As a result, cost development may diverge from initial

expectations as the project progresses. This complexity is continuously encountered over the variety of R&R projects currently in development.

- **Uncertainty source:** No uncertainty present.

5.3.2. Dynamic complexities

Out of the financial complexities, the following belong to the dynamic complexity subcategory:

- **Disruption management vs. cost-efficiency creates financial tension**
  - **Categorization according to complexity categorization framework (Table 4.1):** Costs and benefits are difficult to calculate and are not equally divided (dynamic financial complexity).
  - **Description:** Efforts to minimize traffic disruption inevitably come at a cost, often driving expensive technical measures, thereby setting a trade-off between societal acceptance and financial feasibility. R&R projects operate under cost efficiently principles dictated by budget deficits, meaning that measures taken to counter traffic disruption must be proportionate. It is a form of epistemic uncertainty in the project, as cost estimates and benefit calculations are developed over time while stakeholder requirements will also become more apparent, thereby reducing this uncertainty.
  - **Uncertainty source:** Epistemic.
- **Uncertain distribution of direct and indirect costs**
  - **Categorization according to complexity categorization framework (Table 4.1):** Costs and benefits are difficult to calculate and are not equally divided (dynamic financial complexity).
  - **Description:** It remains difficult to accurately estimate direct and indirect costs, as there is a high degree of uncertainty present in several cost elements and categories. This uncertainty is further reinforced by project developments such as project scope changes, delays, and other disruptions. Moreover, the share of indirect costs in R&R projects has grown relative to greenfield construction projects, in some cases being more than halve of the total project cost. The uncertainty residing in this complexity is a mix of both aleatory and epistemic uncertainty. Aleatory, because prices fluctuate as they are subject to market developments. Epistemic, as uncertainty can and will be reduced through experience with R&R projects allowing for accurate cost breakdown and better reference figures.
  - **Uncertainty source:** Aleatory and epistemic.
- **Strategic misinterpretation due to competition over the limited renewal funds**
  - **Categorization according to complexity categorization framework (Table 4.1):** Strategic misinterpretation (dynamic financial complexity).
  - **Description:** Regional divisions of RWS present projects as more favorable, such as by downplaying costs, risks, or complexity, in order to secure funding over competing projects. Unlike inherent variability, this uncertainty arises from intentionally biased information, which thus lacks a transparent and complete profile. It is a form of epistemic uncertainty in projects, as stronger checks and improved governance may reduce it.
  - **Uncertainty source:** Epistemic.
- **Optimistic bias in early project scope and budget undermines scope-stability and feasibility**
  - **Categorization according to complexity categorization framework (Table 4.1):** Optimistic/pessimistic bias (dynamic financial complexity).
  - **Description:** The practice of underestimating costs is encouraged by organizational developments, as the estimated 'true' costs of projects, resulting from significant contingency reserves or other cost-driving elements, are often perceived as being too high to secure project approval. This is further compounded by the fact that early project scope is frequently underdeveloped. This leads to plans that prove unfeasible once a project progresses and is

handed over between internal PM teams that work on them. These dynamics introduce epistemic uncertainty as the overly favorable assumptions stem from gaps or distortions in the available knowledge.

  - **Uncertainty source:** Epistemic.

- **Persistently distorted perceptions of costs throughout various project phases**
  - **Categorization according to complexity categorization framework (Table 4.1):** 'Cascade of distortion' effect (dynamic financial complexity).
  - **Description:** When costs are misrepresented from the start, all subsequent cost estimation processes inherit this initial bias. An artificially low baseline anchors later estimates, forecasts, and performance assessments, causing the project to appear as if it is continually experiencing financial setbacks. This constitutes epistemic uncertainty that propagates through the project life-cycle, as the consequences downstream cannot be fully anticipated in advance.
  - **Uncertainty source:** Epistemic.

5.4. Legal complexities

This section provides an overview of the legal complexities identified from the practitioner interviews.

5.4.1. Detail complexities

Out of the legal complexities, the following belong to the detail complexity subcategory:

- **Nitrogen-restrictions constrain the range of technical solutions available to PM teams**
  - **Categorization according to complexity categorization framework (Table 4.1):** Comprehensive legislation and policies have a significant impact on the content and process (detail legal complexity).
  - **Description:** The Council of State's (*Raad van State*) ruling on nitrogen emission imposes a strict legal constraint on projects, especially those in the vicinity of Natura2000-areas (European network of nature areas). The ruling restricts the deposition of nitrogen in these areas, forcing PM teams to develop approaches which minimize nitrogen emissions, thereby limiting the available solutions within projects. Examples include not being able to reroute traffic via alternative highways, or using fossil-fuel powered construction equipments, due to the associated emission. The implications of these developments may be fully planned out by a PM team, but require additional efforts and therefore complicate the planning.
  - **Uncertainty source:** No uncertainty present
- **Permit applications under the Environmental and Planning Act require extra preparatory activities**
  - **Categorization according to complexity categorization framework (Table 4.1):** Comprehensive legislation and policies have a significant impact on the content and process (detail legal complexity).
  - **Description:** The Environmental and Planning Act consolidates multiple environmental, spatial, and infrastructure regulations. R&R projects must now apply for permits under this act, e.g., zoning plan deviations, before realization can legally start. The requirements pose a significant administrative burden on the PM team, as they must conclude several preparatory researches and designs before an application can be made. These activities are on the critical path of the project planning, and are to be executed in an relatively early stage of the project, complicating early preparation.
  - **Uncertainty source:** No uncertainty present.

5.4.2. Dynamic complexities

Out of the legal complexities, the following belong to the dynamic complexity subcategory:

- **Developments in nitrogen restrictions potentially lead to a suddenly changing legal environment**
  - **Categorization according to complexity categorization framework (Table 4.1):** Changeable, non-existent, and conflicting laws (dynamic legal complexity).
  - **Description:** Nitrogen regulations are currently stabilized, but underwent major changes in recent years. Possible future adjustments to the rules may again change what impact the regulations pose for R&R projects. It is epistemic uncertainty, as project scope, project approach, and other fundamental dimensions cannot be fully anticipated.
  - **Uncertainty source:** Epistemic.
- **No formal expropriation procedure in R&R projects**
  - **Categorization according to complexity categorization framework (Table 4.1):** Comprehensive legislation and policies have a significant impact on the content and process (detail legal complexity).
  - **Description:** Unlike in MIRT projects (new infrastructure) that have a fixed legal basis for expropriation (project-decision), R&R projects lack a clear legal framework for acquiring (privately owned) grounds. Each project provides its PM team with a novel legal reality, forcing PM teams to design project-specific workarounds when negotiations fail. It is epistemic uncertainty as it results from a lacking legal framework, meaning that clarity could be provided through formalization of the procedures.
  - **Uncertainty source:** Epistemic.

5.5. Organizational complexities

This section provides an overview of the organizational complexities identified from the practitioner interviews.

5.5.1. Detail complexities

Out of the organizational complexities, the following belong to the detail complexity subcategory:

- **Simultaneously developing R&R project requires coordination among many stakeholders**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of involved organizations (detail organization complexity).
  - **Description:** As an increasing amount of structures is reaching their technical EOL, a growing number of R&R projects are carried out simultaneously. Therefore, internal and external coordination efforts with stakeholders will become increasingly cumbersome, as a larger number of entities must be consulted when projects are developed and scheduled. Examples can be found internally (within RWS), as a multiple critical traffic corridors face works, meaning that meticulous planning with network managers is required to keep efficient transport possible in the Netherlands. Externally, RWS must seek alignment with a multitude of local governments, interest groups, businesses, among others that depend on the functionality of infrastructure. Conclusively, as every R&R project affects others, it requires consideration from a large network of stakeholders, complicating the overall process.
  - **Uncertainty source:** No uncertainty present.
- **Integrated contracts introduce overlapping responsibilities and complicated collaboration**
  - **Categorization according to complexity categorization framework (Table 4.1):** Numerous working processes that interfere (detail organizational complexity).
  - **Description:** The utilization of integrated contracts introduces overlapping responsibilities between RWS, contractors, engineering firms, etc. The interdependency between parties and the additional coordination this requires complicates planning, design validation, and risk management efforts. It remains as a detail complexity, however, as the process can ultimately be fully mapped out through planning efforts.

  - **Uncertainty source:** No uncertainty present.
- **Political-administrative reporting pressure results in administrative burden**
  - **Categorization according to complexity categorization framework (Table 4.1):** Numerous working processes that interfere (detail organizational complexity).
  - **Description:** The shift towards intensified reporting, especially called for by higher executives, creates an additional burden while failing to deliver the intended control benefits. Reporting is mainly done ex ante, meaning that it remains to steer ongoing processes. It creates a tension field between the predictability demanded by politicians and executives, while it hampers the flexibility required by PM teams to operate. The administrative burden of multiple reporting streams, combined with evolving governance arrangements, complicates the internal processes. The pressure to produce various reports to demonstrate compliance is experienced as cumbersome, while not providing what is actually wanted, which is an increased level of control to efficiently steer project.
  - **Uncertainty source:** No uncertainty present.
- **Integrating multiple project into a portfolio (contract) requires alignment between individual projects**
  - **Categorization according to complexity categorization framework (Table 4.1):** Numerous working processes that interfere (detail organizational complexity).
  - **Description:** The bundling of multiple projects into a portfolio is not without effort for RWS, as it requires the alignment of multiple schedules, contracts, etc. It complicates the planning of underlying individual projects, as these have an increased interdependency on one another. Once processes and interfaces are mapped out, it the process remains ultimately deterministic.
  - **Uncertainty source:** No uncertainty present.
- **Feasibility of project requirements under pressure due to client-contractor misalignment**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of contracts with numerous interfaces (detail organizational complexity).
  - **Description:** Issues manifest themselves in the contracts between RWS and their contractors, who provide that these contracts often hold requirements that are not realistic or prove unfeasible, leading to delays, conflicts, and possible redesigns. With RWS's move towards functional specification (providing requirements rather than in-house developed structure designs), the requirements and specification they establish have become more critical. Misalignment occurs in the interfaces of these contracts, as it is provided that early-on cooperation and executive-level negotiation is often lacking.
  - **Uncertainty source:** No uncertainty present.

5.5.2. Dynamic complexities

Out of the organizational complexities, the following belong to the dynamic complexity subcategory:

- **Determining the project-specific implications of the 1-to-1 replacement principle**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of decisions with uncertain best solution (dynamic organizational complexity).
  - **Description:** Defining the true implication of the 1-to-1 replacement principle within an individual project is an evolving and process per project. In part due the varying perceptions within PM teams, but also since there is significant differentiation among the assets. The uncertainty regarding this matter is epistemic, as it can be reduced through further formalizing boundary conditions for these types of replacements.
  - **Uncertainty source:** Epistemic.
- **Changes to RWS design guidelines impact ongoing project development**

- **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization (dynamic organizational complexity).
- **Description:** Developments in design guidelines affect their exact implementation. RWS design guidelines, such as the Guideline Design Structures (*Richtlijn Ontwerp Kunstwerken, ROK*), Guidelines Design Highways (*Richtlijn Ontwerp Autosnelwegen, ROA*), Guideline Waterways (*Richtlijn Vaarwegen, RV*) can subjected to change, due to policies evolving over time, altering project project scope requirements for projects in active development and in the future. However, an important note must be made, as this regards guidelines, i.e., they are not mandatory. Deviation from the guidelines is possible, after internal approval. It is epistemic uncertainty, as it is based on policy shifts and technical developments. It presents unknown uncertainties, as the exact implications and chance of occurrence are hard to determine.
- **Uncertainty source:** Epistemic.

• **Changes in asset data governance due to outsourced maintenance for assets**

- **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
- **Description:** Data governance by RWS has evolved over time, due to the performance-based, outsourced maintenance strategy that is currently employed. As maintenance contractors maintain assets, they also govern the management of inspection data and keep track of changes made to the configuration, e.g., moving utility lines. As a result of these developments, records and thus data is fragmented. Furthermore, it has been provided that these contractors do not always keep their records up to data, leading to gaps in maintenance data. The uncertainty in this matter is epistemic, as increased control through contract management will help reduce it.
- **Uncertainty source:** Epistemic.

• **Building blocks reduce on-site flexibility of the implementing organization**

- **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
- **Description:** The shift from contractor-managed technical installations to building blocks, managed and delivered directly by RWS and their preferred supplier, reduces the overall adaptivity of contractors. This implementing organization could traditionally solve on-site problems with their own technicians, whereas compatibility problems currently have to be coordinated via the preferred supplier. These developments reduce the overall flexibility of implementation. It poses epistemic uncertainty, as it results from the inability to foresee all potential difficulties during planning, but may be reduced through formalizing processes and incorporating past experiences.
- **Uncertainty source:** Epistemic.

• **Reuse is not sufficiently integrated in formal procedures and standard contracts**

- **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
- **Description:** Roles and responsibilities in R&R projects have changed over time, making the allocation of risk associated to common R&R aspects unclear in existing contracts. Efforts are made by RWS expert reuse teams, thereby shifting risks from the contracted parties towards RWS to encourage reuse. The uncertainty residing within this complexity is epistemic, as contracts and procedures must formally incorporate the issues presented when reusing structural elements.
- **Uncertainty source:** Epistemic.

• **Cost vs. quality trade-off is under organizational pressure from multiple stakeholders**

  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of decisions with uncertain best solution (dynamic organizational complexity).
  - **Description:** The inherent trade-off between cost and quality in R&R projects creates a continuous field of tension. These tensions are driven by major budget deficits in the coming period decades, which again address the need for a cost-effective approach. However, as RWS is also knowledge-rich organization consisting of many experts in various field, it values technical quality and innovation, with specialists advocating for high standards. As a result, it remains difficult to arrive at objectively cost-effective solutions. This complexity follows from epistemic uncertainty, as a clear framework for balancing cost and quality is currently lacking. This framework is the Base Quality Level (*Basiskwaliteitsniveau, BKN)*, which is supposed to guide practitioners in their decisions, but is still under development. However, even with such a framework in place, PM teams will still decide to which extent it will be utilized in specific cases.
  - **Uncertainty source:** Epistemic.

- **Development of the Base Quality Level (BKN) framework impacts projects in active development**
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
  - **Description:** The Ministry of I&W is currently developing the BKN framework, in an effort to establish guidance for determining the future quality and performance of infrastructure. As developments are currently ongoing, the exact implications for R&R projects currently in active development and in the future remain uncertain. This uncertainty is of an epistemic nature, as it stems from the lack of a baseline, thus creating ambiguity regarding project requirements and scope.
  - **Uncertainty source:** Epistemic.

- **Acquiring and leveraging in-house expertise for alignment and risk embracement**
  - **Categorization according to complexity categorization framework (Table 4.1):** Find and keep motivated people adequate to the challenge (dynamic organizational complexity).
  - **Description:** RWS, among many other organizations active in the construction sector, faces a significant challenge in finding and retaining the professionals adequate to deal with the (technical) complexity of R&R projects. Due to downsizing of the organization in recent years, many formerly in-house experts now work for private firms. As many processes still rely on expert judgment, being able to leverage technical expertise remains of pivotal importance. Technical expertise lays the foundation for substantiated decision-making required to align project approach with the contractor, which must be able to rely on the boundary conditions and assumption provided by RWS. This complexity stems from epistemic uncertainty, as expertise forms its core.
  - **Uncertainty source:** Epistemic.

- **The decision-making process for choosing a contract type or approach is obscured by an array of factors**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of decisions with uncertain best solution (dynamic organizational complexity).
  - **Description:** RWS may choose from a large number of contractual and billing approaches, each with their own trade-offs in risk-ownership, project control, and financial incentives. A single best choice may be difficult to determine if project preconditions are ambiguous. It is epistemic uncertainty, as preparatory efforts and experiences from other projects will aid PM teams in choosing an appropriate contract form for delivery of the project.
  - **Uncertainty source:** Epistemic.

- **Integrated contracts leading to shifts in procurement and risk allocation between parties involved**

  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
  - **Description:** The move towards functional specification and integrated contracts redistributes risks between RWS and contractors, introducing new forms of collaboration and procurement. Although integrated contracts have been around since the 2000s, the exact implication of this contractual approach remain unsure in R&R projects. Experience with these contracts in R&R projects will allow for best practices to be established, but as of now, lacking knowledge results in epistemic knowledge.
  - **Uncertainty source:** Epistemic.
- **Insufficiently formalized financial governance under novel strategic arrangement**
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
  - **Description:** Responsibility for the cost control checks-and-balances has shifted from the Ministry of I&W towards RWS, in an effort to improve operational flexibility. Previously, the Ministry acted as a counterweight, approving cost estimates, and enforcing more cost-cutting solution in infrastructure projects. The dynamics between these two organizations have shifted, especially with regards to the projects executed under the 1-to-1 replacement project. It makes RWS now both the implementer and controller, with no independent overseer for the majority of projects. It is epistemic uncertainty, in the sense that PM teams face unclear expectations in cost control outcomes, due to the evolving responsibilities within RWS as an organization.
  - **Uncertainty source:** Epistemic.
- **Mismatch between intervention urgency and realizability within available budget and capacity**
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
  - **Description:** As a growing number of structures reaches the end of its expected service life, the need for large-scale continues to rise. However, the capacity of RWS to identify, develop, and execute R&R projects is already under pressure. As a result, a field of tension arises between the urgency of interventions and the practical realizability of renewal projects, i.e., the degree to which projects can actually be executed. Additionally, The Ministry of I&W, and thus RWS, faces major budgetary deficits in the near future, meaning that projects will have to be prioritized as there simply is not enough funding to execute all of them. The uncertainty in this complexity stems from the unavailability of knowledge regarding future budgets, prioritization outcomes, production capacity (realizability), etc.
  - **Uncertainty source:** Epistemic.

5.6. Time complexities

This section provides an overview of the temporal complexities identified from the practitioner interviews.

5.6.1. Dynamic complexities

All time complexities, belong to the dynamic complexity subcategory:

- **Phasing and scheduling constraints for project activities under stakeholder agreements**
  - **Categorization according to complexity categorization framework (Table 4.1):** No sequential process of implementation (dynamic time complexity).

  - **Description:** Time windows for traffic accessibility (e.g., rush hour opening, weekly maritime passages), follow from agreements with regional stakeholders. However, they impose strict scheduling constraints, primarily for the contractor. It effectively reduces their time available to work, therefore requiring comprehensive approaches to complete tasks within limited amounts of time. Because these requirements change, based on stakeholder negotiations and evolving priorities, the uncertainty residing in this complexity is epistemic.
  - **Uncertainty source:** Epistemic.
- **Project phasing remains subject to change due to developments in the social environment**
  - **Categorization according to complexity categorization framework (Table 4.1):** No sequential implementation process (dynamic time complexity).
  - **Description:** Project phasing cannot follow a step-by-step sequence, due to changes in stakeholder preferences, political pressure, and evolving requirements. In order to comply with legal and social prerequisites, a complex approach is often required, i.e., using new, existing, and temporary structures to facilitate an to all parties acceptable temporary situation while construction takes place. As a result, it becomes impossible to determine the final layout of the temporary situation and construction stages in advance, as this requires ongoing planning and research efforts. It is epistemic uncertainty, as assumption must continuously be validated throughout the project, and it thus can be reduces through such efforts.
  - **Uncertainty source:** Epistemic.

5.7. Overview of identified complexities

In this chapter, a variety of complexities have been identified through the complexity categorization framework provided by Hertogh and Westerveld (2009). The complexities have been incorporated into an overview, shows in Figure 5.1

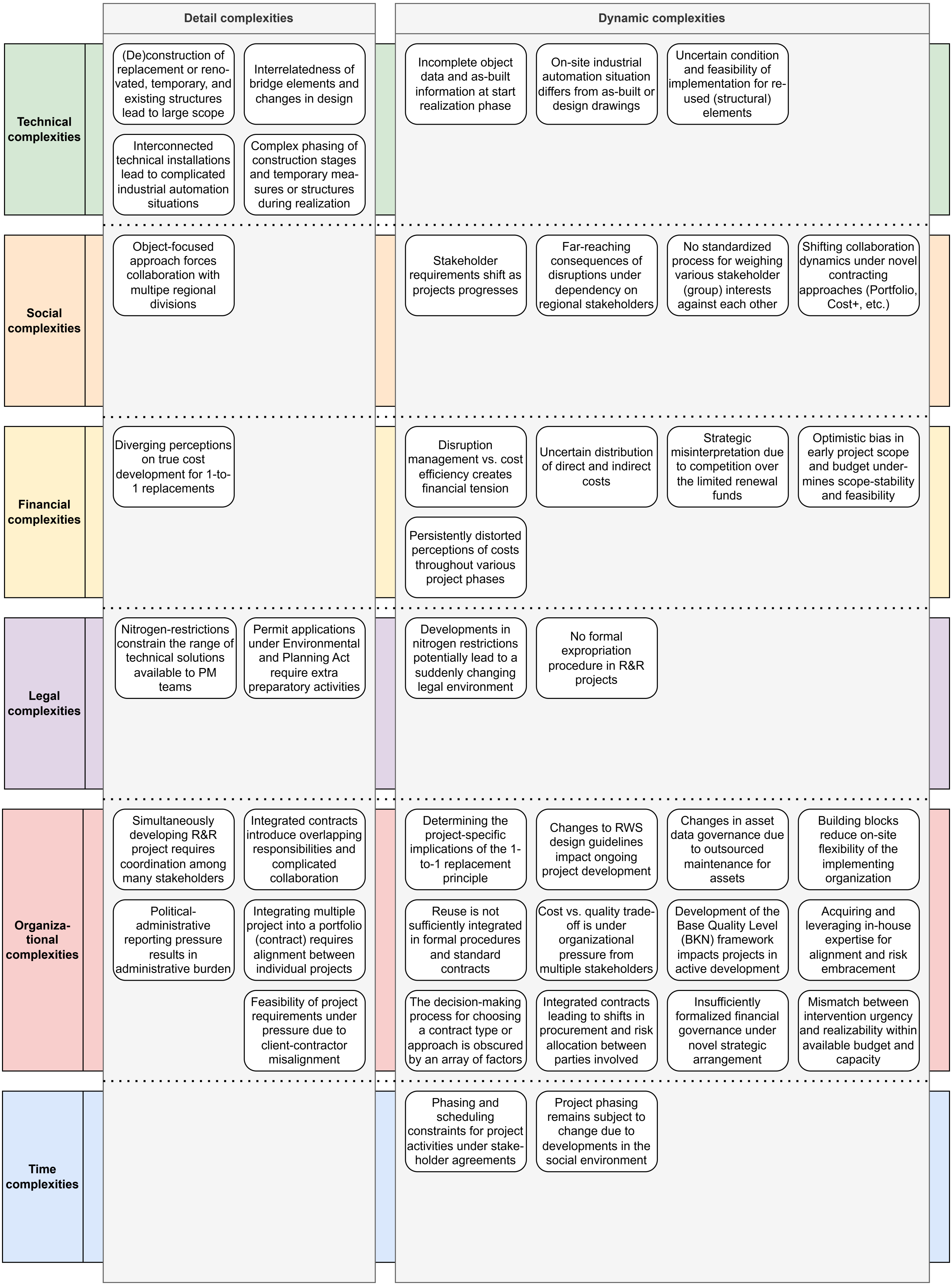

Figure 5.1: An overview of the complexities identified in the practitioner interviews.

5.8. Chapter summary and conclusion

This chapter illustrates that a variety of complexities are present in R&R projects. From the overview presented in Figure 5.1, it can be seen that dynamic complexities are most prominent. This view corresponds with the perception of that practitioners R&R practitioners hold, that these project are uncertain. Furthermore, organizational complexities form the dominant category within the framework, as a significant amount have been identified compared to other those in other categories.

In conclusion, it has now been established which complexities and underlying uncertainty contribute to R&R projects being perceived as challenging. To high-level, but comprehensive overview illustrates the ecosystem of infrastructure renewal at RWS. It provides the foundation for the in-depth research into specific key complexities, as conducted in the next chapter.

6

Unpacking the case study's complexities

This chapter embodies the single case study that has been conducted within this research. The study examines an exemplary R&R project, through which complexities, identified in the previous chapter, are illustrated and examined. By providing real-life examples, the findings are grounded into practice, allowing for better alignment between theoretical findings and empirical evidence. The chapter begins by elaborating on the case study design in Section 6.1, followed by a brief description of key characteristics of the selected case in Section 6.2. Consequently, the complexities identified by practitioners are provided in Section 6.3. The manifestation of these complexities in the project have been illustrated through practical examples, followed by an in-depth analysis of their underlying mechanisms. The results have been visualized in a cause-and-effect diagram in Section 6.4.

6.1. Case study design

This section discusses the overall design of the case study, and its purpose within the research. The first objective of the case study, is to ground the findings from the practitioner interviews (Chapter 5) into practice through illustrating them with examples from an actual R&R project. This will deepen the findings from the interviews, as these are based primarily on the experiences that practitioners have collected from multiple R&R projects, which they have worked on or are currently working on. The second objective of the case study is the most important. This is to identify the primary complexities that cause financial setbacks.

6.2. Case selection

The R&R project that has been selected for the case study is named: R&R Civil Structures A44 (*V&R Civiele Kunstwerken A44*). The A44 is a national highway, and thus a part of the HWN. It is an important traffic corridor for road vehicles traveling between the cities of The Hague and Leiden, and also connects these cities to multiple towns located in the Dune and Flower Bulb Region (*Duin- en Bollenstreek*). It starts at the Burgerveen junction near Burgerveen/Leimuiden, where it splits from the A4 highway, and ends near Wassenaar. The highways has a 2x2 layout over the complete trajectory, i.e., two driving lanes in both directions.

It is one of the oldest highways in the Netherlands, as its construction took place during the 1930's. The first road section between Amsterdam and Sassenheim was opened in 1938. As a result, the highway incorporates several structures that predate the Second World War, which are now nearing their technical EOL. As a safety measure, a weight limit has been instated for some of the structures part of the A44 highway. Since 2020, a weight limit denied access to vehicles heavier than a 100 tons. Per 2025, the weight limit was lowered to 50 tons.

6.2.1. Project scope

The project scope of the R&R Civil Structures A44 project encompasses the replacement of four structures. The structures scheduled for intervention are:

- **Kaag Bridge *(Kaagbrug)*:** A movable bridge that consists of two bascules (north and south bridge) located in Buitenkaag, spanning the Haarlemmermeerse Ringvaart waterway.
- **Hoofdvaart Viaduct (*Hoofdvaartviaduct*):** A viaduct that spans the Hoofdvaart Canal near Abbenes.
- **Spoorweg Viaduct (*Spoorwegviaduct*):** A railroad viaduct, crossing a main railway line near Sassenheim.
- **Lisserweg Viaduct (*Lisserwegviaduct*):** A viaduct carrying the A44 highway over a local road (Lisserweg).
- **Nieuwerkerkertocht Culvert *(Duiker Nieuwerkerkertocht*):** Due to changes to the alignment of the highway at the location of the Kaag Bridge, replacement of this culvert was also included in the project scope.

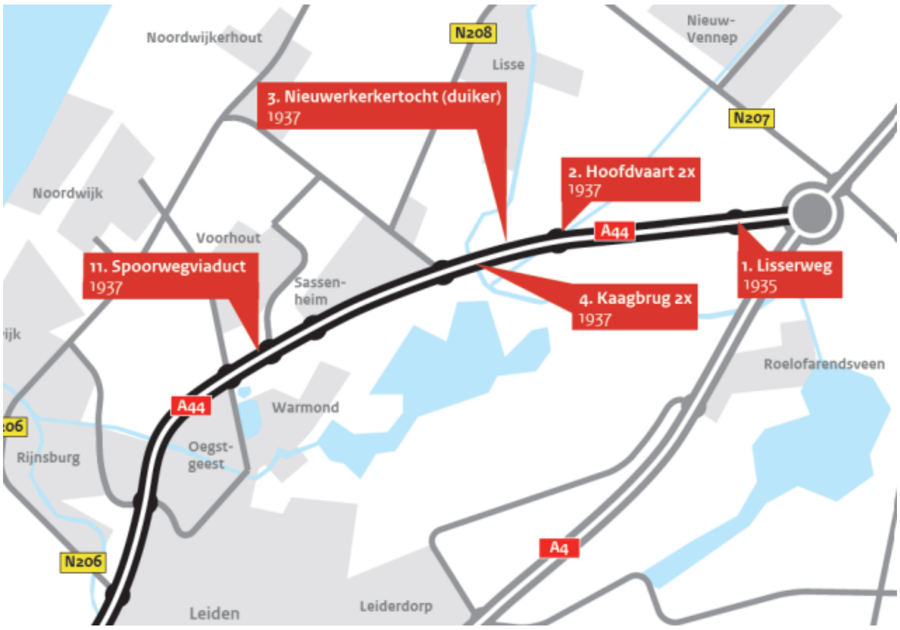

Figure 6.1: Map of the R&R Civil Structures A44 project. Retrieved from: www.projecta44.nl

The Kaag Bridge is the most critical structure within the project scope, as it is the largest and most complex object. This is also reflected by the distribution of project budget, with the Kaag Bridge accounting for approximately 51% of the total cost (Figure 6.2). Since the bridges are movable, it is not only an essential connection for road users, but also for maritime vessels passing through the Ringvaart waterway.

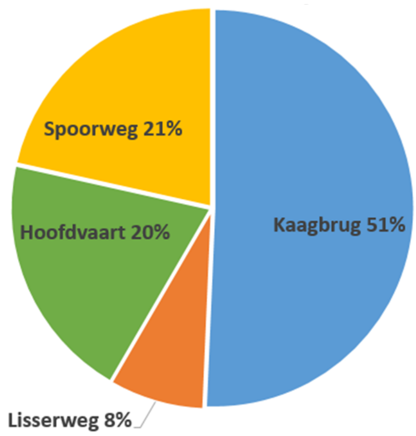

Figure 6.2: Distribution of project budget per object in the project scope of the R&R Civil Structures A44 project. (Rijkswaterstaat, internal document, 2023)

6.2.2. Phasing plan Kaag Bridge

The Kaag Bridge is a bascule bridge, consisting of two separate bridge decks, as shown in Figure 6.3. The bridge complex will be replaced by a structure that again utilizes two separate bridge decks.

Figure 6.3: Top view of existing the Kaag Bridge, displaying the two separate bridge decks. Retrieved from: www.projecta44.nl

First, the south side of the new bridge will be constructed in between the existing bridge Kaag Bridge and a nearby railway bridge. After completion, the newly constructed south side will be utilized to reroute traffic on the A44 in both directions, so that the existing Kaag Bridge can be closes and demolished. After demolition, the north side of the new Kaag Bridge will be constructed on the site that was previously occupied by the existing Kaag Bridge. This approach is needed as the new Kaag Bridge is almost twice as wide as the existing structure, forcing RWS to optimally utilize their available space. This follows from the starting point that no additional grounds are to be acquired.

The significantly wider structure is a consequence of the increased width of driving lanes, and the addition of emergency lanes to the highway at the location of the bridge. The existing Kaag Bridge has narrow driving lanes and no emergency lanes. However, despite utilizing the available space to the fullest extent, no full compliance with the ROA could be achieved, as the full width, for the lanes and thus the entire structure, prescribed by the design guidelines could not be achieved. This forced the PM team design a narrowed emergency lane, but after prolonged coordination with upper management of the GPO division, that ultimately had to provide their formal approval.

The changes to the bridge design also sparked the need for additional road safety research, as the alignment of the highway shifted southward. This research was to ensure compliance with other ROA requirements, such as sight distance in curves, gradient, cross-fall, transition curves, and overall driving comfort, all of which influence traffic safety and operational performance. The works that are to be executed for the realization are carried out nearby existing structures and life traffic. This is to be taken into account, since construction and demolition works must thus be executed in confined areas. Additionally, these activities pose a threat to vehicles crossing the bridge.

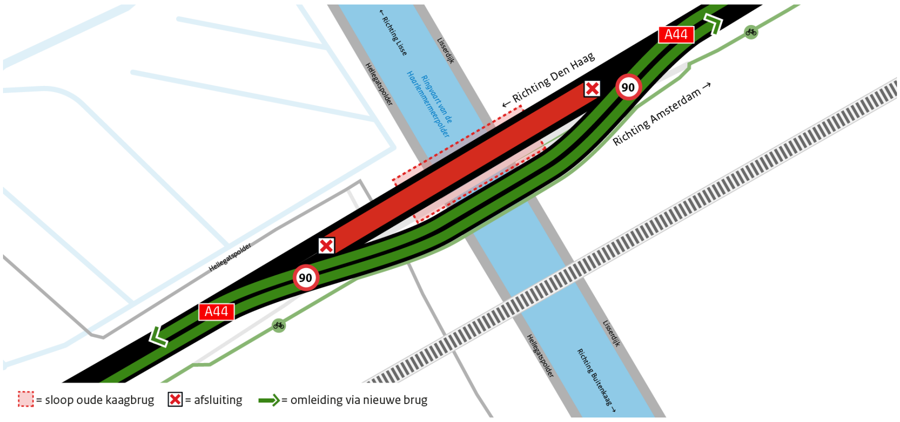

Figure 6.4: Planned rerouting of traffic from the existing bridge (red) over the newly constructed bridge (green). Retrieved from: www.projecta44.nl

Steps of in the phasing of the Kaag Bridge replacement (Figure 6.4):

1. *Construction of the southern part of the new bridge.*
2. *A bypass is created to reroute traffic via the southern part of the new bridge.*
3. *The the existing bridge is demolished.*
4. *Construction of the northern part of the new bridge.*

6.2.3. Phasing plan Spoorweg Viaduct

The replacement of the Spoorweg Viaduct will be executed through a phased approach, aimed at ensuring traffic continuity. A bypass is required at all times for keeping the highway operational. In the case of the Spoorweg Viaduct, this is facilitated through "sawing" the existing viaduct into two halves, which are then replaced one a time.

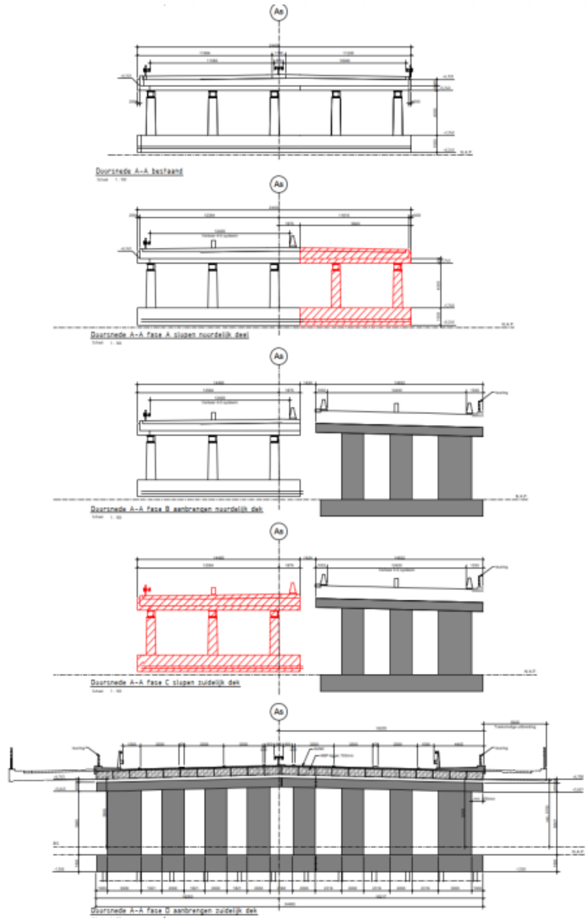

Figure 6.5: Cross-section overview (perpendicular to the traffic flow) of the project phasing of the Spoorweg Viaduct. Retrieved from: www.tenderned.nl

Figure 6.6: Bottom/side view of the existing Spoorweg Viaduct. Retrieved from: www.wegenwiki.nl

Steps of in the phasing in the Spooweg Viaduct replacement (top to bottom, Figure 6.5):

1. *The existing viaduct.*
2. *Sawing of the two halves, followed by the demolition of the northern part of the existing viaduct. Creation of a traffic bypass through rerouting traffic over the southern part of the existing viaduct.*
3. *Construction of the northern part of the new viaduct. Creation of a traffic bypass through rerouting traffic over the northern part of the new viaduct.*
4. *Demolition of the southern part of the existing viaduct.*
5. *Construction of the southern part of the new viaduct, finalizing construction.*

6.2.4. Exemplary character

The case presented by the project R&R Civil Structures A44 serves as an exemplary case for several reasons. First, as it involves a movable bridge and three viaducts, the project encompasses a differentiated project scope. This exemplifies the instrumental nature of the case, as these case seek to elucidate the features of a broader population (Seawright & Gerring, 2008). Additionally, the availability public information, supplemented by information provided by RWS, makes this case suitable for in-depth analysis.

Moreover, the project is currently under active development, with several structures now entering the realization phase. The project encompasses several noteworthy aspects, as indicated by the practitioner interviews. The underlying challenges introduces various detail and dynamic complexities.

Figure 6.7: The Kaag Bridge, with a nearby railway bridge operated by Prorail in the background. Retrieved from: www.infrasite.nl

6.3. Identifying key complexities leading to financial setbacks

During the in-depth interview, the PM team of the A44 project was instructed to compile a list with a top five of the complexities leading to financial setbacks in their project. The list based on the theoretical framework of Chapter 4, is displayed in Table 6.1. Furthermore, the PM team illustrated how these complexities manifested in the project, through providing concrete examples of their occurrence.

Rank	Complexity	Categorization
1	Insufficiently formalized financial governance under novel strategic arrangement	Dynamic organizational complexity
2	Acquiring and leveraging in-house expertise for alignment and risk embracement	Dynamic organizational complexity
3	Far-reaching consequences of disruptions under dependency on regional stakeholders	Dynamic social complexity
4	Complex phasing of construction stages and temporary measures or structures during realization	Detail technical complexity
5	Optimistic bias in early project scope and budget undermines scope-stability and feasibility	Dynamic financial complexity

Table 6.1: Shortlist of the five primary complexities identified during the in-depth interview to cause financial setbacks.

When Table 6.1 is compared to the overview provided in the previous chapter in Figure 5.1, it can be noted that only this research continues on a selected number of complexities, and not for the multitude of complexities identified during the practitioner interviews. It is simply not feasible, within the limited time available to conduct this research, to engage in an in-depth analysis of all complexities. Therefore, a selection has been made through the case study, of those complexities most influential in cuasing financial setbacks. Nevertheless, it must be stated that the complexities not included in the subsequent in-depth analysis are of a lesser importance than those that are included, as their identification and description provided detailed insight in the practical reality of R&R projects. These result still hold theoretical and practical value, but due to the limited time available within this research it was decided to prioritize the key complexities as identified in the case project.

6.3.1. Insufficiently formalized financial governance

The first ranking complexity that has been identified to cause financial setbacks is:

Insufficiently formalized financial governance under novel strategic arrangement.

Problem statement based on the A44 case
Under a novel governance arrangement, RWS is now solely responsible for the financial governance of the vast majority of R&R projects, but without clear guidance. As a consequence, PM team remain unsure who carries the authority to manage critical financial decisions, hampering the overall predictability of projects, and reducing project performance.

Context and detailed description
Since R&R projects have become increasingly abundant, the Ministry of I&W has adopted a different governance approach to offer more financial flexibility to its executive agency. RWS now works with a continuously updated project-programming, which essentially embodies a portfolio management system that monitors all R&R projects, including their schedules and budgets. The rationale for incorporating more (financial) flexibility into the project-programming was to reduce the required interactions between the Ministry and RWS. This allows RWS to allocate budgets as they see fit, thereby reducing a bottleneck in the decision-making processes. It also allowed the Ministry to transfer the funds allocated for infrastructure renewal to RWS as a whole, in an effort to speed up their production process due to the urgency of many R&R projects. The project-programming established two main components (Ministry of Infrastructure and Water Management, 2025):

- **Governance structure:**
  - **1-to-1 replacement:** No direct involvement of the Ministry. Encompasses the vast majority of R&R projects.
  - **Policy-driven:** RWS and the Ministry make joint decisions on the most critical starting points of the project.
  - **Special:** A joint steering group is present throughout the full duration of the project.
- **Schedule and budget:** The structural planning and sequencing, determining which projects will be executed when, and what budget will be made available.

Traditionally, the Ministry acted as the client for new infrastructure, through commissioning the project in which it is build . In this role, the Ministry acted as a ”financial counterweight” in the conversations regarding project cost developments. In the array of 1-to-1 replacement R&R projects, this financial counterweight is no longer present, leading to a transformation of the checks-and-balances performed in the financial decision-making. Under the current approach, RWS must perform these internally, which has prompted a shift of responsibility towards board members, and department heads. Key figures include the COO (Chief Operations Officer), CFO (Chief Financial Officer), and upper management of GPO. At RWS, the COO is responsible for managing and accelerating the overall infrastructure renewal task (*vernieuwingsopgave*). This often implicates that, if a project is to encounter a financial setback, the PM team must report and discuss this with the COO. The COO must then decide how the situation will be managed.

Observations from the R&R project Civil Structures A44
The shift in financial governance has placed projects in a complex transition phase. It is presented that, when unexpected issues arise, which may possibly require additional funding, there are two possible options: (i) The project is halted completely to find a solution, or (ii) the funds available are spent without knowing whether it was the optimal decision, as it may be at the expense of other priorities.

This dilemma primarily concerns the COO, who has effectively taken a role similar to the one previously held by the Ministry of I&W. The COO governs the funds allocated for infrastructure renewal, and must therefore decide what the course of action will be if a financial setback is encountered. Are additional funds allocated to the project to ”solve” the problem? Or must other priorities, such as traffic disruption mitigation or sustainability, be deprioritized in order to create budgetary room?

It has become apparent that those involved in such decisions are without clear guidance. Without a well-defined mandate, now largely concentrated at the COO or other directors, it has become challenging to execute project in a manner that is predictable and cost-effective. It is provided that, ideally, a continuous dialogue with the funding authority is in place to discuss the uncertainty margin, i.e., the budgetary allowance that account for risks and unforeseen developments. This is critical as the funding authority ultimately determines the quality standard: what is acceptable financial performance for this type of project, and what is not? Should additional funds be allocated to the project, or will this be at the expense of other priorities?

As it remains unclear what constitutes "healthy financial performance," problems will continue to arise. These problems mainly manifest themselves in the unpredictability of the project. It obscures the identification of a cost-effective approach, thereby also hindering the acquisition of additional funds if this proves to be necessary. Setbacks in individual projects can therefore cascade into others, as all R&R projects are incorporated into the overarching project-programming. The ongoing source of epistemic uncertainty can lead to a range of negative consequences, the extent and likelihood of which remain uncertain.

Multi-cause analysis

- **Cause 1.1: The financial governance is insufficiently formalized, leading to ambiguity regarding priorities and approval when financial setbacks are encountered.**
  - *General mechanism:* A PM team, when encountering a financial setback, must ideally decide what their action will be: (i) lower the functional requirements, (ii) simplify the chosen solution, or (iii) acquire additional funds (Horvat et al., 2022). To decide on this, a trade-off analysis between multiple priorities must be made, such as cost-efficiency, sustainability, and stakeholder management, etc.
  - *Evidence from A44:* The PM team indicates that it was unclear who was exactly responsible to formally agree and confirm financial decisions. In the project, both the COO and CFO have been involved in various financial decisions. The lack of clear guidance left the project unsure how to manage various situations. This uncertainty in the financial decision-making prolonged various critical decision-making processes, with as a consequence, obscured priorities and delays driving additional costs.
- **Cause 1.2: The starting point regarding reuse of structural elements varies per project and may change during project development.**
  - *General mechanism:* Reuse of structural elements is a topic of increasing interest from a sustainability perspective, and can be most critical to project performance as it has the ability to significantly decrease or increase costs, construction time, and traffic disturbance. Significant steps are made in the facilitation of reuse, as choosing to reuse structural elements, such as girders, parts of the superstructure, or foundations must be thoroughly prepared through various researches and logistical operations. To engage in these elaborate efforts, funds must allocated by the appropriate funding authority.
  - *Evidence from A44:* For the construction of the new Kaag Bridge, approximately 200 girders originating from another highway will be reused. An expert team of RWS identified, inspected, refurbished, and supplied these girders through a direct delivery. Consequently, the main responsibility of the contractor was to implement the girders into their design for the new bridge. This development is in line with RWS's sustainability and circularity objectives. It was, however, added to the project scope in a later stage. With reuse of these girders not being a starting point in the project, no budget was made available for the additional costs made for facilitating the reuse. This prompted the PM team to escalate this matter to their funding authority. Since additional funds had to be acquired, a financial setback was encountered.

6.3.2. Acquiring and leveraging in-house expertise

The second ranking complexity that has been identified to cause financial setbacks is:

Acquiring and leveraging in-house expertise for alignment and risk embracement.

Problem statement based on the A44 case

Gradual organizational transitions, combined with a workforce reduction in the early 2000s, and the current nationwide shortage of technical professionals has impacted the organization's overall capabilities and performance. The resulting challenges are most evident in efforts to ensure project feasibility through effective alignment with market stakeholders, and in the ability to leverage internal expertise to accurately assess and embrace the risks associated to project performance.

Context and detailed description
Between 2002 and 2011, RWS has reduced its workforce by around 20%, which totals to approximately 2100 FTE (Algemene Rekenkamer, 2013). One of the primary rationales for a downsizing of the staff is linked to the connotation that market parties would be able to facilitate activities, previously conducted in-house, more efficient. The emphasis of this outsourcing strategy in which more technical capabilities are allocated at external firms, has led to professionals leaving the organization. In this strategy, the shift towards the "functional specification," has played a central role. The setting of functional speciations entails that a contractor will execute a contractors as they see fit, within the technical and legal boundaries set by RWS.

How the expertise of the organization's technicians are managed and leveraged, is critical for adequately assessing and embracing the uncertainty in R&R projects. Despite the aforementioned organizational developments, RWS still knows a great number of experienced professionals and experts belonging to various technical disciplines. It is this knowledge, that must be adequately managed in order to fully capitalize on its potential in the infrastructure renewal efforts.

Observations from the R&R project Civil Structures A44
An example of these dynamics in the project Civil Structures A44 can be found at recently started realization of the Lisserweg Viaduct replacement. Upon execution of the intervention, beams were found in the underground. The discovery of structural elements during the realization phase is not uncommon in R&R projects, as the as-built situation often differs from what is displayed on design documentation. The risk of unknown parts of the structure residing in the underground was identified during development of the project, but despite research efforts from the contractor, there were not found until the actual realization. It provided the PM team with a situation in need of ad-hoc management, as removing these beam could potentially affected the structural integrity of the viaduct.

Figure 6.8: The beams discovered during the realization of Lisserweg Viaduct replacement. Retrieved from: www.projecta44.nl

Responsibility for the consequences that this discovery entails were allocated at RWS, causing concerns among those involved about potential complications. If something is to go wrong, then the highway would have to be closed, and the structural safety of the viaduct would compromised. Consequently, the PM team opted for a careful approach, delaying the project, as provided in communication towards regional stakeholders (Rijkswaterstaat, 2025c):

> The previously announced nine-day closure of the A44 in March 2026 will be postponed. The environmental manager expects that it will take some time before a new schedule is announced. The beams are part of the construction of the current viaduct. We cannot simply remove them. This makes the new working method more complex in any case. As soon as we know more, we will immediately inform local residents, road users, and other stakeholders. We are therefore carefully examining how we can keep the current viaduct safe while we build the foundations for the new viaduct. We are taking extra care to ensure that no unsafe situations arise for traffic or the surrounding area.

No ”quick fix” was developed, as making decisions on a potential short-term solution remains incredibly difficult, also due to legal and liability constraints. Individuals involved in such decisions, could be held (personally) accountable if severe unforeseen circumstances occur. This drives that individuals are careful when taking risks. Therefore, it remains important to leverage knowledge, so that risks can be properly assessed. However, it also takes willingness, grounded in the expertise, of those making the decisions. By taking risks earlier on, project might appear more expensive, as changes or adjustments take place during the front end stages. This will, however, ultimately save costly alterations during the realization of the project.

Multi-cause analysis

- **Cause 2.1: Insufficient management of RWS-retained as-built risks under the integrated contract.**
  - *General mechanism:* Integrated contracts types such as Design & Construct are commonly used in Dutch infrastructure projects. The contract type emphasizes the ”design obligation” of the contracted party, as the contractor is responsible for providing the design that will ultimately be constructed. Despite the allocation of responsibilities under this contract type, RWS remains ultimately responsible for managing both the contractor and the design process. Therefore, the RWS must retain control, applying sufficient technical expertise to effectively manage the design process and their contractors.
  - *Evidence from A44:* Early project documents made available in preparation for the tender highlighted a typical risk associated with R&R projects: The discovery of hidden parts of the structure during realization of the project, that are not indicated on design drawings or other documentation. Such discoveries may involve non-visible structural elements residing beneath the surface or underground. In the case of the A44 project, the risk of underground discoveries was specifically allocated at RWS. Therefore, RWS instructed the contractor to investigate whether structural elements were concealed below ground level.

    The contractor conducted several exploratory trenches and trial drillings, but nothing was found. However, during exaction works during the actual realization phase of the Lisserweg Viaduct, beams were found at a lower depth than had been examined. With no (financial) incentive for the contractor to perform a ”comprehensive” investigation, as the risk of underground discoveries was not assigned to the contractor, the trial trenches and drilling were insufficient to detect the hidden beams. With the risk of underground discoveries allocated at RWS, a more in-depth supervision could have been instated to ensure that the research was conducted thoroughly. As a consequence of this discovery during realization, the planning was severely disrupted.
- **Cause 2.2: Insufficient access to and utilization of RWS's technical expertise hampers making substantiated decisions on critical issues and presenting them convincingly internally and externally.**
  - *General mechanism:* In every project, a variety of critical decisions must be made by its PM team. For those decisions, it is of pivotal importance that those ultimately responsible posses sufficient technical expertise. As RWS underwent an organizational downsizing, several in-house capabilities have since deteriorated, and today's nationwide shortage of technicians makes rebuilding them a difficult task. Therefore, RWS utilizes specialized market parties to conduct various researches, often forming critical fundaments on which the decision-making

depends. However, despite the utilizing expertise from market parties, RWS remains ultimately responsible. This means the PM team must retain sufficient technical knowledge to critically asses the results provided by these market parties. Without a careful substantiation of these results, it becomes difficult to make well-informed decisions and to gain agreement from other stakeholders, such as contractors.

– *Evidence from A44:* The PM team indicated that doubts over structural safety hindered choosing a short-term decision, that would potentially limit the disruption caused by the discovery of the beams at the Lisserweg Viaduct. Potential consequences, such as the closure of the highway due to a risk of collapse, understandably pose a major concern to RWS and the individuals responsible, who may feel personally liable. As the risk of discovery was allocated to RWS, it was their responsibility to determine the appropriate course of action. With no standardized short-term solution in reach, it was decided to engage in comprehensive research efforts, thereby delaying the project.

6.3.3. Far-reaching consequences of disruptions

The third ranking complexity that has been identified to cause financial setbacks is:

Far-reaching consequences of disruptions under dependency on regional stakeholders.

Problem statement based on the A44 case
R&R projects involve infrastructure assets that remain in operation during interventions, which can consequently cause significant traffic disruption and pose major social impact for daily users such as commuters, businesses, and local governments. Stakeholders must therefore be managed carefully, while balancing disruption-mitigation measures and cost-efficiency, as failing to do so may result in public or political-administrative opposition.

Context and detailed description
The Netherlands is characterized by a densely populated and highly developed landscape. This built environment poses considerable challenges for PM teams working on R&R projects. During a project's realization, traffic disruption is unavoidable. Nevertheless, completely shutting down an asset within the HWN or HVWN is rarely ever feasible. The way in which traffic disruption is managed, i.e., the measures taken to ensure traffic continuity, has major social impact for those dependent on the infrastructure. It is import to maintain support from regional stakeholders, as failing to do so might result in their opposition. Consequences may range from complaints, to political-administrative actors blocking the permits required by PM teams for project realization.

Observations from the project Civil Structures A44
This dilemma also emerged in the Civil Structures A44 project. The PM team allocated additional funds to facilitate a temporary situation with an increased level of road safety. Based on the social context, the PM team felt it was necessary to maintain progress and mitigate potential opposition. Ignoring these developments could have prompted local complaints or led to the temporary situation being judges as unsafe, especially if disturbances caused hazardous traffic conditions.

The PM team provided that, if all went well, the overall impact may remain limited. However, if a severe incident (e.g., a fatal accident) was to occur on the detour route, then this would pose a major problem. In this case, the situation would inevitably escalate to the higher political levels, with their involvement slowing down progress and driving costs even further. Risk assessment in these situations is difficult, as not all effects are easily expressed monetarily. Moreover, the PM team takes a serious stance in responsibility, entailing that they simply cannot let dangerous situations develop without intervention.

Multi-cause analysis

- **Cause 3.1: PM teams feel compelled to take additional precaution measures due to changing stakeholder requirements and hard-to-assess social effects, despite the existing procedures.**
  – *General mechanism:* PM teams operate in a dynamic environment which includes numerous external stakeholders. These stakeholders may include local governments such as municipalities or provinces, as well as commuters, businesses, and all others who are dependent

on the infrastructure. This elaborate network of regional stakeholders must be managed carefully, as their preferences, and consequently their requirements, may shift as realization of the project approaches.

As the project becomes more tangible, for example through approaching closures and traffic rerouting, stakeholders may pressure the PM team for additional measures to further decrease the level of traffic disruption. These measures typically go beyond what has been established in the original project scope, through the Customer Requirement Specification (*Klanteisenspecificatie, KES*) procedure. The KES procedure defines the regional stakeholders' requirements for project execution, particularly those related to reducing traffic disruption.

– *Evidence from A44:* Safety is stated as a top priority in the case project. Additionally, the PM team states that the social consequences of the project (safety, political capital, reputation, willingness of cooperation) can be severe, are difficult to estimate, and cannot easily be monetized. As a result, it remains challenging to determine what measures are proportionate to the severity of the stakeholder-related issues that develop, causing the PM team to default to precautionary measures. From the perspective of executing projects in a cost-efficient manner, allocating additional funds for increased disruption mitigation poses a threatening, cascading effect to other priorities.

- **Cause 3.2: Lack of a "project-decision" makes PM teams dependent on municipalities for permit approval, which can bottleneck decision-making.**
  - *General mechanism:* Traditionally, projects for construction of new infrastructure were executed under the MIRT framework, which provided a specific legal instrument: the project-decision (*projectbesluit*). This instrument is absent in R&R projects, meaning that PM teams work under the "regular" Environmental and Planning Act permit system. In this system, permits are issued by municipalities. As a consequence, PM teams are highly dependent on municipal cooperation, as there is no alternative legal route. If disagreements persist, the case must be brought before a legal court.
  - *Evidence from A44:* The PM team indicates that they felt pressured to implement additional measures to limit traffic disruption. Additional funds were allocated to enhance the robustness of deviation routes. Members of the public may express their concerns through submitting complaints, and if such situation are not managed, political-administrative escalation may occur. Continuous complaints may therefore lead to heightened political-administrative examination, and potentially permit blockage. This would especially be the case if a serious incident, such as a fatal accident were to occur as a result of the temporary situation. This political-administrative scrutinization will inevitably slow down decision-making in the project, driving additional costs.

6.3.4. Highly complex phasing

The fourth ranking complexity that has been identified to cause financial setbacks is:

Complex phasing of construction stages and temporary measures or structures during realization.

Problem statement based on the A44 case

Whereas traditional construction projects focus solely on building a new structure, R&R projects typically include the renovation or replacement, and (partial) demolition of the existing structure. This combination of activities, along with utilization of various temporary works to ensure structural integrity and traffic continuity, necessitates a complex construction phasing throughout realization of the project.

Context and detailed description

The project scope of an R&R project is typically more diverse than the project scope of an greenfield construction project. When the time for intervention has arrived, and renovation is selected as the approach for renewal of the asset, then various preparatory activities may be required. This typically includes the (partial) deconstruction of specific elements, such as the dismantling of a bridge machine room, or removing materials to allow access to concealed parts of the structure. In the case of replacement, the existing bridge must eventually be demolished.

Additionally, the temporary situation prior to and during realization of the project contributes significantly to the project scope. In the temporary situation, two main functionalities must be facilitated through incorporating specific project scope. The first functionality relates to structural integrity of the structure, which may become at risk due to the nearing technical EOL. To safeguard the structure until the the intervention has been finalized, a number of measures can be taken. Temporary load-bearing supports can be used to stabilize the structure, and traffic restrictions can reduce the intensity of loading cycles.

The second functionality is the facilitation of traffic continuity, ensuring that this is conducted in a manner that is safe to both road/waterway users and construction workers. This typically includes the design and realization of traffic deviation routes, utilizing a traffic bypass, and employing construction zone protection. In some cases, auxiliary structures are employed, such as temporary bridges or temporary fixed bridge decks (for otherwise movable bridges).

Observations from the project Civil Structures A44
In the R&R project Civil Structures A44, a total of four structures are to be replaced. The project scope includes one movable bridge and three viaducts. Executing their replacements in a safe manner while ensuring traffic continuity is a complex task, requiring a comprehensive phasing plan. The complex phasing required for the replacement of structures is illustrated through the phasing plans of the Kaag bridge (Section 6.2.2) and Spoorweg Viaduct (Section 6.2.3).

Multi-cause analysis

- **Cause 4.1: Widening and reinforcing of structures to comply with modern technical regulation and RWS design guidelines is not sufficiently incorporated into early cost calculations.**
  - *General mechanism:* To comply with modern technical regulations and RWS design guidelines, it is often needed to undertake a major overhaul of the legacy design of the original structure. Safety standards have increased through the years, now setting new standards many specifications with regards to strength and resilience, e.g increased thickness of a bridge deck or the overlay of concrete elements. Additionally, road and waterway design guidelines dictate other measures for reducing the risk and severity of accidents.
  - *Evidence from A44:* The existing Kaag Bridge was built in the 1930's, and by current standards is considered to be narrow. To comply with the ROA, it is necessary to increase the width of the driving lanes and add emergency lanes. As a result, the replacement structure is almost twice as wide as the original structure. Early cost calculations are primarily based on material unit prices and surface area of the structure that is to be constructed. If the implications of modern regulations and guidelines, i.e., a widened structure with an increased surface area, is not incorporated in early cost calculations, then a financial setback will inevitably emerge. Consequently, this financial setback is not the result of the project itself, but rather a consequence of inaccurate early cost calculations, that do not account for the additional surface area of the replacement structure.
- **Cause 4.2: Cost reference numbers do not sufficiently account for the complex phasing required for a bridge replacement including a traffic bypass.**
  - *General mechanism:* Closing a bridge that is a part of a national highway for an extended period of time is almost never a viable option for RWS. This would cause unacceptable levels of traffic disruption for large regions. As a consequence, the replacement of a bridges often encompasses the construction of a traffic bypass, allowing for traffic continuity during project realization. Creating a bypass may require building a new structure first, or using a part of the existing structure, to reroute traffic. Additionally, these bypasses must be constructed on the grounds owned by RWS, as legal constraints limit the acquisition of additional grounds.

    These developments drive that construction must be phased, often consisting of various cycles of construction and demolition. Ideally, it would be most efficient to first demolish the existing structure, and then build the replacement structure. As a consequence, the phased approach drives additional costs compared to a traditional, linear approach. In early cost calculations, such as those presented in the Prognosis Report (Rijkswaterstaat, 2022), do not specifically account for the costs associated with complex phasing. As a consequence, when it becomes clear during the plan development phase that such complex phasing is required, costs are higher than initially anticipated, resulting in a financial setback.

- *Evidence from A44 (Kaag Bridge):* The team first constructs the south side of the new bridge. As construction is finished, traffic in both directions will be rerouted over the new structure. The old bridge is then closed and demolished, after which the cleared area will be used to build the new north side of the bridge.
- *Evidence from A44 (Spoorweg Viaduct):* Work proceeds in halves. The existing viaduct is cut lengthwise, separating the viaduct into two halves. Traffic flow remains on the south side while the north side of the viaduct is demolished and replaced. After the new north side is completed, traffic is transferred to it, enabling the contractor to demolish and replace the south side of the viaduct.

6.3.5. Optimistic bias in early project scope and budget

The fifth ranking complexity that has been identified to cause financial setbacks is:

Optimistic bias in early project scope and budget undermines scope-stability and feasibility.

Problem statement based on the A44 case
An optimistic bias is often observed in R&R projects, leading to underestimation of both project scope and the budget required for execution. Misalignment primarily emerges during the handover of the project from the preparatory phases, managed by a regional division, to the subsequent development by a national division, during which the initially proposed plans may prove infeasible.

Context and detailed description
An optimistic bias seems to be affecting the early stages of R&R projects, in which the emphasis lies defining project scope and the budget required for realization. If the project scope is to change in a later stage, the stability of the project scope is immediately negatively affected. As this initial project scope hold a strong relationship with the budget reserved for execution of the project, project scope changes can undermine the overall feasibility of the project. In R&R projects, multiple mechanisms can contribute to instability of the project scope, with some of them stemming from an optimistic bias.

As an increasing amount of structures approaches their technical EOL, more intervention projects will be executed. However, most experience at RWS stems from traditional greenfield projects, meaning that the experience gained in R&R is currently still overshadowed by the extensive expertise developed in the past decades. As a consequence, it is indicated that identifying the full scope of an R&R project remains difficult, leading to gaps in the project scope.

Observations from the project Civil Structures A44
The PM team indicate that, shifting definitions, subjected to organizational and political-administrative developments, lead to unstable project scope. It is therefore provided that, it is better for R&R projects to aim for a well-supported, stable, and robust project scope. The robust characteristic relates to the stability of the project scope, decreasing the risk of sudden changes.

Moreover, it is stated that the primary moment when the an optimistic bias in the project scope emerges, is during the project handover between different RWS divisions. At RWS, the initial project phases of R&R projects (OIB, RA, and in some cases PF) are executed by a regional division. The plan development realization phases are primarily carried out by GPO. This was also the case in the R&R Civil Structures A44 project, where this team found themselves faced with an optimistic bias in the early project scope and budget.

As the RWS design guidelines, such as the ROA, form an starting point in the project, the structure that is to be build must comply with these guidelines. However, space restrictions prevented the new Kaag Bridge from full compliance, as the wider driving lanes and added emergency lane could not adhere to the width prescribed. Coordination was sought with the upper management of the GPO division, to determine how this problem could be solved. Eventually, the width of the lanes in question were decreased in the design, so that the new Bridge could fit in the space available. As these compliance problems were not foreseen in the early project phases, changes to the project scope had to be made. Additionally, coordinating this decision-making process requires time, driving additional project cost.

Besides the coordination required for compliance, a "bridging strategy" was also required in this project. The technical EOL of the structures dictated their replacement to be scheduled before 2024, but this proved to be unachievable, with the finalization of the intervention now set for 2030. In the case of the A44, measures included in the bridging strategy consisted of a 50 ton weight limit, an overtaking ban for lorries, the continuous repair of cracked concrete, and a heightened inspection regime for the assets (Rijkswaterstaat, 2025f).

Multi-cause analysis

- **Cause 5.1: Inability to comply with the RWS design guidelines specified in the project scope form due to spatial constraints necessitates ongoing coordination.**
  - *General mechanism:* The project scope form establishes what regulations or guidelines form the minimum requirements. At a minimum, structures in the Netherlands must be constructed in accordance with the prevailing technical regulations, such as Eurocodes or NEN-norms. However, in the Netherlands, RWS is required by the Ministry of I&W to develop infrastructure in compliance with their own design guidelines (ROK, ROA, RV). These design guidelines prescribe a "higher quality level" than the mandatory technical regulations, offering an increased level of safety and structure resilience.
  - *Evidence from A44:* The A44 case knows two prominent changes mandated by RWS design guidelines. First, the vertical alignment (height difference between highway sections) in between the structures will be adjusted. Low-lying sections in between structures blocked drivers' line of sight on the highway. Secondly, and most important as evidence to this mechanism, the replacement Kaag Bridge had to be significantly wider to comply with ROA requirements. As a consequence, the new structure will be almost twice as wide as the original structure. However, no additional grounds could be purchased or expropriated. Fortunately, the PM team benefited from the fact that grounds owned by RWS were available in between the existing Kaag Bridge and a nearby railway bridge, which is owned by ProRail.

    Despite the PM team being able to utilize additional space, it did not provide sufficient room to construct the new structure in full compliance to the ROA. Due to limited space, the driving and emergency lanes could not be constructed in the full width that was prescribed, meaning that the PM team had to coordinate efforts to deviate from the design-guideline requirements. As a result, the PM team indicated that this formed an issue requiring extensive coordination, delaying progress.
- **Cause 5.2: Limited RWS overview of intervention urgency results in intervention dates exceeding the technical EOL, necessitating the implementation of a bridging strategy.**
  - *General mechanism:* The inspection regime for RWS structures is currently too infrequent, caused by a lack of capacity. This provides that there is no validated overview of structures and their technical EOL, causing interventions to be scheduled later than the technical EOL date would dictate. As a consequence, a strategy is needed to "bridge" the time between the technical EOL and finalization of the intervention. This bridging strategy often consists of measures to safeguard the structural safety of the asset (additional load-bearing support, emergency repairs) or measures to reduce traffic loads (overtaking bans, weight limits).
  - *Evidence from A44:* RWS started the Civil Structures A44 project in 2021, due to various signals indicating the approaching technical EOL of some structures. In the initial project scope, 17 structures were included. After in-depth inspections and further analysis, it was established that four objects were in need of urgent intervention, with their technical EOL set for 2024. The other structures were cleared for another 15 years of service without R&R intervention. After further project development, it emerged that the first structure (Lisserweg Viaduct) would be replaced in 2025, and the last in 2030 (Spoorweg Viaduct). As a consequence of the intervention dates exceeding the technical EOL, a bridging strategy was required.

    This strategy consists of a weight limit (50 tons), an overtaking ban (for lorries), and continuous repairs to rapidly degrading concrete elements. As a consequence of insufficient capacity to execute inspection and develop timely subsequent R&R projects, a bridging strategy is required, driving additional costs. These costs are not included in early cost calculations, meaning that they trigger a financial setback when it becomes clear that such measures must be incorporated into the project scope in a later project phase.

6.4. Cause-and-effect diagram

The results of the analysis in this chapter have been summarizes into a cause-and-effect diagram. The diagram, shows in Figure 6.9 visualizes what mechanism underlie the key complexities that cause financial setbacks in the case study.

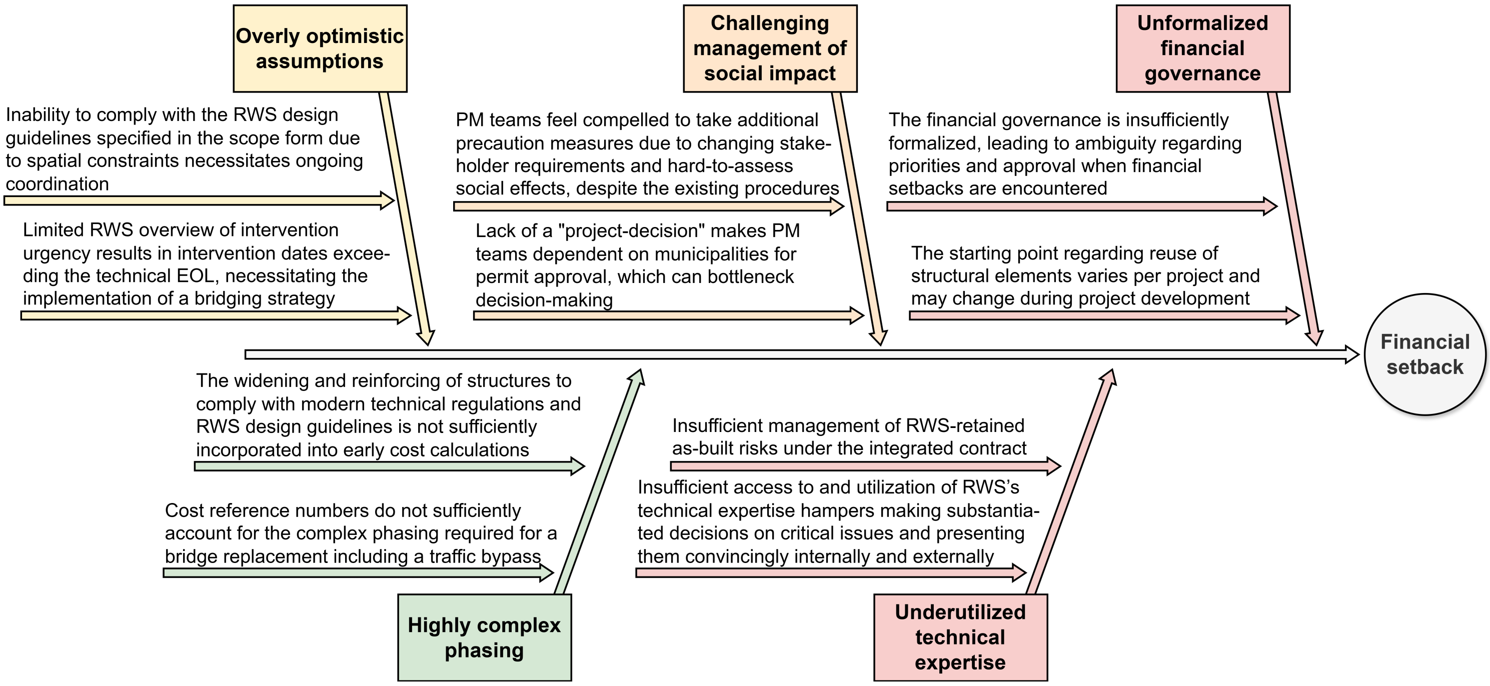

Figure 6.9: Cause-and-effect diagram of the primary complexities leading to financial setbacks and their underlying mechanisms in the case project.

6.5. Chapter summary and conclusion

This chapter present the case study that has been conducted in order to establish which of the complexities identified in Chapter 5 embody the primary causes of financial setbacks in the Civil Structures A44 project. The case project, involves the replacement of four structures, which included one movable bridge and three viaducts, all of which are incorporated in the A44 highway.

In conclusion, the case study provided practical examples, which illustrate how five complexities manifest themselves in the project, and why these cause financial setbacks. These key complexities underwent an subsequent in-depth analysis, to establish which mechanism underlie them. In total, ten mechanism were identified and summarized in the cause-and-effect diagram. This diagram provides the foundation for the next chapter, in which measures to improve the effectiveness of the R&R Approach project delivery framework are designed.

Part III

Develop

7

Framework enhancement and mitigation approaches

This chapter encompasses the process of designing mitigation measures aimed at managing the complexities identified to cause financial setbacks in the previous chapter. The recommendations are provided per complexity, provided in Sections 7.1 to 7.5. How these recommendations can be implemented in the R&R Approach and the organizational processes of RWS, is stated in 7.6.

7.1. Insufficiently formalized financial governance

The first key complexity identified as causing financial setbacks has been defined as:

Insufficiently formalized financial governance under novel strategic arrangement.

This complexity has been found to result from two main causes. To improve the management and/or mitigation of these causes, recommendations 1.1 and 1.2 have been provided below.

- **Cause 1.1: The financial governance is insufficiently formalized, leading to ambiguity regarding priorities and approval when financial setbacks are encountered.**
- **Recommendation 1.1: Reduce uncertainty in the financial decision-making through formalization, by instating director(ate) that acts as a central point of contact for PM teams and thus oversees the project-programming, prioritizes issues, and provides formal approval.**

  RWS is a large organization, with management and administration distributed across various levels. The most prominent actors in critical financial decision-making for R&R projects are executives such as the CFO, COO, and the upper management of the GPO division. Uncertainty in projects stems from finding who is formally authorized to make financial decisions. Additionally, making such decision is a difficult task: allocating funds to cover a financial setback may imply that another priority will receive less resources.

  Overseeing the numerous priorities across all R&R projects, e.g., production capacity, sustainability, or quality, while balancing them against cost, is a complex undertaking due to the many intricate relationships both at the individual project level and the overall R&R project-programming. To establish a centralized decision-maker, and to clarify who is authorized to make critical financial decisions, a central director(ate) supported by relevant staff may be appointed. This will establish a formalizing framework, enabling PM teams to consult a central authority, clarifying guidance in the financial decision-making, and reducing the epistemic uncertainty that is currently present.

- **Cause 1.2: The starting point regarding reuse of structural elements varies per project and may change during project development.**
- **Recommendation 1.2: Design standard procedures for the reuse of structural elements to reduce technical uncertainty, through establishing universal starting points and dedicated**

expertise.

- *Set identifying possibilities for reusing structural elements within the project as a mandatory starting point to seize the opportunity for improving project performance.*

  Reusing structural elements, especially those embedded in hard-to-reach locations, offer a major opportunity to improve project performance. In general, it will simplify the design and construction process, saving cost and reducing traffic disruption.

- *Determine the priority of reusing structural elements obtained from other projects (external) in relation to cost-efficiency, and establish an uniform starting point for all R&R projects.*

  Reusing structural elements from other projects or structures contributes to sustainability and circularity objectives, but it in some cases it also entails additional costs. Extra budget must be allocated to facilitate the process required for identifying, refurbishing, and implementing reused elements into the design and construction process of the renewed structure. As significant budget deficits are already expected for infrastructure renewal, it is advisable to determine if reuse is a priority that is to be pursued, or that it must be ignored due the fact that R&R projects must be executed in a cost-effective manner.

- *Set up a dedicated expert cluster at the Bridge Yard, which can act as a panel to support PM teams in determining reuse possibilities for R&R projects in the RA phase.*

  Reusing structural elements is never without risk. Potential issues may be related to structural integrity, integration into the design, or overall logistics. RWS is currently developing its 'Bridge Yard,' which is a physical location where (parts of) bridges will be renovated and stored, and where specific bridge types (movable, steel, concrete) will be consolidated into dedicated and continuous workflows. Establishing a dedicated expert cluster at the Bridge Yard will allow for a centralized panel of specialists to support PM teams in determining possibilities for the reuse of structural elements in their projects, thereby potentially enhancing project performance.

7.2. Acquiring and leveraging in-house expertise

The second key complexity identified as causing financial setbacks has been defined as:

Acquiring and leveraging in-house expertise for alignment and risk embracement.

This complexity has been found to result from two main causes. To improve the management and/or mitigation of these causes, recommendations 2.1 and 2.2 have been provided below.

- **Cause 2.1: Insufficient management of RWS-retained as-built risks under the integrated contract.**
- **Recommendation 2.1: Develop a standardized, comprehensive framework that explicitly defines how the as-built situation and presence of hidden elements is determined, and which defines the minimum level for asset data maturity.**
  - *Explicitly define how the as-built situation and presence of hidden elements is determined.*

    As documentation and design-drawings often do not reflect the true as-built situation, research must be conducted to establish the actual on-site situation. Through inspection, the actual situation is established prior to an intervention. Additionally, an investigation is required for elements hidden in the underground or embedded in the structure. Within this investigation, attention must be paid to elements which are potentially hard-to-locate, for example because of irregular distribution or deep placement, making them easily overlooked. This must prevent them from emerging as a surprise during realization.

    As the risk of these discoveries during realization may be assigned to RWS, it is of pivotal importance that the contractor is required to conduct a thorough investigation. If the risk has been assigned to RWS, then there is no financial incentive for the contractor to conduct a comprehensive investigation. By standardizing mandatory investigations, a consistent framework can potentially be applied across all R&R projects

- *Define the minimum level for asset data maturity, to prevent continuous distortion of data through targeting key areas in data collection and processing.*

  Data collection is embodied by inspections and investigations prior to realization, whereas their processing is embodied by the internal processes in the project delivery framework. To prevent continuous distortion of input, processing, and the subsequent output, action is required in several areas:

  * The input data, consisting of inspections and investigations must be accessible, interpretable, relevant, and accurate (Wang & Strong, 1996). This can only be achieved if recommendation 2.1 is sufficiently in place. Without strict checks on the investigations conducted, such as through review by experts, situations will continue to develop in which assumption are not verified, thereby providing distorted input for subsequent processes. If this input information does not correspond to the actual on-site situation, then this input will pose a severe, persistent disturbance to all cost estimation and planning processes that utilize this data.
  * The processes must be formalized (Joslin & Müller, 2016). The second point is essential as formalized processes offer a standardized approach (roles, governance, information provision), making processes predictable.
  * The organizational culture must encourage the identification escalation of early warning signs (persistent uncertainties) (T. Williams et al., 2012). This point relates back to the insights provided by practitioners that there is a focus on what is already known, i.e. topics within their expertise and experience, and less on what is not known, i.e. the persistent uncertainties. Inadequate escalation takes away opportunities for timely mitigation or adaptation, consequently pushing the uncertainty into the next project phase in which it may cause major disruption.

- **Cause 2.2: Insufficient access to and utilization of RWS's technical expertise hampers making substantiated decisions on critical issues and presenting them convincingly internally and externally.**
- **Recommendation 2.2: Develop an R&R playbook that outlines procedures to address common R&R problems, including guidance in which internal or external parties may be consulted when determining a solution.**
  - Incorporate recent experiences into the 'R&R playbook,' enabling project teams to take quick action when faced with a common problem encountered in infrastructure renewal, such structural integrity or traffic safety concerns. Additionally, this playbook must direct PM teams as to which internal (RWS) or external (private) party can be consulted when encountering issues in specialized domains. The appropriate expertise can then be consulted and utilized for developing a solution. As numerous unforeseen situations may develop in R&R projects, each of which may lead to significant delays, it remains important to enable PM teams to efficient decision-making. Delays drive indirect costs and jeopardize the intricate planning of traffic closures and deviations inherent to R&R projects.

7.3. Far-reaching consequences of disruptions

The third key complexity identified as causing financial setbacks has been defined as:

Far-reaching consequences of disruptions under dependency on regional stakeholders.

This complexity has been found to result from two main causes. To improve the management and/or mitigation of these causes, recommendations 3.1 and 3.2 have been provided below.

- **Cause 3.1: PM teams feel compelled to take additional precaution measures due to changing stakeholder requirements and hard-to-assess social effects, despite the existing procedures.**
- **Recommendation 3.1: Reduce the uncertainty in stakeholder management and traffic disruption mitigation through establishing a higher order of cooperation.**

- *Let the Ministry of I&W establish non-negotiable anchor-points in coordination with umbrella corporations, and incorporate these into Traffic Disruption Mitigation Plan.*

  As PM teams may feel pressured to implement disproportionate measures due to shifting stakeholder preferences, they require robust agreements to strengthen their position. As an increasing number of R&R projects will be in simultaneous execution in the future, traffic disruption will be inevitable and grow in severity. To counter the fragmented stakeholder management, which currently requires substantial time and effort, the Ministry of I&W could organize a higher order of stakeholder cooperation. This must transcend the hectic playing field at the level of individual projects.

  By developing non-negotiable anchor-points in collaboration with umbrella corporations, and incorporating these in the Traffic Disruption Mitigation Plan (Rijkswaterstaat, 2024b), PM teams are better protected against taking disproportionate disruption-mitigation measures as a project's realization approaches. Since umbrella corporations represent the interests of stakeholders groups, e.g., the Dutch Hospital Association, Safety Regions, Association of Netherlands Municipalities, legitimacy is safeguarded. Through higher-order communication and the establishment of universal mitigation principles aligned with cost-efficiency, projects can achieve more consistent decision-making and reduce disproportionate expenditures.

- *Build in flexibility in the Traffic Disruption Mitigation Plan by designing various levels of traffic disruption mitigation measures, thereby limiting the development of project-specific approaches.*

  Stakeholder management in R&R project is often perceived as the provision of tailored solutions. To maintain flexibility while streamlining stakeholder management, the Traffic Disruption Mitigation Plan (Rijkswaterstaat, 2024b) can incorporate multiple levels, consisting of minimal, standard, or extensive measures for traffic mitigation. It provides PM teams with semi-tailored solutions, reducing the efforts that would normally be required for establishing all mitigation measures.

- **Cause 3.2: Lack of a "project-decision" makes PM teams dependent on municipalities for permit approval, which can bottleneck decision-making.**
- **Recommendation 3.2: Increase the regional stakeholders' understanding of the critical need for R&R projects, communicate non-negotiable anchor points, and simultaneously strengthen relationship between PM teams and the municipalities on which they are dependent.**

  - *Communicate the non-negotiable anchor-points to regional stakeholders, and establish a procedure that requires financial contribution from stakeholders if their requirements change during later project phases.*

    Regional stakeholders must be made aware that the anchor-points, established by the Ministry of I&W and umbrella corporations, are non-negotiable to safeguard PM teams from adopting disproportionate traffic disruption mitigation measures. For changes to the requirements provided by regional stakeholders, a procedure must be set in place that manages these changes if they emerge after initial establishment. Stakeholder requirements often shift as a the project progresses towards the realization phase, driving additional costs due to scope changes. Therefore, it must be established that changes to stakeholder requirements, after they have been initially established through the KES procedure, cannot be approved without financial contribution from the stakeholder.

  - *Raise awareness throughout the organization of the absence of the project-decision in R&R projects and the consequent dependence on cooperation with municipalities.*

    RWS PM teams must be aware of the fact that there is no project-decision present in R&R projects. Without this legal instrument, expropriation is only possible with the cooperation from a municipality. Similarly, PM teams operate under the 'regular' permit system of the Environmental and Planning Act, in which permits are issued by municipalities. Maintaining a strong relationship with the municipality is therefore of utmost importance and should be actively safeguarded.

– *Raise awareness of the risks of continued opposition from regional stakeholders, and establish that changes to stakeholder requirements introduced later in the process can only be accommodated if the requesting stakeholder contributes financially to the resulting costs.*

  Continuous opposition from regional stakeholders, such as filling complaints, blocking permits, or through other forms of protest, may impose severe consequences. Financial resources are already under pressure, meaning that measures taken (e.g., for traffic disruption) must be proportionate to the severity of the issue. However, if regional stakeholders do not approve of plans even after additional negotiation, then extreme situations result. Without intervention, full closures of infrastructure may be in order for extended periods of time. It is therefore of great importance that regional stakeholders understand that R&R projects will never be without traffic disruption, but failing to execute these projects will allow far more unfavorable conditions to develop.

7.4. Highly complex phasing

The fourth key complexity identified as causing financial setbacks has been defined as:

Complex phasing of construction stages and temporary measures or structures during realization.

This complexity has been found to result from two main causes. To improve the management and/or mitigation of these causes, recommendations 4.1 and 4.2 have been provided below.

- **Cause 4.1: Widening and reinforcing of structures to comply with modern technical regulation and RWS design guidelines is not sufficiently incorporated into early cost calculations.**
- **Recommendation 4.1: Ensure that early cost calculations, which are mainly based on material unit prices and the surface area of structures, account for the fact that modern bridge replacement structures are often much wider than the original structure.**
  - The 1-to-1 replacement principle emphasizes construction of a replacement structure with equivalent functionality to that of the existing one. However, legacy structures, constructed decades or even nearly a century ago as is the case at the A44 highway, are based on different design principles that differ significantly from current standards. Modern technical regulations and guidelines entail improvements for structure design that offer increased levels of safety and structure resilience. For bridges, it means that structures typically become wider to accommodate modern driving and emergency lanes. Additionally, structures are designed to handle heavier and more intense traffic.

    Early cost estimations, such as those presented in the R&R Prognosis Report (Rijkswaterstaat, 2022), currently do not account for these developments. The significant increase in surface area and/or material volumes due to the widening and reinforcing of designs drives additional costs. If these are not accounted for in the initial estimations, but only calculated when a project enters active development, then a financial setback will be encountered.

- **Cause 4.2: Cost reference numbers do not sufficiently account for the complex phasing required for a bridge replacement including a traffic bypass.**
- **Recommendations 4.2: Ensure that cost reference numbers used in early cost calculations reflect the associated costs with the complex phasing for creating traffic bypasses, and develop standardized phasing plans to ground early estimation into practice.**
  - *Ensure that the early cost estimates include the cost associated with the complex phasing that is required to create a traffic bypass during project realization.*

    As continued full closures of Dutch highway bridges are not an viable option to RWS, a bypass must be created to ensure traffic continuity during project realization. In some cases this will only be possible constructing part of the replacement structure first (Kaag Bridge), or by rerouting traffic over a section of the existing structure while simultaneously demolishing the other (Spoorweg Viaduct).

A phased approach consisting of alternating construction and demolition reduces the overall efficiency of these activities. As a result, additional costs are inevitable. Failing to account for these costs in the initial estimate will result in an immediate financial setback once the project enters active development.

– *Develop standardized phasing plans to ground early cost estimations into practice.*

  A limited set of available phasing plans is available in bridge renewal. The various configurations of the stages in which the realization of a bridge replacement may take place, can essentially be reduced to three options: (i) Construct (a part) of the replacement bridge and utilize this as the traffic bypass, (ii) utilize half of the existing bridge as the traffic bypass and demolish the other half, or (iii) install a temporary bridge as the traffic bypass while replacing the existing structure.

  Detailing this set of possible phasing configurations and compiling them into standardized plans provides insights to PM teams during early project development, which may then benefit from the experiences of other projects. Over time, data can be connected to the phasing plans, such as reference numbers for cost estimation and planning. Through providing these early insights, individual PM teams don't have reinvent the wheel, thereby establishing more accurate early cost estimates and plannings.

7.5. Optimistic bias in early project scope and budget

The final key complexity identified as causing financial setbacks has been defined as:

Optimistic bias in early project scope and budget undermines scope-stability and feasibility.

This complexity has been found to result from two main causes. To improve the management and/or mitigation of these causes, recommendations 5.1 and 5.2 have been provided below.

- **Cause 5.1: Inability to comply with the RWS design guidelines specified in the project scope form due to spatial constraints necessitates ongoing coordination.**
- **Recommendation 5.1: Asses whether on-site space allows construction of the widened, reinforced replacement bridge in full compliance with the design guidelines during the RA phase, and develop a fallback option based of on a minimum-version of those guidelines to reduce ongoing design-concession coordination.**
  - *Asses during the RA phase whether the space available on-site allows for widened and reinforced structures, that follow from compliance to RWS design guidelines.*

    As mentioned earlier, options for acquiring additional grounds are limited in R&R projects. Therefore, the PM is expected to construct the replacement structure within the grounds already owned by RWS. However, this requirement may lead to conflicts, as the replacement structure may be wider than the existing one. If it ultimately proves not possible to comply with the spatial dimensions prescribed by RWS design guidelines, coordination must be sought with the appropriate higher authority.

    Through collaboration, the boundaries of what is and what is not feasible in terms of space must be determined, and the resulting design decision must be formally approved. This coordination can delay projects, as alignment must be achieved with multiple internal stakeholders. Conducting investigations during the RA phase can clarify what design concessions may be necessary due to spatial constraints in an early stage. This will reduce the alignment efforts in later project phases, where time is critical and any delay can immediately trigger a financial setback.

  - *Develop a minimum-version of the RWS design guidelines which may be used as if insufficient on-site space is available for compliance to the standard-version, thereby establishing a fallback option.*

In many projects, PM teams will face spatial restrictions that prevent them from designing a replacement bridge in full compliance with the current RWS design guidelines. If this situation arises, then significant coordination efforts are required to determine what concessions will be made to the design, i.e. how requirements are to be implemented in a lesser, space-saving way. Furthermore, deviation from the RWS design guidelines requires formal approval from the appropriate authority.

To reduce the ongoing coordination efforts between the aforementioned actors, it can be helpful to develop a fallback option. This fallback option may consist of a minimum-version of the RWS design guidelines, e.g., a ”ROA-minimum.” It prescribes what concessions can be made, if there is not enough space available to comply to the ”ROA-standard,” thereby providing predetermined and standardized anchor-points during coordination efforts. This also allows for the appropriate authority to engage in a streamlined procedure for providing approval.

- **Cause 5.2: Limited RWS overview of intervention urgency results in intervention dates exceeding the technical EOL, necessitating the implementation of a bridging strategy.**
- **Recommendation 5.2: Aim to reduce the necessity of implementing bridging strategies through intensifying the inspection regime, and account for this bridging strategy in the early cost estimates of R&R bridge projects.**
  - *Account for a bridging strategy in the early cost estimates.*

    With the continuously increasing number of bridges requiring intervention, the chance that this intervention will take place after the technical EOL of the structure increases, necessitating a bridging strategy. Measures aimed at reducing loads through restricting traffic require internal coordination and alignment with regional stakeholders, generating indirect costs. Other measures, such as deploying load-bearing supports or performing (emergency) repairs, drive direct costs. The costs associated with a bridging strategy must be incorporated in early cost estimates. Failing to do so will trigger a financial setback if it ultimately proves necessary when a project enters active development.
  - *Intensify the inspection regime, particularly through additional assessment of the technical EOL of bridges, thereby reducing the likelihood that a bridging strategy is required.*

    The rationale for an intensification of the inspection regime stems from the fact that scheduling an intervention later than the technical EOL necessitates a bridging strategy. By improving insight into which structures are in urgent need for intervention, bridging strategies may be minimized or avoided entirely. Enhanced inspections will also reduce the inherent aleatory uncertainty in R&R projects by establishing the actual condition of structures, beyond the data that can be retrieved from asset management systems.

7.6. Enhancement of the R&R Approach

The recommendations established for enhancement of project delivery in R&R projects can be divided into two main categories. The first category encompasses the recommendations that can be directly incorporated in an enhanced version of the R&R Approach, as they are a reflection of steps or products in the project delivery framework that must be explicitly included. The second category highlights the recommendations that target the (early) cost estimation and overall governance processes at RWS.

7.6.1. Recommendations for project scope identification

To improve the identification of project scope, which is promoted through conducting several preparatory researches explicitly in earlier project stages, recommendations have been incorporated in the R&R Approach. The enhanced version of the framework is shown in Figure 7.1.

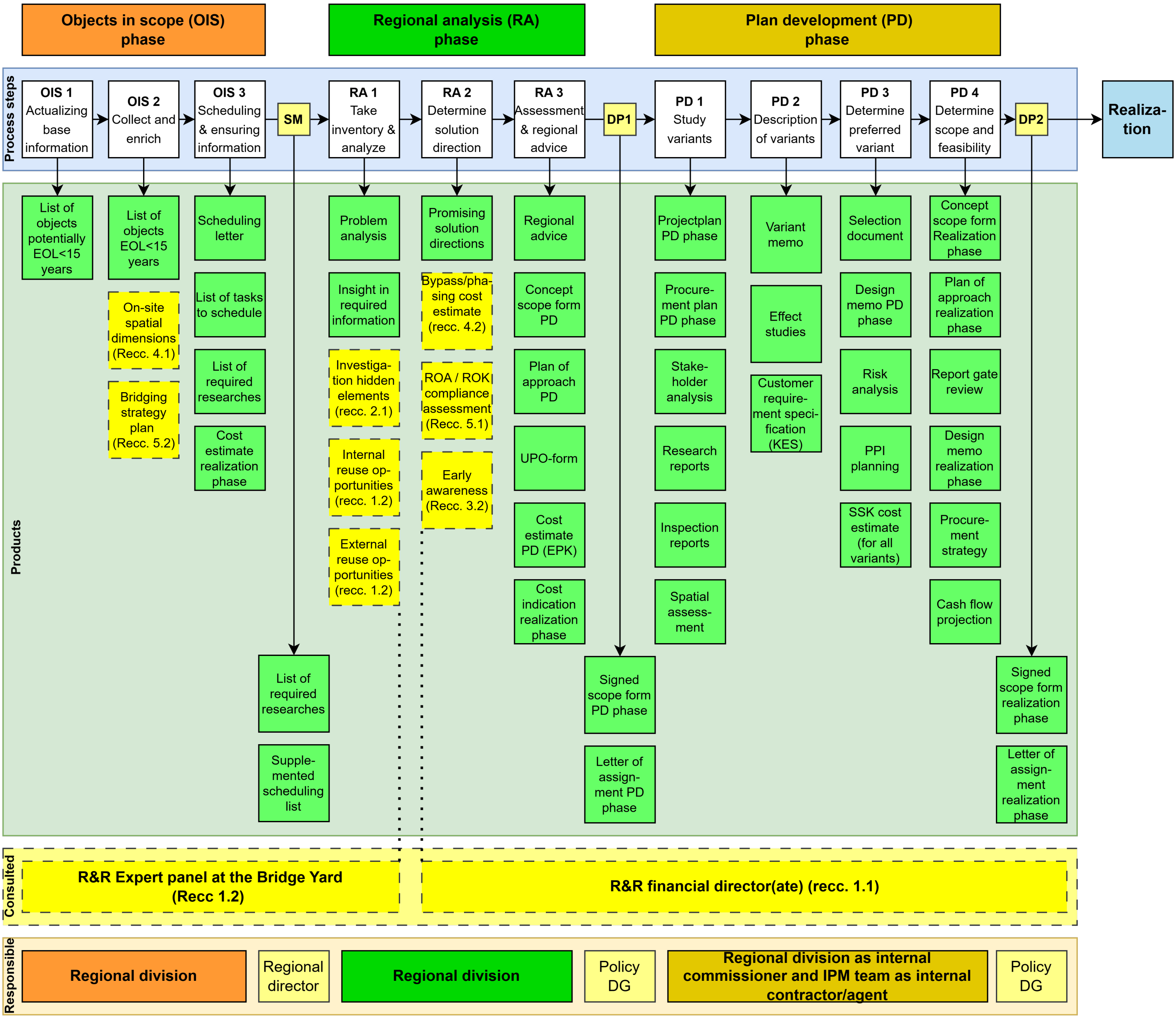

Figure 7.1: The enhanced R&R Approach. The striped yellow blocks are recommended processes/products to improve the project delivery framework.

Objects in scope phase

In the first phase of the R&R Approach, the OIS phase, two recommendations have been included. The first recommendation (Recommendation 4.1) dictates that the space that is available to RWS to construct a renovated or replacement bridge, i.e. the on-site spatial dimensions, are to be determined during the "collect and enrich" step. With options to acquire additional grounds often limited or not present at all, the space available for the new structure is a fundamental starting point in any R&R project. As RWS can only work within these grounds, determining it in an early stage is of key importance.

The second recommendation regards the bridging strategy, which must be implemented if the date on which the intervention will be finalized exceed the technical EOL (Recommendation 5.2). As a growing amount of structures is reaching this EOL, the chance of an intervention R&R project "not being on time" increases. Although this can be mitigated through intensifying the inspection regime, thus having a better overview of which objects need to be prioritized for intervention, the immense amount of structures in the RWS base will inevitably complicate these efforts. As a result, it remains likely that a bridging strategy, and all the measures it includes, remains an essential part of the project scope in bridge renewal projects.

Regional analysis phase

In the second phase of the project delivery framework, the RA phase, several recommendations have been provided to identify project scope that is critical for an accurate estimate of the project's cost and performance. In the first step (RA 1), the standardized investigations into potentially hidden elements (Recommendation 2.1), and researches determining opportunities for the reuse of structural elements within and outside of the project (Recommendation 1.2), have been added to the framework.

In the next step (RA 2), the cost associated to the complex phasing (Recommendation 4.2), required for the creation of a traffic bypass during realization of the project, must be determined. Furthermore, the PM team must determine if it possible to fully comply with the RWS design guidelines (Recommendation 5.1), or if any restrictions prevent this. Given that the guidelines are a mandatory starting point in R&R projects, it is critical to determine if full compliance is possible early on, as deviating from these guidelines requires a prolonged coordination and formal approval from the appropriate authorities. The final recommendation included in this step, is to spread early awareness among regional stakeholders (Recommendation 3.2). This early awareness consist of communicating the framework for stakeholder management, which specifically includes the non-negotiable anchor points, potentially reducing opposition later on.

Establishing continuous support for PM teams

As has been established by now, large-scale R&R projects are a relatively new development in the infrastructure sector. To support PM teams in their efforts to renew infrastructure, they must be supported by specialist teams, tailored to provide expertise in niche, but critical areas of R&R projects. An expert panel, incorporated in the Bridge Yard, can be assembled so that every project has access to specialists, providing expert judgment in matters where not all team may have sufficient expertise individually (Recommendation 1.2). Furthermore, to deal with the many financial decisions that RWS is now solely responsible for in the majority of R&R projects, a financial director(ate) can be instated (Recommendation 1.1). This director(ate) must establish a formal and standard interface, authorized to decide on critical financial decision in R&R projects.

7.6.2. Recommendations for cost estimation

Recommendations for improving the accuracy of the cost estimation process transcend enhancement of the project delivery framework. This is because financial setbacks may emerge when a project enters active development, and not only during the project itself. This is a direct consequence of the high-order cost estimation process utilized for the R&R Prognosis Report (Rijkswaterstaat, 2022), as this early cost estimate methodology does not account for specific cost drivers inherent to bridge renewal. The process of emerging financial setback has been established below:

1. *The R&R Prognosis Report is produced, but does not sufficiently account for project scope and costs inherent to bridge renewal, such as implementing a bridging strategy, the complex phasing required to create a traffic bypass, or the increase in surface area of a modern bridge.*
2. *Based on the early cost estimate in the Prognosis report, a budget is allocated to an R&R project so that it can be executed.*
3. *As the R&R project enters active development, the PM team makes an in-depth estimation of project costs which includes project scope that is aligned with the practical implications of infrastructure renewal, which has not been included in the high-order estimate of the Prognosis Report.*
4. *A financial setback emerges, as there is a discrepancy between the project budget (based on the Prognosis Report) and the cost estimate during active development (which includes full project scope).*

The developments described above indicate that the current cost estimation methodology must be improved. The Prognosis Report is published biannually, with the aim of improving the cost estimates included within. Therefore, the overarching recommendation for the cost estimation process is to include project scope inherent to bridge renewal by standardizing high-level scope elements. This ensures that the cost associated with this scope are visible in early estimations.

Part IV

Deliver

8 Discussion

Large-scale infrastructure renewal is still a relatively new development in the Netherlands, but addressing it effectively will become a matter of growing concern in the coming years. The findings of this research highlight how the R&R Approach and supporting procedures function, and what challenges are encountered during project execution. The practical application of processes is highlighted, emphasizing which improvements are already in progress and which areas remain in need of enhancement. Following the compilation of results, it remains important to understand their meaning within the larger context of this research. Therefore, this discussion reflects upon the research findings in Section 8.1, the limitations of the research in Section 8.2, and its relevance in Section 8.3. The discussion concludes with recommendations to infrastructure managers in Section 8.4, and for future research in Section 8.5.

8.1. Findings

In this section, the findings of the research are discussed. This section highlights several key areas in which results have been provided.

8.1.1. Applicability of theoretical framework

The theoretical framework proposed by Hertogh and Westerveld (2009), developed for the identification and categorization of project complexities, has been found to be an effective method to explore the various challenges that are encountered in R&R projects. The six differentiated categories, capture the richness of the complexities encountered, especially compared to other complexity identification and categorization frameworks. The six categories directed this research to look for specific manifestations of complexities, and therefore supports the researcher in identifying real-life examples, grounding the findings in reality.

8.1.2. Dominance of dynamic organizational complexities

From the practitioners interviews, in which various challenges faced in R&R projects were illustrated, the abundant presence of dynamic organizational complexities became clear. As Hertogh and Westerveld (2009) describe, dynamic complexities are essentially uncertainty, as it relates to the potential of a process and/or products to evolve over time through self organization and co-evolution, and to the limited understanding and predictability of phenomena. The presence of the many dynamic organization complexities emphasize that there is significant uncertainty residing in the roles, structures, and approaches within the processes and activities that RWS engages in for infrastructure renewal. As a consequence, reducing uncertainty plays a major role in increasing overall organizational and project performance.

Moreover, it can be concluded that infrastructure renewal projects face a novel reality, encountering different conditions than construction projects (network expansions). The dominance of dynamic organizational complexities are a direct consequence of the novelty of large-scale R&R interventions, in which the project delivery organization is relatively inexperienced, resulting in many processes knowing an insufficient level of formalization.

8.1.3. Reducing uncertainty

As argued in the previous section, uncertainty is present in many aspects of the project delivery organization. Additionally, other complexity categories, also highlight the dominance of dynamic complexities over detail complexities, indicating the presence of uncertainty. Some of this uncertainty has been found to be of an aleatory nature, as it is caused by the inherent randomness of phenomena, such as the exact condition of structural elements. However, the primary source(s) of uncertainty have been found to be epistemic, as they are caused by a lack of knowledge.

In the case of R&R projects at RWS, much of this epistemic uncertainty stems from processes and products with which RWS is not yet familiar. New financial governance arrangements, different roles and responsibilities than in greenfield projects, and the complex landscape of regional stakeholders that hold significant power, are just some of the example of the novel reality that the project delivery organization faces. Many of the practices used in traditional construction projects, such as the MIRT project delivery framework, cost estimation methodologies, and procedures for establishing stakeholder requirements (KES), do not optimally align with infrastructure renewal.

As a result of the diminished effectivity of traditional tools for R&R projects, practitioners are provided with inaccurate or unfeasible starting points. Their products and processes are less formalized than their counterparts to network expansion projects, requiring them at times to create ad hoc, project-specific solutions. This raises the question if formalization is the right approach. Under high uncertainty, loose structures can outperform tight organizational structures (Nogueira & Raz, 2006). However, when assessing the overall maturity of the organizational structure, processes, and products utilized in R&R projects, it can be concluded that a base structure is not sufficiently present for all aspects of renewal projects. Therefore, formalization (i.e., applying structure with the aim of increasing predictability) will be a helpful development.

A generic technical solution, similarly aimed at reducing the uncertainty associated with bridge renewal, is the utilization of a prefabricated or modular bridge. Using such a modular structure, may enhances the overall construction efficiency, safety, and sustainability (Krystallis & Mahi, 2024). This may encompass a prefabricated (temporary) bridge, which requires no on-site assembly, as it will be hoisted into its final position and thereby simplify overall construction efforts. This approach has also been used for the Suurhoff Bridge, which is elaborated upon in Chapter 2. Furthermore, developments continue to take place in modular bridge design, with various firms offering standardized (temporary) bridges for a variety of situation (Russell et al., 2013). However, making use of such a technical solutions to avoid uncertainties is not possible for every R&R project. Restrictions may prevent their usage, such as RWS safety requirements or the need for waterway access.

8.1.4. Enhancement beyond the project delivery framework

It has been found that enhancing overall project delivery of R&R projects can be achieved through targeting several areas, thereby transcending the original aim of this research to enhance the project delivery framework for R&R projects. Not only this framework, embodied in the R&R Approach, is in need of improvement, but also other surrounding systems and procedures.

Within RWS, attention is required to the arrangements and governance structures, which oversee the formal approval of critical technical and financial decisions. PM teams are often left in search of who is the appropriate authority to approve decision in their projects, for example when a structure must deviate from a RWS design guideline. Additionally, ambiguity in financial decisions may lead to a project being halted, or the allocation of funds without a clear understanding of whether the expenditure is justified compared to other organizational priorities. The expertise for decision-making is present within the organization, but the absence of defined roles and responsibilities make coordination efforts within time-consuming.

Beyond RWS, the Ministry of I&W could also take steps to ensure more efficient infrastructure renewal. Much efforts persist in the management of regional stakeholders such as municipalities, driving costs in the R&R projects executed by RWS. Awareness lacks among these regional stakeholders, as they potentially request disproportionate traffic disruption mitigation measures that put the cost-effectiveness of the project under pressure. A role is allocated to the Ministry of I&W, which must negotiate universally acceptable measures with umbrella corporations representing groups of regional stakeholders, defining anchor points that R&R projects may use as a defense against taking disproportionate measures.

8.2. Limitations

The primary limitations of this research are a direct result of the research framework employed to conduct it. Although knowledge has been established for infrastructure renewal in general, some recommendations and framework enhancements remain specifically tailored to R&R project for bridges. As a result, the generalizability of the results of this research towards for other types of structures (e.g., tunnels, locks) remains limited.

Moreover, the case study encompasses the replacement of several structures under the 1-to-1 replacement principle, implying that the functionality of the structures remained identical after intervention, and that RWS is solely responsible for project governance without direct involvement of the Ministry of I&W. This is in contrast some other R&R projects as these may be developed under other principles, that do include functionality changes and/or (intensified) coordination with the Ministry of I&W. The findings of this research may not fully align with these projects, as they are essentially of a different nature.

In addition to this general statement of the limitations of this research, several underlying elements and methods have been highlighted to discuss their specific limitations.

8.2.1. Theoretical framework

The theoretical framework proposed Hertogh and Westerveld (2009) has been the foundation of complexity identification and categorization in this thesis. In this section, the use of theoretical framework has been reflected on. The main limitations that emerged during its practical application are:

- **After identification and categorization, complexities need further analysis to determine their underlying mechanisms:** After identification and categorization of a complexity, additional steps remain required in order to design appropriate mitigation measures or management approaches. A complexity remains at the level of an abstract phenomenon, which does not directly reveal its underlying mechanisms. Therefore, additional in-depth analysis and research is remains essential for determining what mechanisms underlie the complexity. As a result, the main purpose of the theoretical framework remains at the level of identification and categorization, and not mitigation or management of complexities.
- **The framework's categories are not mutually exclusive:** Complexities may operate on the intersection of two complexity categories, resulting in overlap. A common symptom of this phenomenon is that technical, financial, and legal complexities also encompass an organizational element. For example, the complexity ”Far-reaching consequences of disruptions under dependency on regional stakeholders,” occurred as a consequence of two underlying mechanisms. The first mechanism directly relates to social complexity under the framework, but the second mechanism involves the lack of a legal instrument, and therefore also relates to legal complexity.

  This trait of the framework emerged during the development of recommendations and framework enhancements. Therefore, it remains important to critically asses potential recommendations or mitigation measures, and include solution space beyond the ”true” categorization of the complexity. Conclusively, it can be stated that the framework is not mutually exclusive, as the multifaceted nature of R&R projects inevitably leads to overlapping categories.

8.2.2. Interviews

The participants in the interviews were recruited through convenience sampling. Although this approach has proved to be valuable, as it allowed to include key individuals that hold relevant experience, it has also had major influence on shaping the results of the research. Additionally, as a consequence of the sampling approach, the results cannot be generalized beyond the sample (Acharya et al., 2013; Koerber & McMichael, 2008).

Semi-structured interviews were conducted among seven practitioners involved in RWS R&R projects. A weakness that this proposes to the research, is that the researcher's perspective affects the research question, methodological approach, and the analysis and interpretation of data, as there is also not precise qualitative scientific method to investigate the research question (Diefenbach, 2009). This is true for the research, again emphasizing the responsibility of the sole researcher in a thesis, and necessitating a comprehensive discussion of the research and its results.

The individuals originated from a multiple organizations, such as contractors (planning and cost experts), RWS (PM teams, cost pool), and the Ministry of I&W (policymakers). Although individuals from multiple organization were interviewed, most of them are a part of RWS. Therefore, the project management perspective is dominant and may underrepresent views from from other actors, such as higher RWS management, contractors, or policymakers. This follows from the fact that stakeholders within projects (practitioners) may hold heterogeneous perspectives (Cuppen et al., 2016). Additionally, it is provided that participants may be influenced by a self-serving bias, which involves the internal attribution of successes and the external attribution of failures (Cristofaro & Giardino, 2020). As a consequence, the framing of problems might be skewed towards external attribution, i.e the perception of problems stemming from elsewhere.

8.2.3. Case study

This research originally set out to determine the primary complexities causing financial setbacks through a quantitative analysis of project cost data. While this initially seemed feasible in collaboration with RWS, it ultimately proved not to be, due to confidentiality restrictions. As a consequence, an alternative approach had to be developed to identify the key complexities in R&R projects. Therefore, a single case study was selected as the substitution method.

While performing a single case study allows for an in-depth examination of a topic, a researcher must be wary of its (potential) limitations. As Willis (2014) argues, advantages of a single case analysis include that they offer empirically-rich, context-specific, holistic accounts, also contributing to theory building and in a less extent to theory testing. However, the limitations mainly relate to the generalizability of the research towards other cases, as it is based on non-random selected samples (interviews and case).

In this research, generalizability is not a main objective, as the research knows an exploratory nature, aimed at illustrating the reality the reality of bridge renewal projects. Therefore, the objective of a single case study is not being statistical, as the aim is not to produce outcomes that are generalizable to all populations (Gaya & Smith, 2016). Within this context, other populations may include other types of structures, R&R projects at other public organizations, or RWS R&R projects encompassing different starting points or guiding principles.

The case study performed contains a substantial element of narrative, as complexity and uncertainty is illustrated through concrete examples, originating from real-life situations faced during the project. Therefore, these narratives approach the complexities and contradiction of real life situations (Flyvbjerg, 2006).

8.3. Relevance

This section addresses the relevance of the research and its results. The academic relevance, specific contributions to the theoretical framework, and the practical relevance have been stated.

8.3.1. Academic relevance

The approach enabled for capturing the richness of information residing within R&R projects, and has ultimately proved pivotal in illustrating the challenges, complexities, and uncertainties that practitioners face in their efforts to renew infrastructure. As was already concluded from the literature studies, literature on R&R projects for Dutch infrastructure is limited. Although other researchers have studied infrastructure renewal prior to this research, there is a lack of illustrated examples that display why R&R projects are perceived to be challenging and costly.

Current academic literature is primarily focused on the AM perspective, or is not generalizable towards the Dutch infrastructure context due to international differences. As a result, theoretical value of the research is found in filling a research gap present in the academic literature.

8.3.2. Contributions to the theoretical framework

In this research, the theoretical framework provided by Hertogh and Westerveld (2009) has been utilized in the form proposed by both the aforementioned authors and Dunović et al. (2014). The effectiveness of the framework for complexity identification and categorization has been discussed in Section 8.1, which concluded that the framework offers an structured and comprehensive method, which allows for a complete overview of complexities in projects.

Additionally, the limitations of the approach have been stated in Section 8.2. The main limitations of the framework relate to two points. The first point is that, the identified and categorized complexity need further analysis, as the level on which classification process remains too abstract to developed actual mitigation or management practices. The second point relates to the tendency of overlap between various complexity categories. With many complexities consisting of manifestations that are located on the intersection between categories (e.g., legal and organizational), their exact distinction is obscured.

Besides a reflection upon the strength and limitations of the theoretical framework, it is important to state the academic contributions to the prior conclusions and remarks made by Hertogh and Westerveld (2009) in their original publication. These contributions are:

- **Social complexity is perceived as the core of in construction projects, but in R&R project organizational complexity is currently dominant:** Hertogh and Westerveld (2009) concluded that social complexity was the core complexity in construction projects, meaning that is the most influential out of all the complexity categories. However, this research comes to a different conclusion, as organizational complexities are perceived as the most dominant. This highlights the differences in the nature of construction projects and R&R projects.
- **There is little empirical evidence for the effectiveness of the proposed management strategies, which also proves to be true for R&R projects:** Hertogh and Westerveld (2009) propose a number of management approaches for project, depending on the level of detail and dynamic complexity of project. Some recommendations, such as the X-factors, propose concrete measures that can be implemented, e.g., a higher-order of stakeholder cooperation, which has been useful in the management of the social complexity in Chapter 7 (recommendation 3.2). However, other recommendations such as the proposed management strategies (e.g., dynamic management), remain primarily academically grounded. The level of abstraction to which the management strategies are detailed, reduce their applicability in real-life projects.
- **The effects of having competent individuals partaking in projects is labeled as a critical area for future research with the top of the iceberg having been scraped, and is again highlighted in this research:** Hertogh and Westerveld (2009) addressed the pivotal role of adequate professional in construction projects. In this research, the importance of having adequate and experienced staff emerges again, especially in complexities that concern the technical expertise of PM teams. Therefore, it can be confirmed that the effect of competent people makes a significant difference in project performance. This is especially true for R&R projects, as some processes and procedures remain insufficiently formalized as of now, and still heavily rely on expert judgment.

8.3.3. Practical relevance

The findings of this research explicitly define critical activities and products to improve the performance of R&R projects. The rationale for the recommendations provided is to make renewal projects for bridges more predictable and effective, through defining steps in the R&R Approach that are critical for producing accurate (early) cost estimates, and for identifying project scope inherent to bridge replacement projects. Therefore, the practical relevance is captured in the provision of the available information regarding R&R projects, and the recommendations for public infrastructure managers in the next section.

8.4. Recommendations for public infrastructure managers executing R&R projects

It must be noted that great efforts are put into the formalization of R&R practices, not only by RWS, but also by the Ministry of I&W and contractors. The recommendations of this research aim to strengthen the existing approach, through providing concrete and practical improvements. Therefore, the main recommendation is to incorporate the enhancement measures, also provided in an overview in the conclusion of the research (Chapter 9).

Furthermore, it is important to realize that the financial setbacks encountered in R&R projects (i.e., the moments when it emerges that costs are higher than anticipated) are a direct result of the practices that RWS currently uses. The novelty of large-scale R&R interventions means that it poses a different way of working to PM teams and the overall organization, which currently use of a project delivery framework and other tools that are not yet optimized for infrastructure renewal. As a result, initial assumptions regarding baseline cost estimates, project scope definitions, and execution strategies often prove inaccurate and require substantial adjustment during project implementation. A proposed solutions may turn out be unfeasible, and continued coordination efforts are required to develop a viable alternative.

Some real-life examples of these events, that inevitably disturb the stability of the project scope, are insufficiently taking into account that: (i) Replacement bridge structures are wider and reinforced, (ii) significant efforts are required to facilitate the reuse of structural elements, or (iii) that complex phasing of construction stages and temporary structures is required to create a traffic bypass during project realization. Other examples that illustrate the prolonged coordination efforts can for be found in the many interactions needed to deviate from RWS design guidelines when on-site space is lacking, or the multi-level financial discussions that take place in prioritizing project ambitions and formally approving them.

In this sense, financial setbacks are created through a mechanism of wrongful initial assumptions and unpredictable discussions later on. Consequently, another recommendation is for RWS to be wary of this phenomenon. As this mechanism drives additional costs, early cost estimations for R&R are inaccurate, and can only be improved by mapping out the nuances inherent to infrastructure renewal.

8.5. Recommendations for future research

The foundation laid in this research opens up multiple pathways for further research, in which two main directions can be distinguished. The first pathway may continue its focus on bridges and viaducts, deepening and expanding current knowledge. Although the case project encompassed a movable bridge and three viaducts (concrete bridges), they represent only a fraction of the structures in the highly differentiated RWS asset base.

By examining multiple cases into a future study, other types of bridge structures may be included, consisting of other configuration and/or materials, will allow for a holistic perspective. Similarly, future studies can be conducted for other types of structures in the RWS asset base, such as navigation locks, tunnels, and aqueducts. This will optimize the R&R Approach project delivery framework for specific types of structures.

The second pathway for potential further research encompasses a comprehensive analysis of the various actors that are involved in infrastructure renewal. Other than RWS as the executive agency tasked with executing R&R projects, other organizations also assert their influence over infrastructure renewal. Policymakers at Ministry of I&W guide decisions and starting points through the policies they establish. Additionally, contractors and consortia can add valuable input, as their bottom-up input is a valuable source of feedback.

Challenges will continue to arise, as long as the interfaces that these organizations share are not aligned. The shift from traditional large-scale construction projects, to ensuring that the current infrastructure remains operational, has sparked new dynamics in cooperation. Therefore, increasing project performance will inevitably require further research into the network of actors, their interfaces, and the steps required for effective cooperation.

9 Conclusion

In this chapter, the study is finalized by providing conclusions to all parts of the research. The underlying research questions, each providing a fundament required to answer the main research question, are provided in Sections 9.1 to 9.4, emphasizing the stepwise progression of the research. In Section 9.5, the synthesis and concluding remarks with regard to the research and its results are stated. Before the supporting conclusions of this thesis are revisited, the main question is restated and answered below:

How can RWS enhance the project delivery framework for R&R projects involving bridges within the HWN and HVWN, by specifically targeting the challenges faced in project scope identification and cost estimation?

This research concludes that RWS can enhance the R&R Approach project delivery framework through including several measures to identify critical project scope inherent to bridge renewal, and improve the overall cost estimation methodology by conducting research that establishes cost driving project scope in the early cost estimates. Currently, financial setbacks are primarily the result of assumptions that fail in practice. This occurs because the project delivery framework, cost estimation methodology, and related procedures, originally developed for greenfield construction projects, are not yet fully aligned to the distinct needs of infrastructure renewal. Therefore, it has become clear that improving project performance requires necessitates several interventions, including some that reach beyond the project delivery framework.

9.1. Determining the project delivery framework

Before enhancement of the project delivery framework utilized in R&R was possible, it was needed to determine which framework is actually used by RWS, and to which extent this is effectively supports projects. Therefore, the first research question was developed, which was:

What are the prevailing project delivery frameworks used in R&R projects for bridges in the Dutch HWN and HVWN by governmental infrastructure managers and to what extent do they support effective project delivery in terms of project scope definition and cost estimation?

The efforts conducted for this question, captured in Chapters 2 and 3, provided that the R&R Approach is the primary project delivery framework used in infrastructure renewal. This framework consist of three preparatory phases before an R&R project enters the realization phase, which are: (i) objects in scope, (ii) regional analysis, and (iii) plan development. These stages are essential for renewal projects, as they focus on mapping asset conditions, regional stakeholder requirements, and the determination of critical project scope. The three stages distinguish R&R projects from typical greenfield construction projects, as they focus on the specific needs of infrastructure renewal.

It is provided that the framework was, and currently still is, in active development. As a result, there were various concerns over its effectiveness in supporting practitioners, particularly for the PM teams that use it as their guiding tool. While the framework provides a structured process, the exact practical application varies between individual projects. Moreover, although R&R projects and AM are becoming a matter of growing concern for RWS, there is still uncertainty regarding the role of R&R interventions within the broader AM framework.

9.2. Retrieving challenges, complexity, and uncertainty encountered in R&R projects

A structured approach had to be developed, which allowed for a breakdown of the challenges that practitioners encounter in the R&R projects they have been involved in. To support this process, the second research question was formulated:

What challenges do practitioners encounter in R&R projects for bridges in the HWN and HVWN, and how can the complexities and uncertainties from which they result be categorized?

The foundation for identifying and categorizing complexities, including their underlying (uncertainty) source, has been provided in the theoretical framework presented in Chapter 4. The theoretical framework has been employed to explore complexities that practitioners encounter in Chapter 5. The theoretical framework offered by Hertogh and Westerveld (2009) provided an effective method to identify and categorize complexities. Additionally, the framework distinguishes between detail and dynamic complexity, which allows for a clear demarcation of the complexities nature. A key notice is that dynamic complexities showcase the characteristics of uncertainty. The uncertainty in dynamic complexities has additionally been classified as aleatory or epistemic, providing insight into possible management or mitigation strategies.

The practitioner interviews provided in-depth information regarding the challenges faced in R&R projects, which were then analyzed through the theoretical framework. Figure 9.1 displays the complete overview of complexities identified in the interviews. Within, the presence of a high number of dynamic organizational complexities can be seen, highlighting their dominant position in R&R projects.

The dynamic organizational complexities primarily stem from epistemic knowledge that is embedded in various processes, as many of these processes present a novel way of working to PM teams. They are not sufficiently formalized, as the theory of the project delivery framework does not correspond to an effective practical application. Therefore, it is possible to reduce the uncertainty through development of the project delivery framework, and further integration of common practices into the organizational procedures and governance.

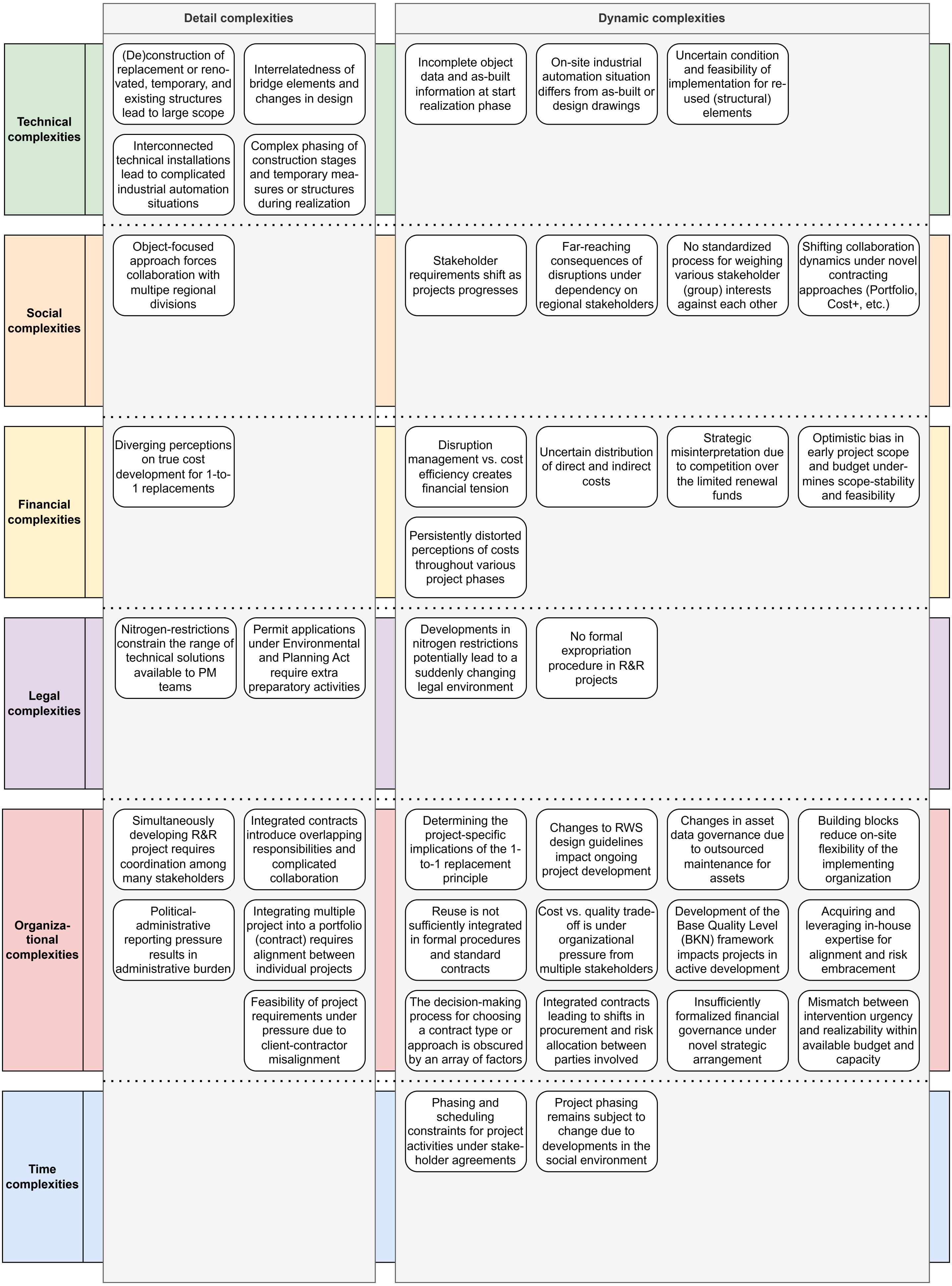

Figure 9.1: An overview of the complexities identified in the practitioner interviews.

9.3. Analysis of key complexities that lead to financial setbacks

Although the theoretical framework employed for the previous research question led to a variety of complexities being identified, it did not yet provide detailed insights into the underlying mechanism that caused it. Consequently, the the third research question was derived to establish and in-depth analysis, which was:

Which complexities are primarily responsible for causing financial setbacks, and what mechanisms underlie these effects?

The research conducted for the identification and analysis of the primary complexities that caused financial setback in the A44 Civil Structures R&R project, are embedded in Chapter 6. Within the case study of this project, it was established that five complexities were predominantly responsible for causing financial setbacks. These complexities are shown in Table 9.1. The findings presented in the table correspond with the conclusion of the second research question: organizational complexities hold a dominant position in R&R projects. A similar conclusion can be drawn from the list provided here, as the top two complexities are categorized as dynamic organizational complexities. Again, both of these complexities stem from epistemic uncertainty.

Rank	Complexity ID	Categorization
1	Insufficiently formalized financial governance under novel strategic arrangement	Dynamic organizational complexity
2	Acquiring and leveraging in-house expertise for alignment and risk embracement	Dynamic organizational complexity
3	Far-reaching consequences of disruptions under dependency on regional stakeholders	Dynamic social complexity
4	Complex phasing of construction stages and temporary measures or structures during realization	Detail technical complexity
5	Optimistic bias in early project scope and budget undermines scope-stability and feasibility	Dynamic financial complexity

Table 9.1: Shortlist of the five primary complexities identified during the in-depth interview to cause financial setbacks.

The complexities, which are the primary causes of financial setbacks, underwent an in-depth analysis to uncover which mechanisms underlie them. Through this examination, it was found that each complexity resulted from two underlying mechanisms. These result are shown in Figure 9.2.

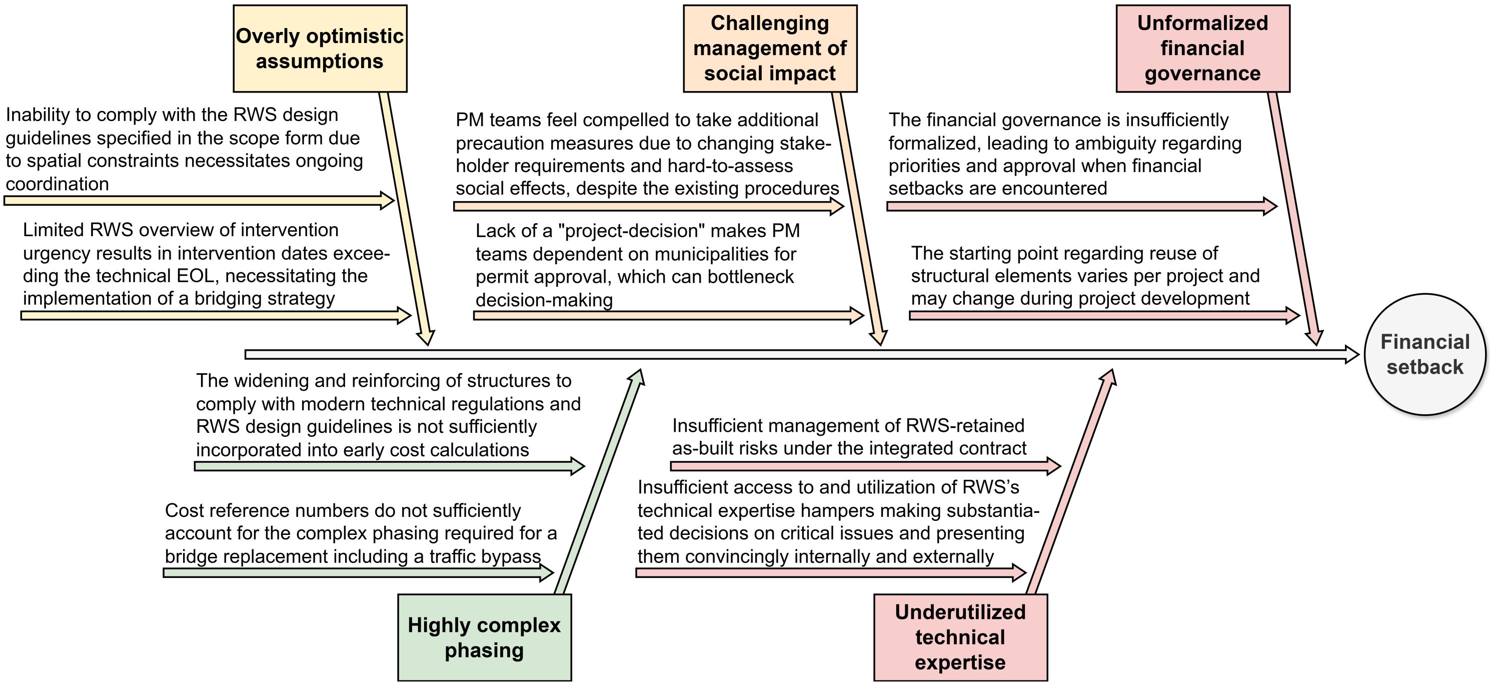

Figure 9.2: Cause-and-effect diagram of the primary complexities leading to financial setbacks and their underlying mechanisms in the case project.

9.4. Enhancement of the project delivery framework in R&R projects

To improve the project delivery framework and surrounding procedures in infrastructure renewal projects, several measures were designed. The interventions, aimed at enhancing project delivery, thereby provide the answer to the fourth research question, which was:

What measures can be included in the prevailing project delivery framework so that project scope identification and cost estimation is enhanced for R&R projects encompassing bridges?

A number of measures must be implemented in the R&R Approach, overall organizational governance, and the cost estimation process utilized in R&R projects, to improve their effectiveness. Furthermore, some recommendations reach beyond the project delivery framework, as they target other key areas such as financial-decision making or the organizational structure. Chapter 7 displays these initiatives. An overview of the proposed measures is provided in Table 9.2, thereby providing the answer to the final research question.

Complexity	**Recommendations**
Insufficiently formalized financial governance under novel strategic arrangement	Recommendation 1.1: Reduce uncertainty in the financial decision-making through formalization, by instating director(ate) that acts as a central point of contact for PM teams and thus oversees the project-programming, prioritizes issues, and provides formal approval.
	Recommendation 1.2: Design standard procedures for the reuse of structural elements to reduce technical uncertainty, through establishing universal starting points and dedicated expertise.
Acquiring and leveraging in-house expertise for alignment and risk embracement	Recommendation 2.1: Develop a standardized, comprehensive framework that explicitly defines how the as-built situation and presence of hidden elements is determined, and which defines the minimum level for asset data maturity.
	Recommendation 2.2: Develop an R&R playbook that outlines procedures to address common R&R problems, including guidance in which internal or external parties may be consulted when determining a solution.
Far-reaching consequences of disruptions under dependency on regional stakeholders	Recommendation 3.1: Reduce the uncertainty in stakeholder management and traffic disruption mitigation through establishing a higher order of cooperation.
	Recommendation 3.2: Increase the regional stakeholders' understanding of the critical need for R&R projects, communicate non-negotiable anchor points, and simultaneously strengthen relationship between PM teams and the municipalities on which they are dependent.
Complex phasing of construction stages and temporary measures or structures during realization	Recommendation 4.1: Ensure that early cost calculations, which are mainly based on material unit prices and the surface area of structures, account for the fact that modern bridge replacement structures are often much wider than the original structure.
	Recommendations 4.2: Ensure that cost reference numbers used in early cost calculations reflect the associated costs with the complex phasing for creating traffic bypasses, and develop standardized phasing plans to ground early estimation into practice.
Optimistic bias in early project scope and budget undermines scope-stability and feasibility	Recommendation 5.1: Asses whether on-site space allows construction of the widened, reinforced replacement bridge in full compliance with the design guidelines during the RA phase, and develop a fallback option based of on a minimum-version of those guidelines to reduce ongoing design-concession coordination.
	Recommendation 5.2: Aim to reduce the necessity of implementing bridging strategies through intensifying the inspection regime, and account for this bridging strategy in the early cost estimates of R&R bridge projects.

Table 9.2: Overview of complexities and their recommendations.

The recommendations established for enhancement of project delivery in R&R projects can be divided into two main categories. The first category encompasses the recommendations that can be directly incorporated in an enhanced versions of the R&R Approach, as they are a reflection of steps or products in the project delivery framework that must be explicitly included. The second category highlights the recommendations that target the (early) cost estimation process at RWS.

Each of the recommendations targets an area that is critical to the planning, development, and execution of R&R projects for bridges. Some of these recommendations have a direct link to the R&R project delivery framework. Therefore, these recommendations have been incorporated in the project delivery framework, as can be seen in Figure 9.3.

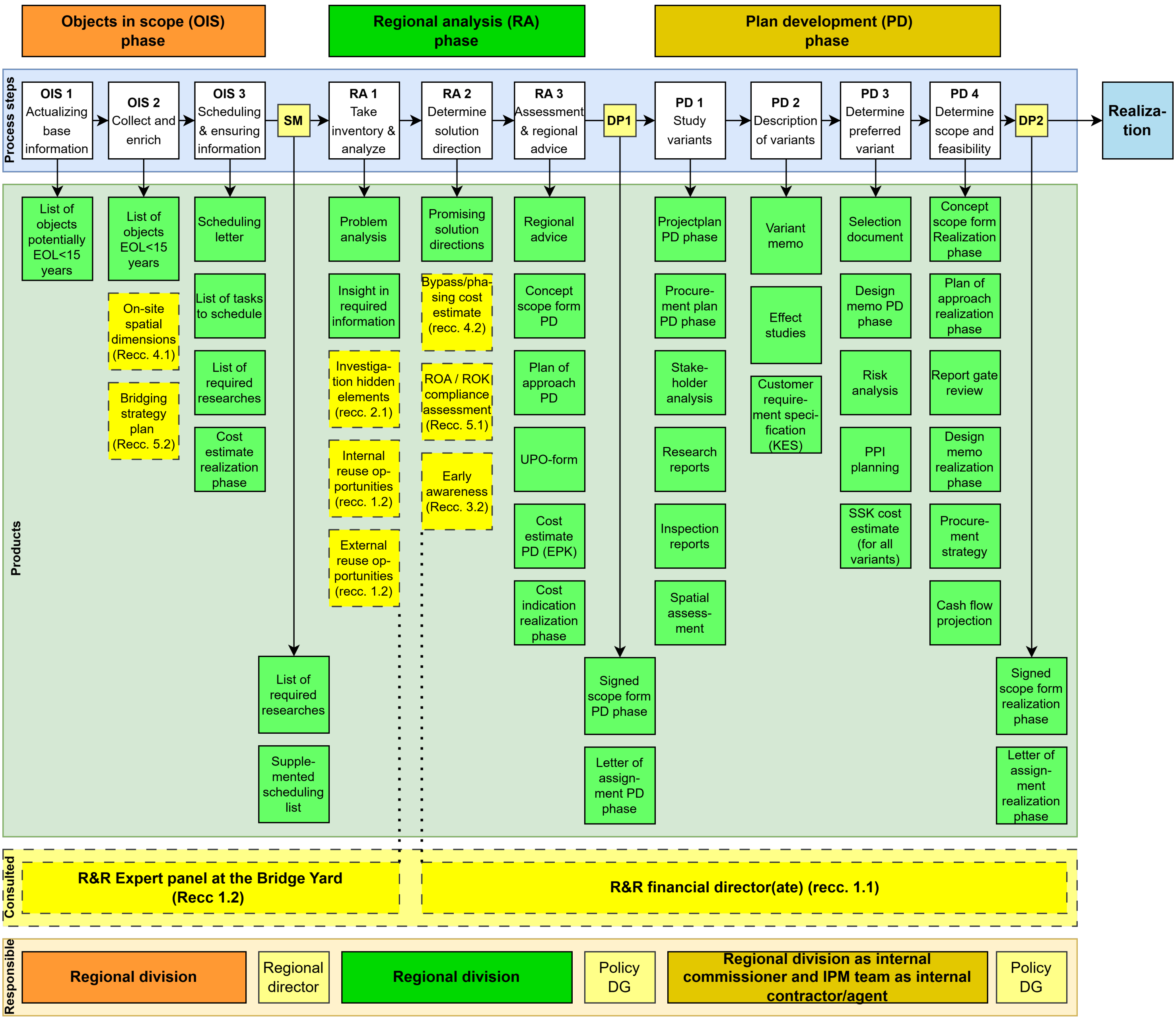

Figure 9.3: The enhanced R&R Approach. The striped yellow blocks are recommended processes/products to improve the project delivery framework.

9.5. Synthesis and concluding remarks

The discussion in Chapter 8 highlights several overarching insights of R&R project delivery. R&R projects are dominated by dynamic organizational complexities, stemming from evolving governance structures, unfamiliarity with roles and responsibilities, limited formalization, and high levels of epistemic uncertainty. Collectively, these and other (categories of) complexities significantly influence project performance. Furthermore, the research's exploratory nature, based on a single case study, limits the generalizability of its findings, yet it still provided value insight grounded in practice. Also, the study fills in a notable gap in academic literature, by offering concrete examples that illustrate how R&R projects are executed by RWS. Current literature on R&R projects remains limited, as it primarily discusses foreign practices that are not easily projected onto Dutch infrastructure due to international differences, or remain on the level of AM-related practices.

The findings emphasize that many financial and organizational setbacks originate from early assumptions that fail to capture the complexities inherent to infrastructure renewal, and the subsequent coordination efforts required to manage them. Public infrastructure managers should therefore prioritize improving the early identification and assessment of project aspects inherent to R&R projects, such as widened and reinforced structures, traffic bypasses, and reusing structural elements. Finally, further research may be conducted to validate and expand the findings of this research towards other types of bridges and different structures, and strengthen the alignment of interfaces between RWS, the Ministry of I&W, contractors, and regional stakeholders.

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A

AI usage statement

This appendix provides a statement on how AI has been utilized during this research. Since this research regards the Dutch infrastructure sector, AI has been used for translation purposes. With many text being originally Dutch, AI provided time-efficient translations. Additionally, AI provided suggestions for overall text-smoothening, increasing readability of text segments.

AI has also been used to make changes to and structure the code inside of the Overleaf text editor software, used to generate this document. Within this code, the original texts of the author are embedded. To conclude this statement, all texts in this thesis have originally been developed by the author.

B

The initial R&R Approach

Since the 2000s, the large scale renewal of infrastructure has become a matter of growing concern in the Netherlands. As a result, a project delivery framework was developed: the R&R Approach. The current version of this approach finds its origins in an initial version of the framework. The initial version of the R&R approach is highlighted in this Appendix. The appendix discusses the preparatory steps included in the project delivery framework in Section B.1. This is followed by three possible pathways on which a project may continue. These include measures incorporated in the Service Level Agreement (SLA) as displayed in Section B.2 or large-scale intervention either carried out under the R&R Approach or the MIRT framework, respectively discussed in Sections B.3 and B.4. The present version of the R&R Approach, currently used in R&R projects, can be found in Chapter 3.

B.1. Preparatory steps

In this section, the activities that take place until the first decision point of the R&R approach are described. After this first formal decision point, there are three options in which the project may continue. To provide a general overview, Figure B.1 has been provided.

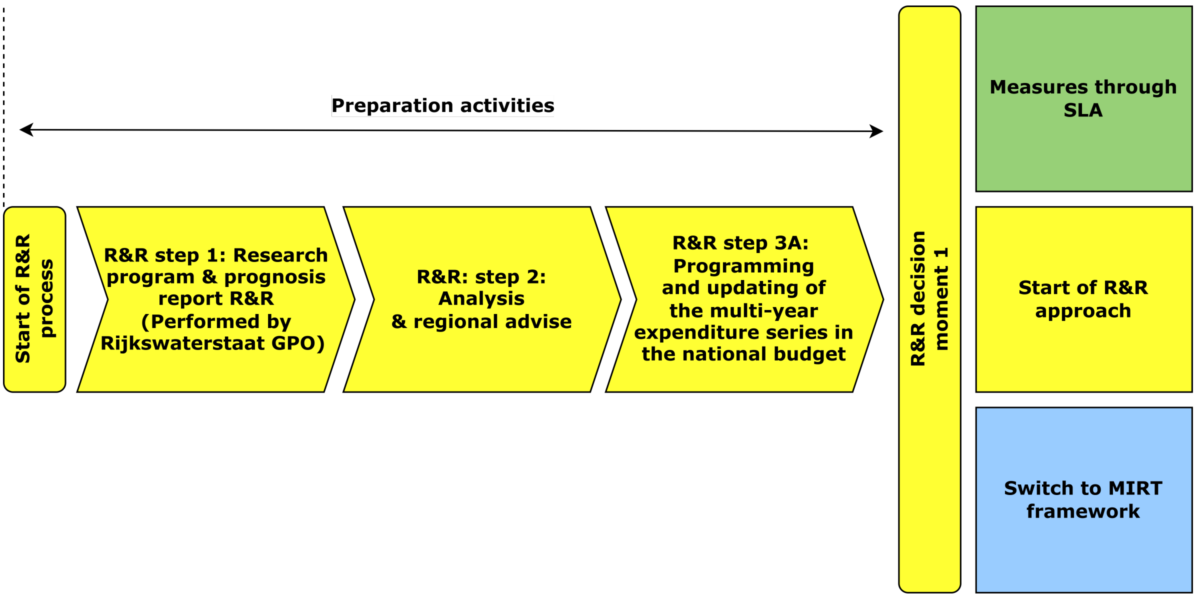

Figure B.1: Possible project pathways

When an infrastructure asset is operation, it is used by road and/or waterway users. During this period, various activities take place for the M&M of the asset. These include (small-scale) maintenance and other tasks that facilitate the determination of asset condition, such as regular inspections and monitoring. Through this bottom-up approach, the asset manager may address the need for intervention if an asset has (almost) reached end-of-life. Likewise, assets can be assessed top-down by RWS through (national) programs and asset management data. After identification and assessment, an asset may be classified as being in need for intervention, serving as the trigger to start the R&R process.

After the initial trigger, the R&R process has formally started. Parallel to the M&M activities during the operational phase, three steps of the R&R process also take place. They have been described by van der Vlist et al. (2016):

- **R&R step 1:** The asset is incorporated in the general research programs and the cost prognosis report of RWS. This report encompasses an assessment of the (expected) budgets that are required for the renewal of the total inventory of Dutch infrastructure assets. Through analysis, the expected period in which end-of-life is expected is calculated through statistical analyses, which incorporate the uncertainties. It must be noted that this period is not a moment in time, but rather a window.
- **R&R step 2:** A more in-depth analysis of the object(s) within project scope is conducted. In this, regional stakeholders (local governments, local residents, etc.) are also consulted, offering them an opportunity to discuss shifts in regional needs. This can potentially lead to different requirements for the asset that is to be renewed, compared to those that were adhered to during for the original construction. The step is concluded by composing a priority list of objects, including a preliminary invoice (cost prognosis) to the regional directorates.
- **R&R step 3A:** Programming (and updating) of the multi-year expenditure series in the national budgets, in this case, primarily the Mobility Fund. Initial insights are gained into the required and available budgets.
- ***R&R decision moment 1:*** In this decision point, the choice for the subsequent project approach is made. Measures can be taken through the SLA (B.2), the project remains within the R&R approach (B.3), the project makes a switch to the MIRT framework (B.4).

B.2. Measures through the SLA

No further steps are followed. Intervention takes place via M&M measures that are incorporated in the current Service Level Agreement (SLA).

B.3. Continuation of the R&R approach

The R&R approach is meant for projects that are considered to be of a low to moderate complexity and/or do not require (significant) changes in design, due to there not being any intended changes in the functionality. This approach was specifically developed to manage R&R projects belonging to either of the following classifications (Nationaal Kennisplatform voor Water en Klimaat, 2020):

1. **R&R 'one-on-one replacement':** Based on the current design, an replacement of the asset is realized. A similar construction is placed with the same functionality specification as the existing structure at the site where it is currently located (van der Vlist et al., 2016).
2. **R&R 'regular':** (Limited) research is performed for the asset to determine required changes in design to meet updated functionality requirements.

The current set of principles and practices is deliberately stated as an 'approach'. This approach is less formalized than other methodologies such as the MIRT framework, thus leading to it being referred as an approach and not a framework.

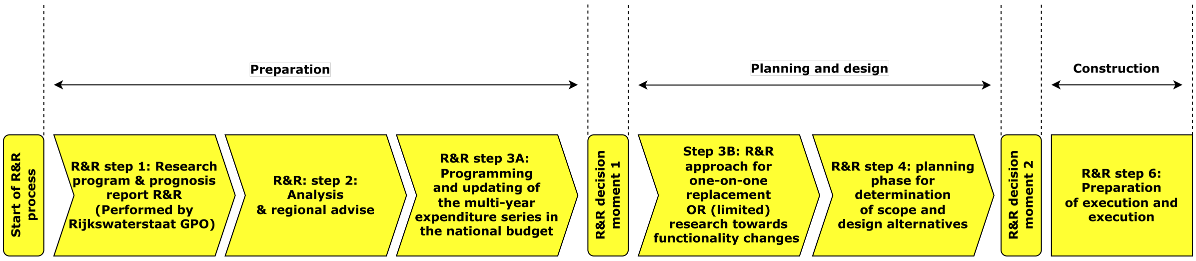

Figure B.2: The complete R&R approach

If has been decided that the R&R approach will be adhered to then the following steps take place:

- **R&R step 4: planning phase for determination of scope and design alternatives:** In this step, the exact scope of the project is determined in collaboration with the local stakeholders. Taking this into account, the preferred design alternative is decided upon. In the context of R&R, this translates to the selection of an updated design that is in alignment with modern specifications.
- ***R&R step 5/decision moment 2:*** At this decision moment, the Ministery of I&W chooses the preferred alternative design that will be developed into detail, so that it can be placed on the market via a tendering procedure. Through this procedure, a qualified contractor (or consortium) will be selected that can execute the project.
- **R&R step 6: preparing for realization and execution:** After finalizing the contract with the contractor, the final preparations take place for the execution of the project. With the completion of all prior steps, the project will now be executed.

B.4. Switch to the MIRT framework

If intervention is necessary to renew the asset and the project scope classified as complex and/or includes significant changes in functionality, then the asset is taken into the MIRT framework. It will however, not pass through all MIRT process steps that a regular construction project would go through, as can be seen in Section 3.1.

If it has been decided that a project will be planned and developed through the MIRT framework, then it will make a formal switch. According to the information available, it is then placed in one of the first three steps of MIRT, meaning that it will be taken up into the preparation, exploration or plan development phase (see Figure 3.1). It must be noted, however, that it is not clear which criteria are used to determine in which step of the MIRT framework the renewal project will start.

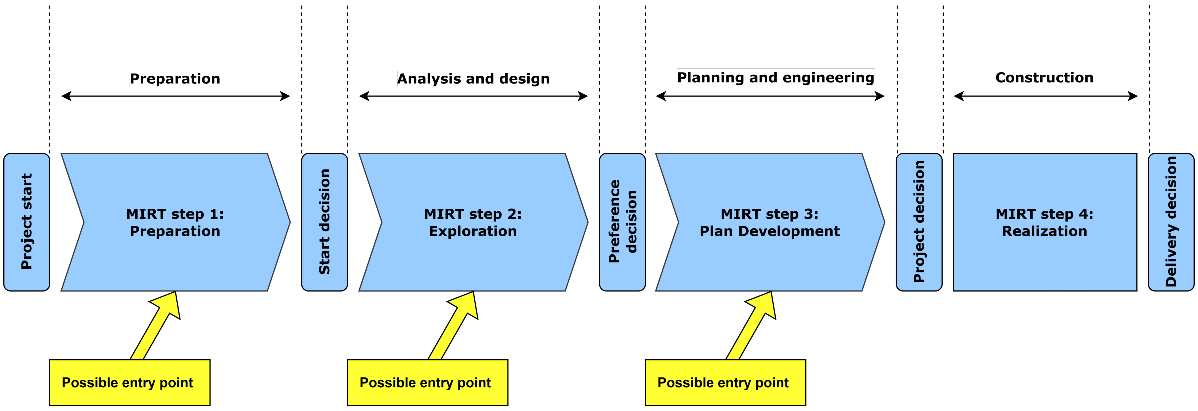

Figure B.3: Possible entry point for an R&R project in the MIRT framework

C

Challenges and complexities retrieved from the practitioner interviews

This appendix displays the full description of the challenges that practitioners encounter in R&R projects, which have been established through the interviews. The practitioners have each provided their insights from the perspective of their respective organization.

C.1. Interview participants

The challenges that are practitioners involved in RWS R&R project encounter were retrieved through a series of semi-structured interviews. These interviews were held among seven participant, who are all currently working on renewal projects. The interviewees work at various organizations, allowing to gat a holistic perspective of the challenges at hand. An overview of the individuals who have partaken in the interviews is provided in Table C.1.

Identification number	**Organization and role**
R1	Contractor, planning expert
R2	Contractor, cost expert
R3	RWS, cost expert
R4	RWS, project management
R5	Ministry of I&W, policymaker
R6	RWS, project management
R7	RWS, project management

Table C.1: Overview of respondents.

C.2. The technical landscape of R&R projects

In this section, challenges regarding technical project aspects are discussed, in order to identify the complexity from which they stem.

Technical complexity arises from the use of unproven technologies and technical uncertainties encountered during project execution.

C.2.1. Technical vs. functional feasibility of the starting point 1-to-1 replacement

Within the infrastructure renewal, 1-to-1 replacement is a key starting point for the majority of R&R projects. It is a policy instated by the Ministry of I&W urging RWS to execute R&R projects cost-effective, as implementing functionality upgrades drives additional costs. Therefore, the renovated or replaced asset's functionality must be equivalent to the original structure. This requirement results from the fact that major budget deficits are expected in the coming decades (Ministry of Infrastructure and Water Management, 2025). Despite seemingly being a clear instruction, PwC and Rebel (2020) estimated that 90% of 1-to-1 replacements actually did include a upgrade of functionality, indicating that the principle holds a certain nuance.

While an existing functionality level can be maintained after an intervention, a renewed structure must comply with current technical regulations. In the Netherlands, infrastructure complies to national regulations such as NEN-norms, but also to European regulations such as Eurocodes, which provide a common approach to the structural design of buildings and other civil engineering works (European Union, 2025). These regulations are mandatory, meaning that deviating from them is not an option. Besides these regulatory frameworks, RWS has developed their own set of design guidelines for infrastructure. These technical regulation push toward higher standards, often increasing safety and durability of infrastructure.

In RWS projects, their design guidelines are incorporated as a starting point, meaning that deviation is not possible without formal approval from the appropriate authority. The most prominent design guideline for bridges are the ROK, ROA, and RV. The ROK is a guideline for the design of civil engineering structures, developed in-house by RWS (Cementonline, 2025). The other design guidelines respectively prescribe requirements for highway and waterway design.

Practitioner insights

The notion that 1-to-1 replacement are nuanced, is shared among a substantial part of the respondents (R1, R2, R3, R4, R7). Functional 1-to-1 replacements are possible, given that, policymakers want to retain the current functionality. Additionally, it is also possible that the choice is made to increase or decrease the functionality of the asset. However, what is never possible in practice, is a technical 1-to-1 replacement (R1, R4).

Legacy bridge designs, developed many decades ago, are now obsolete. Higher safety standards prescribe wider driving lanes and continuous emergency lanes, while technical standards dictate more robust structures to withstand heavier modern traffic. It urges RWS to redesign assets to bring them up to standard, often implying reinforced (increased material usage) and larger (higher or wider) structures.

Before any inquiry can be made on the space, budgets, time, or materials required for construction of a new structure, a PM team must perform profound research, as these are subject to significant technical uncertainty. A practical illustration of this uncertainty, can be found in the increased spatial dimensions of a replacement bridge, that was to be significantly wider than the existing structure (R4):

> When a bridge becomes wider than the existing structure, additional space is needed to accommodate this. For the 'interim decision point' (*tussenbesluit*), it was investigated whether this space could indeed be obtained, as this is often a determining factor for the project's realization timeline. In addition, an assessment has been of what is maximally possible within the space available [to RWS currently].

This viewpoint is shared by another respondent, who offers a similar experience (R7):

> It [constructing a replacement structure] is referred to as a replacement, but it is, in fact, a new bridge. From a planning perspective, it falls under the [municipal] zoning plans, with essentially, the same type of asset being reconstructed. This distinction is not universally recognized.

As the RWS design guidelines demand a wider bridge, the PM team had to determine the feasibility of the bridge design within the space available, optimizing their options within ground owned by RWS. This initial uncertainty obscures project outcome, as it remains unsure what the final structure will be and what this will cost. This is recognized by PM teams and policymakers, but it remains difficult to estimate as another respondent explains (R5):

> The uncertainty is recognized, as can be seen from the fact that uncertainty margins [in cost estimates] have been calculated. However, the question remains whether it is sufficiently accounted for in the final budget [of the R&R project]. It currently appears that the budget,

which is based on the R&R Prognosis Report (Rijkswaterstaat, 2022), does not adequately consider the nuances inherent to a 1-to-1 replacement.

It remains a complicated matter, because what figures should be assigned to this? Uncertainties only become more visible in projects that are currently under development, as active cost estimates are produced. These projects therefore receive a different assessment than projects scheduled in the distant future [as more scope is more detailed], which are still primarily based on the Prognosis Report.

As can be noted, projects in active development truly reveal what the nuance in the 1-to-1 replacement holds for individual R&R projects. The implications are subject to ambiguity, personal interpretation, and organization or political-administrative developments.

Complexity identification

Within this challenge, the following complexities have been identified:

- **(De)construction of replacement or renovated, temporary, and existing structures lead to large project project scope**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large-scale product (detail technical complexity).
  - **Description:** Within R&R projects, the project scope is large as it encompasses the renovation or the replacement of an entire bridge, which potentially also includes the surrounding complex. Furthermore, comprehensive measures are required to establish a temporary situation which allows for execution of the project in a safe manner where traffic flows are maintained. As a consequence, the project scope consists of many elements, all critical to ensure effective and safe functionality of the asset after the intervention.
  - **Uncertainty source:** No uncertainty present.
- **Interrelatedness of bridge elements and changes in design**
  - **Categorization according to complexity categorization framework (Table 4.1):** Many connections among parts of the product (detail technical complexity).
  - **Description:** Elements of the design are severely interrelated, meaning that a change in one part immediately affects others. Design changes mandated by modern design guidelines, i.e., the upgrades to designs required for compliance with technical regulations or guidelines, affect the design as a whole. The interdependence makes the system complicated, as intricate relationships dominate the system.
  - **Uncertainty source:** No uncertainty present.
- **Determining the project-specific implications of the 1-to-1 replacement principle**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of decisions with uncertain best solution (dynamic organizational complexity).
  - **Description:** Defining the true implication of the 1-to-1 replacement principle within an individual project is an evolving and process per project. In part due the varying perceptions within PM teams, but also since there is significant differentiation among the assets. The uncertainty regarding this matter is epistemic, as it can be reduced through further formalizing boundary conditions for these types of replacements.
  - **Uncertainty source:** Epistemic.
- **Changes to RWS design guidelines impact ongoing project development**
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization (dynamic organizational complexity).
  - **Description:** Developments in design guidelines affect their exact implementation. RWS design guidelines, such as the Guideline Design Structures (*Richtlijn Ontwerp Kunstwerken, ROK*), Guidelines Design Highways (*Richtlijn Ontwerp Autosnelwegen, ROA*), Guideline Waterways (*Richtlijn Vaarwegen, RV*) can subjected to change, due to policies evolving

over time, altering project project scope requirements for projects in active development and in the future. However, an important note must be made, as this regards guidelines, i.e., they are not mandatory. Deviation from the guidelines is possible, after internal approval. It is epistemic uncertainty, as it is based on policy shifts and technical developments. It presents unknown uncertainties, as the exact implications and chance of occurrence are hard to determine.

  - **Uncertainty source:** Epistemic.

- **Diverging perceptions on true cost development for 1-to-1 replacements**
  - **Categorization according to complexity categorization framework (Table 4.1):** Perception of cost developments differs from calculations (detail financial complexity).
  - **Description:** Stakeholder expectations for cost developments differ from actual developments. The development of costs can be perceived in various ways, depending on the role and knowledge of specific stakeholders, with practitioners and executives sharing no common perception. RWS practitioners are aware of the complex and uncertain nature of R&R projects, and thereby the costs associated, but this is not shared among all members of the organization and Ministry of I&W. As a result, cost development may diverge from initial expectations as the project progresses. This complexity is continuously encountered over the variety of R&R projects currently in development.
  - **Uncertainty source:** No uncertainty present.

C.2.2. Unavailability of asset data and as-built information

A substantial amount of the objects that are now reaching their technical EOL, have been constructed in the 1960's and 1970's (ABN-AMRO, 2025; TNO, 2021). The year of construction for some objects goes back even further. In some cases, assets might be younger, but still be in need renewal. Conclusively, assets in the RWS asset base span a broad range of construction dates, now forming a (historically) diverse set of structures in the Netherlands.

Over the lifetime of an object, regular maintenance is carried out, damages are repaired, and changes are made. As a result of the multitude of small-scale interventions to which an asset is subjected, it remains critical to have a clear record of them. In many cases, this has proven to be lacking, providing that PM teams are faced with low-quality data, hampering the establishment of the as-built situation, thereby obscuring insight into the current condition and configuration of the asset(s) within the project scope.

As has been concluded, RWS is struggling in with its data governance, lacking reliable and standardized information in their AM (Improven, 2021). A challenge within the AM of RWS, is the sheer number of objects that are under management of RWS. As De Raat (2023) indicates, the agency is responsible for 64.000 structures, in addition to roads and waterways, meaning that an in depth investigation of each object is not always feasible. Next to the sheer number of structures proving challenges, they are also highly differentiated.

Practitioner's insights

The challenges faced with regards to asset data and the as-built situation emerged in almost all interviews (R1, R2, R3, R4, R6). It remains a persistent problem for R&R projects as the current condition and configuration of the object is one of the fundamental presumptions in any R&R project (R6). Discrepancies between the presumed and actual as-built situation may disruption of the intended project execution.

An example has been provided regarding the foundations of a bridge, which ensure overall stability of the structure. These foundations may have been compromised by changes in ground water, e.g., rising or declining ground levels or changes in salinity (R1). Determining the condition of foundations requires significant efforts, under the assumption that it is possible in the first place. Therefore, providing guarantees for the condition of foundations proves difficult, if not impossible (R1, R2). In some cases, additional research and calculations are conducted (R2, R3). However, even if the results of these researches show that reuse is possible, a contractor cannot be forced to agree with the results, as they must guarantee the remaining service life of the foundations and therefore may still prefer replacement (R3).

Additionally, as-built documentation indicates the changes to the configuration of the asset, e.g., by keeping track of utility cables and piping in the area. With regards to this, one respondent mentioned that cables which were moved or added later on are lacking documentation, and that these cannot be removed without determining if they are still in use, as illustrated by the following insight (R6):

> In R&R projects, it is very important to have accurate as-built drawings. These drawings are leading within the project, as they provide overview of the situation at hand. Therefore, this documentation forms a key starting point. Currently, there is no standard RWS procedure which facilitates maintaining these as-built drawings. Many of the existing as-built drawings were created decades ago, and have since been only minimally updated, if at all.
>
> Keeping these drawings up to date requires funding [for administrative work], and the parties contracted for executing asset maintenance are primarily evaluated on the performance of the asset [performance based maintenance]. Due to this lack of governance, as-built drawings are not always properly maintained.

The insights provided clearly indicate that the obscured as-built situation interferes with the performance of R&R projects. It can lead to problems during realization, disrupting project execution, generating additional costs, and disrupting the intricate planning of construction stages and traffic closures.

Complexity identification

Within this challenge, the following complexities have been identified:

- **Incomplete object data and as-built information at start realization phase**
  - **Categorization according to complexity categorization framework (Table 4.1):** Technical uncertainty (dynamic technical complexity).
  - **Description:** There is technical uncertainty regarding the configuration and condition of objects in R&R projects. Asset data is often missing or incomplete, with as-built drawings lacking maintenance throughout the service life of the object. This is in part due to lacking data, which can be reduced through inspections and research efforts (epistemic), but also due to the natural deterioration of elements, which cannot be accurately determined at all times (aleatory).
  - **Uncertainty source:** Epistemic and aleatory.
- **Changes in asset data governance due to outsourced maintenance for assets**
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
  - **Description:** Data governance by RWS has evolved over time, due to the performance-based, outsourced maintenance strategy that is currently employed. As maintenance contractors maintain assets, they also govern the management of inspection data and keep track of changes made to the configuration, e.g., moving utility lines. As a result of these developments, records and thus data is fragmented. Furthermore, it has been provided that these contractors do not always keep their records up to data, leading to gaps in maintenance data. The uncertainty in this matter is epistemic, as increased control through contract management will help reduce it.
  - **Uncertainty source:** Epistemic.

C.2.3. Implementation of industrial automation and building blocks

The vast majority of infrastructure assets in the Netherlands contains some form of hardware and software. It facilitates the daily operations of the asset, e.g., by controlling the opening procedures of bridges. The current technical installations applied to bridges is judged to be too diverse and complex, leading to malfunctions, delays and safety risks (Rijkswaterstaat, 2025e). To reduce the differentiation among these technical installation utilized in the industrial automation of assets, efforts are made to implement so-called ”building blocks”.

A building block is configurable, standard hardware or software that is applied in bridges and tunnel, aimed at making the management of these objects less complex. The aim of using these building blocks is to increase uniformity among objects, through reusing standardized parts (TNO, 2022). Prominent within the industrial automation of bridges, is the 3B-building block, which handles operation, control, and monitoring. Example functionalities include the activation of the signaling, barriers, and movement of the bridge deck (Comaen, 2025). Using building blocks is a common requirement included the project contract, to strengthen standardization efforts. The building blocks are supplied by RWS, in what is referred to as a ”direct delivery.” RWS supplies the part, and states full responsibility for its technical functionality and feasibility. (Instituut voor Bouwrecht, 2022).

Practitioner's insights

Although the efforts in standardizing the technical installations among the asset base is perceived to be a welcome development, it is not always without challenge or discussion (R7). Respondents have provided several insight regarding these building blocks and direct delivery materials. It is provided that (R2):

> The delivery of technical installations of bridges, that is, the software and hardware used to control and secure them, does not always proceed smoothly. These installations are provided by RWS as building blocks, in an effort to reduce the variety of systems in the asset base and thus increase uniformity. However, the success of this approach depends heavily on the [on-site] integration of the building blocks.
>
> It can happen that the software does not match the local situation, requiring adjustments to either the software, the hardware, or both. This integration work is now primarily handled by the supplier, for which communication takes place via RWS. In the past, these technical systems were not part of a direct delivery by RWS, but the responsibility of the project contractor. If issues arose, the contractor’s technicians could often solve them relatively quickly on-site.

The respondent indicates that on site flexibility has been reduced, limiting the abilities of the contractor on site. Besides this, as repairing problems is now facilitated through RWS and the party from which they receive the materials (supplier), the chain of communication is significantly longer. Another remark is made on the difficulties for building block implementation (R3):

> The building blocks or direct deliveries have become a major cause of significant cost overruns, especially the control and operating systems. These systems are subject to numerous requirements, for instance, cybersecurity regulations, but these requirements can be unrealistic.
>
> Many thing can go wrong with the technical installations, as they are highly interconnected within entire structure [and complex]. Everything is interwoven, which makes it complex. For example, the technical installation of a bridge might also be connected to a lock that is part of the same complex.

Complexity identification

Within this challenge, the following complexities have been identified:

- **Interconnected technical installations lead to complicated industrial automation situations**
  - **Categorization according to complexity categorization framework (Table 4.1):** Many connections among parts of the product (detail technical complexity).
  - **Description:** Technical installations of bridges are interwoven with many subsystems of the surrounding complex or other structures. A failure or mismatch in one technical installation, e.g., a building block, can pose significant consequences to others.
  - **Uncertainty source:** No uncertainty present.
- **On-site industrial automation situation differs from as-built or design drawing**

  - **Categorization according to complexity categorization framework (Table 4.1):** Technical uncertainty (dynamic technical complexity).
  - **Description:** Changing requirements and local adaptations of building blocks introduce epistemic uncertainty, since full compliance needs or software mismatches often only appear during implementation. Some uncertainties are known, but unforeseen uncertainties might also present themselves during on-site installation.
  - **Uncertainty source:** Epistemic
- **Building blocks reduce on-site flexibility of the implementing organization**
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
  - **Description:** The shift from contractor-managed technical installations to building blocks, managed and delivered directly by RWS and their preferred supplier, reduces the overall adaptivity of contractors. This implementing organization could traditionally solve on-site problems with their own technicians, whereas compatibility problems currently have to be coordinated via the preferred supplier. These developments reduce the overall flexibility of implementation. It poses epistemic uncertainty, as it results from the inability to foresee all potential difficulties during planning, but may be reduced through formalizing processes and incorporating past experiences.
  - **Uncertainty source:** Epistemic.

C.2.4. Facilitating reusing construction elements

Reusing construction elements is a strategy proposed in infrastructure projects to contribute to circularity goals, and has the potential to save project costs. However, in order for a project to engage in these sustainable efforts, a formalized process is required to support it.

Reuse of structural elements in R&R projects is a pivotal development, not only to increase the sustainability of RWS projects, but also to improve material cost and emission. In recent times, (raw) material prices have increased significantly (Ministry of Infrastructure and Water Management, 2024). This urges the infrastructure sector to rethink material usage, reducing waste, and optimizing processes.

Besides sustainability, optimizing the reuse strategy in a project can have positive impact on cost, traffic disruption, and simplification of construction. As R&R projects engage in the renewal of existing infrastructure, there is always an ”old” asset on site. If structural elements, e.g., foundations, concrete, floors, can be reused, it may save the construction efforts normally required to construct new ones. However, reusing structural elements does introduce uncertainty into a project. Reused elements must, at a minimum, comply with modern technical regulations and guidelines, prove feasible for implementation in the replacement or retrofitted design, and have sufficiently long remaining service life.

Practitioners insight

The reuse of structural elements was regarded as a frequent point of friction in renewal projects by all practitioners. An introduction to some of the practical questions associated with reuse is provided:

- *Is the concrete layer protecting the reinforcement bars sufficient, so that it will last the required service life? (R1, R2)*
- *Are the foundations in the ground still structurally sound of have they been compromised? (R3, R7)*
- *Can cables be laid in the current cable ducts or are they blocked? (R2)*
- *Will structural elements, originating from other projects, be used in the project that we are currently working on? (R4)*

These questions provide an indication of the uncertainty inherent to reuse, necessitating additional research efforts for mitigation. Besides these practicalities, reuse may also prove problematic with regards to regulation compliance, as one respondent explains (R2):

> For some renovation projects, the machine room of the bridge is also retrofitted. However, the new design must abide by the prevailing regulations, such as the Standards for Machine Safety and the Occupation Health and Safety (OHS) regulations *(Arbowet)*. Examples of measures include shielding off moving parts, setting up emergency escape routes, or mounting handrails. The implementation of these measures is not always feasible, e.g., because of a lack of space. The requirements that cannot be complied to remain as outstanding issues, which can prevent the bridge from entering service.

Another point of discussion between the parties involved in infrastructure renewal, is the assessment of structural elements that are to be reused. It follows from the fact that if this assessment proves wrong, the expected (and contractually required) service life of the asset can be severely affected, thereby harboring major financial consequences for the party holding responsibility. If for example, the foundation of a bridge fails, then it is at risk of sinking, damaging the structure and making it inoperable. In some of the contracts between RWS and the contractor, these risks are allocated at the contractor, which may therefore prefer to construct new foundations, in order for mitigation of the risks associated with reus (R2). It is a symptom of the fact that, as is noticed in various aspects of the contractual landscape of R&R projects, there is currently no framework guiding reuse (R6).

PM teams developed a project-specific approaches to establish whether reuse of specific structural elements is possible. An example of this has been provided (R7):

> The stability [of the foundations underneath the floor of the bascule chambers] has not been determined on the basis of historical documents. The piles [in the foundation] have been procured by the original contractor. What the project team did instead, was to drill into the [lateral] support piles at several locations, in order to extract samples. These support piles provided lateral stability to the bascule chamber when the bridge was still movable. The cross-sections of these samples were examined, allowing for their composition to be determined.
>
> The concrete proved to be very strong, with an exceptionally high compressive strength, and showed no signs of deterioration. The RWS project team carried out this investigation themselves, although the drill samples were analyzed in an [external] laboratory. For this [overall internal process], RWS drew on its in-house expertise, involving specialists in fields such as concrete technology and foundations.

The respondent also provided that reuse remained as an issue between the PM team and the contractor despite all efforts, as questions regarding the feasibility of the reuse still would continue. However, neglecting this opportunity for reuse would result in far higher project costs, as an new foundation and longer span would be required due to a less optimal placement of piers. Additionally, traffic disturbance would be far greater due to prolonged construction efforts. Another respondent provided an insight into reuse with regards to the contract used (R6):

> From a political perspective, reuse is a key topic, but before it can be effectively implemented, a clear understanding of the situation at hand is required. The contract of project must also align with this objective. The reuse of structural elements is an aspect that is currently not yet sufficiently incorporated into standard contracts. In contrast to the reuse of materials such as sand or asphalt, which is already widely practiced.

Complexity identification

Within this challenge, the following complexities have been identified:

- **Uncertain condition and feasibility of implementation for reused (structural) elements**
  - **Categorization according to complexity categorization framework (Table 4.1):** Technical uncertainty (dynamic technical complexity).
  - **Description:** There is technical uncertainty regarding the condition of structural elements, as a result of difficult assessment of their expected remaining service life. Therefore, guaranteeing service life becomes difficult, and establishing the true condition of a structural elements is not without cumbersome effort. The uncertainty originates from both aleatory

uncertainty (continuously changing element state) and epistemic uncertainty (lack of information due to insufficient formalization of research).

- **Uncertainty source:** Aleatory and epistemic.

- **Reuse is not sufficiently integrated in formal procedures and standard contracts**
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
  - **Description:** Roles and responsibilities in R&R projects have changed over time, making the allocation of risk associated to common R&R aspects unclear in existing contracts. Efforts are made by RWS expert reuse teams, thereby shifting risks from the contracted parties towards RWS to encourage reuse. The uncertainty residing within this complexity is epistemic, as contracts and procedures must formally incorporate the issues presented when reusing structural elements.
  - **Uncertainty source:** Epistemic.

C.3. Management of the social and legal environment

In this section, challenges regarding social project aspects are discussed, in order to identify the complexity from which they stem. Social complexity stems from differing stakeholder interests, perceptions, and attitudes, particularly when high impact is involved.

C.3.1. Providing technical solutions under changing stakeholder requirements

R&R projects are carried within the Dutch built environment, characterized by a densely populated, highly developed landscape. Every object that will be subject to an R&R intervention, must remain (partially) operational. Therefore, large-scale R&R projects are fundamentally different than the construction of new infrastructure (networks expansions), as a temporary situation must be facilitated. Identifying the activities and measures required for the temporary situation prior to and during realization remains an critical aspect of any R&R project.

Due to the construction works on and around the asset, measures must be taken in order to guarantee the safety nearby traffic, but also of the construction workers. As a result, the functionality and performance of the bridge may be restricted due to safety measures. For a bridge, consequences may range from partial closure through the enforcement of weight and/or speed limits, narrowed driving lanes, or being closed for maritime traffic. Additionally, temporary constructions, e.g., a temporary bridge for traffic continuation or supporting elements to ensure structural safety, may be in order. This is all necessitated by the fact that a complete, prolonged shutdown of infrastructure incorporated in the HWN or HVWN is often unacceptable.

For R&R projects, support from regional stakeholders is critical. Without their approval, project performance is at stake. Stakeholders could organize their protest, or municipalities could deny permits. In order to encourage a good relationship between parties, RWS engages in significant efforts for stakeholder management. Through conducting conversations among stakeholders, their requirements for project execution and the renewed asset are collected. The compiled set of requirements is formalized in the customer requirement specification, also known as KES.

Complying with stakeholder requirements is often strongly associated with measures aimed at ensuring regional accessibility, particularly by reducing traffic disruption. Such measures inevitably generate additional costs, and thereby put the cost-effectiveness of the project under pressure. As a result, projects may find themselves in a field of tension between requirements set by the organizational frameworks or guidelines, and the need to maintain project performance, i.e. allocating funds in a way that allows the project to progress.

Practitioner insights

Making lasting agreements has proved difficult within R&R projects. The most prominent dilemma provided is within field of tension regarding reducing traffic disruption (R1, R2, R3, R4, R5, R6). In these agreements, local governments, emergency services (hospitals, police stations, fire stations), and the regional infrastructure manager, are key stakeholders. These are consulted at the front end of the R&R project, but stakeholder management has proven challenging as practitioners state that is hard to make lasting agreements (R4, R5, R6). Practitioners indicate stakeholder management takes place within a dynamic setting. The evolving environment prevents static planning, as indicated by one respondent (R4):

Certain aspects will inevitably continue to surface due to the dynamic nature of the project. Ideally, everything would remain as stable as possible from start to finish. However, the context can shift, sometimes at moments that are far from ideal. The aim is to capture this in clear agreements, but the question remains: what should and shouldn't be included?

These dynamics produce a constant stream of additional, or changed requirements. Examples from the respondents include additional maintenance roads (R3), or reducing traffic disruption through keeping a highway partially open (R1, R2, R4). These dynamics often emerge when the realization phase draws near, and when the true implications of the initially agreed upon measures can be felt. It is then, that stakeholders deem the measures not as acceptable as anticipated (R5). Additionally, agreements are sometimes based on early presumptions, which may prove to be not feasible during the actual execution of the project (R6). An illustrating example of the dynamics at play in the stakeholder management of R&R projects, and the heavy demands this poses for the stakeholder manager, is given by one respondent (R3):

> The stakeholders in surrounding area [the region] are a source of new requirements, which are consistently accommodated. This remains an ongoing process. Examples includes requests for a wider road, preventing closures during inspections. When the costs of a renovation and replacement project are calculated, such requirements are not included in the initial scope. Over time, however, these requests are approved. Ideally, all requirements should be collected at the outset, followed by strict management to prevent additional requirements from being introduced along the way.
>
> The stakeholder manager carries a heavy responsibility in facilitating the temporary period, as no one wants a closure [of the asset]. Ideally, the region would accept, figuratively speaking, no more than a one-week closure, which creates significant tension. It is difficult for the upper management of RWS to push back against this.

An additional problem inherent to continuously deviating from the organizational frameworks or guidelines, which advocate for cost-efficiency, is that it sets a precedent. It reduces overall project efficiency, from the viewpoint that a standard or uniform approach equals an efficient project execution (R4). This respondent additionally remarks:

> Within RWS, there is a disruption management strategy aimed at minimizing inconvenience as much as possible. However, as more and more [R&R] projects are being executed simultaneously, suboptimal outcomes regarding disruption will become increasingly common. Measures to prevent disruption also incur costs. Especially in the context of securing approval from local authorities, it remains important to maintain both political and societal support, and therefore to limit disruption. This is particularly relevant due to the dependence on permits issued by local authorities.
>
> Additionally, there is a growing societal trend toward lower tolerance for disruption. Nevertheless, it must also be acknowledged [by society] that, without the R&R projects, an growing number of malfunctions, functional limitations, and safety issues will arise [for Dutch infrastructure].

Another respondent again addresses the critical reason for adhering to the frameworks organizational frameworks and guidelines that advocate cost-efficiency within infrastructure renewal (R5):

> In today's approach, significant amounts of funds are spent managing political-administrative uproar, while the overall budgets are already insufficient. Every euro spent on gestures to appease political concerns is a euro not spent on the primary objective: maintaining infrastructure assets. While minimizing disruption is indeed a valid project goal , the issue is that political unrest often results in measures that are not proportionate from a disruption standpoint alone. The maintenance agenda is priced based on an investment logic, which

> does not necessarily align with political-administrative reasoning. These two viewpoints inherently conflict. However, maintaining political support is critical, as authorities grant the necessary permits. Therefore, having predefined anchor points to fall back on can be crucial for the success of the infrastructure upkeep challenge.

However, despite the costs associated for accommodating stakeholder requirements, they cannot be easily ignored. Potential consequences may be severe, as illustrated (R4):

> I will probably spend about one million euros extra on a hindrance-mitigation measure, purely because I feel it is necessary in order for the project to continue. In other words, it would ultimately cost me more if I did not do it. What would happen if you did not spend that money? To put it simply, the reality is that there would be many complaints from the surrounding community. It could also, for instance, lead to unsafe situations arising due to the disruption caused in certain areas. Naturally, we would have to respond to that; it is not something that can simply be ignored. If that were to escalate, it would reach the political-administrative level, and spread further.
>
> So I believe it would, on balance, cost more if we did not make that investment now. It is difficult, because some things cannot be expressed directly in monetary terms, e.g., safety. Even if it would not amount to the full million [of euros], if truly unsafe situations were to arise, I would not consider that responsible. It is also a matter of risk assessment: if everything goes well, it may all blow over without serious consequences, but if, for example, a fatal traffic accident were to occur on a diversion route because the situation ultimately proved unsafe, that would be an unacceptable issue.

RWS is skilled in devising creative solutions to tackle these problems, but this often comes at a significant cost (R5, R6). An example can be found in the strategic phasing of construction: When a bridge was to be replaced, the phasing of construction stages were scheduled so that it allowed traffic to continue to use highway. The method employed here was to construct a new bridge first, reroute traffic via this new structure, and only then demolish the old structure (R4). Regarding the temporary situation which is often to be facilitated in order to maintaining traffic flow, one respondent remarks the following (R1):

> In MIRT projects [for constructing new infrastructure] there is no temporary phase during construction, but in R&R there is: The structure is currently used by traffic, and therefore a (temporary) replacement must be arranged. This makes the scope complex. Additionally, the temporary situation is often not so temporary. For example, at other organizations, anything that remains in place for longer than a year is classified as new construction [not as temporary]. Subsequently, the scope changes significantly, as the temporary situation becomes much more dominant than initially anticipated. Therefore, the phasing costs [cost associated to unconventional constructing staging and utilization of temporary measures] are often underestimated.

The insights provided with regards to stakeholder management highlight the delicate balance between cost-efficiency and project performance. It is an area of key interest within R&R projects, as the overall challenge will inevitably increase due to the rising number of R&R projects that must be simultaneously executed in the near future.

Complexity identification

Within this challenge, the following complexities have been identified:

- Complex phasing of construction stages and temporary measures or structures during realization
  - **Categorization according to complexity categorization framework (Table 4.1):** Many relationships between part of the product (detail technical complexity).
  - **Description:** In facilitating a temporary situation for ensuring safe construction and continuity of traffic, a variety of measures must often be included so that a traffic bypass may be constructed. It drives a phasing of construction stages, in which alternating stages of construction and demolition are employed during intervention. Additionally, temporary measures or structures are required prior to and during the realization phase, such as weight

limits, reinforcement structures, temporary bridges, and others to ensure safe traffic continuation. Developing an appropriate phasing strategy for R&R projects requires significant efforts by PM teams, but ultimately, it can be fully planned.

  - **Uncertainty source:** No uncertainty present.

- **Stakeholder requirements shift as projects progresses**
  - **Categorization according to complexity categorization framework (Table 4.1):** Changing stakeholder requirements (dynamic social complexity).
  - **Description:** Regional stakeholders may introduce new or changed requirements as an R&R project progresses. When the realization phase draws near, it often emerges that additional measures are requested to alleviate negative side-effects of the project. In order to sustain overall stakeholder and political-administrative support for the project, it is of pivotal important to manage these stakeholder requirements adequately. Failing to do so may result in opposition, thereby inevitably hampering project performance. The development described here pose epistemic uncertainty, as it arises from the incomplete knowledge regarding the future position of stakeholder demands.
  - **Uncertainty source:** Epistemic.
- **Disruption management vs. cost-efficiency creates financial tension**
  - **Categorization according to complexity categorization framework (Table 4.1):** Costs and benefits are difficult to calculate and are not equally divided (dynamic financial complexity).
  - **Description:** Efforts to minimize traffic disruption inevitably come at a cost, often driving expensive technical measures, thereby setting a trade-off between societal acceptance and financial feasibility. R&R projects operate under cost efficiently principles dictated by budget deficits, meaning that measures taken to counter traffic disruption must be proportionate. It is a form of epistemic uncertainty in the project, as cost estimates and benefit calculations are developed over time while stakeholder requirements will also become more apparent, thereby reducing this uncertainty.
  - **Uncertainty source:** Epistemic.
- Far-reaching consequences of disruptions under dependency on regional stakeholders
  - **Categorization according to complexity categorization framework (Table 4.1):** Major impact on the environment (dynamic social complexity).
  - **Description:** The social impact of traffic disruption and the measures taken to mitigate this require careful consideration by PM teams. However, not al demands made by stakeholders are feasible, as they may require a disproportionate allocation of funds. In the tension that arises from this, issues may lead to reputational damage, or possibly political-administrative scrutinization. Additionally, PM teams are highly dependent on the approval of permits, granted predominantly by municipalities. As a result, project feasibility and planning depends on these entities. Conclusively, the overall opposition that may arise from not adequately managing regional stakeholders is difficult to fully estimate, as this is continuously developing as the project progresses. This uncertainty is epistemic as it can be reduced through coordination efforts among local stakeholders, but this will require significant efforts while risking potential shifts in preferences.
  - **Uncertainty source:** Epistemic.
- **Simultaneously developing R&R project requires coordination among many stakeholders**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of involved organizations (detail organization complexity).
  - **Description:** As an increasing amount of structures is reaching their technical EOL, a growing number of R&R projects are carried out simultaneously. Therefore, internal and external coordination efforts with stakeholders will become increasingly cumbersome, as a larger

number of entities must be consulted when projects are developed and scheduled. Examples can be found internally (within RWS), as a multiple critical traffic corridors face works, meaning that meticulous planning with network managers is required to keep efficient transport possible in the Netherlands. Externally, RWS must seek alignment with a multitude of local governments, interest groups, businesses, among others that depend on the functionality of infrastructure. Conclusively, as every R&R project affects others, it requires consideration from a large network of stakeholders, complicating the overall process.

  – **Uncertainty source:** No uncertainty present.

- **Project phasing remains subject to change due to developments in the social environment**
  – **Categorization according to complexity categorization framework (Table 4.1):** No sequential implementation process (dynamic time complexity).
  – **Description:** Project phasing cannot follow a step-by-step sequence, due to changes in stakeholder preferences, political pressure, and evolving requirements. In order to comply with legal and social prerequisites, a complex approach is often required, i.e., using new, existing, and temporary structures to facilitate an to all parties acceptable temporary situation while construction takes place. As a result, it becomes impossible to determine the final layout of the temporary situation and construction stages in advance, as this requires ongoing planning and research efforts. It is epistemic uncertainty, as assumption must continuously be validated throughout the project, and it thus can be reduces through such efforts.
  – **Uncertainty source:** Epistemic.

C.3.2. Trade-offs in reducing traffic disruption

In R&R projects, the impact to those affected by the works may be severe. A situation might even be more critical when there is an absence of alternative routes, i.e. another bridge connection to a certain area. The obstruction of a primary connection can therefore significantly impact regional stakeholders, such as local residents, businesses, and others that rely on a functional bridge.

The network of users, holding differentiated interests, mean that decision-makers often face dilemmas in weighing these interests against each other. Since every R&R intervention encompasses an asset that is currently in use, disruption of traffic remains inevitable. Regional stakeholders, such a municipalities, provinces, but sometimes also local firms or residents, face accessibility limitations. Moreover, the agreements made regarding the mitigation of traffic disruption, also hold implications for stakeholders such as the PM team and their contractor(s).

Assets facing large-scale intervention may pose major disruption of the transportation network(s) in certain regions. Examples include traffic jams, inaccessible waterways, and emergency services not being able to reach their destination in time. To mitigate these negative consequences, agreements are established among stakeholders, often posing restrictions to the time windows in which bridges are completely taken out of service.

Practitioner insights

Agreements established with regional stakeholder may include how a bridge can remain partially operational during construction works (R2). Potential measures include temporary or substitute bridge decks utilized during the replacement of a bascule bridge, however, such decks cannot be opened for shipping traffic but do allow road traffic to pass (R1). Choosing the right approach in related matters requires a thorough and substantiated decision-making process, as another respondent illustrates (R5):

> One aspect concerns making choices about which users of the asset will experience disruption: Do you prioritize less disruption to the HWN or the HVWN? One example involves a renewal project where a temporary, fixed bridge was installed. This allowed for continued road traffic, but due to the closure of the waterway, the maritime manufacturing industry located behind it [the temporary bridge] experienced such significant disruption that its entire business was affected. This raises the question: how should the interests of the manufacturing industry be weighed against those of road users? This is a discussion that must take place with provinces, municipalities, and other representatives. These are precisely the

> matters where collaboration and public support can be sought. With frameworks aligned at a higher level, the commotion and pressure of an individual project can potentially be transcended.

This was also implied by another respondent (R6):

> It is important to clearly communicate the consequences of certain measures or requirements to stakeholders. Moreover, 'minimizing disruption' means something different to each stakeholder. Minimizing disruption for road users, for instance, may in fact result in increased disruption to those carrying out the construction work."

Two respondents provided possible causes of this disruption of the construction work. Contractual requirements can limit working on technical installation to specific time windows. For example, when a bridge must be accessible during rush hours, or open once a week to allow maritime vessels to pass (R1, R2). This poses a serious time restriction on activities such a testing the control and security installation, effectively cutting the net time in which they must be executed. The situation presented to the contractor might, as a result, prove to be unfeasible and obstructing contract compliance (R2).

Complexity identification

Within this challenge, the following complexities have been identified:

- **No standardized process for weighing various stakeholder (group) interests against each other**
  - **Categorization according to complexity categorization framework (Table 4.1):** Different meanings and perceptions (dynamic social complexity).
  - **Description:** Every stakeholder present in an R&R project defines "minimizing disruptions" differently. It depends on whether preference is given to road users, maritime vessels, or construction teams. The conflicting perceptions make it difficult for a PM team to weigh interest against each other, requiring significant efforts to balance these in the decision-making process. While a guiding framework for reducing traffic disruption is available, a project-specific approach still remains required to determine stakeholder priority. The uncertainty this poses is epistemic, as preferences and solutions can be explored through negotiation, but currently requires efforts.
  - **Uncertainty source:** Epistemic.
- **Phasing and scheduling constraints for project activities under stakeholder agreements**
  - **Categorization according to complexity categorization framework (Table 4.1):** No sequential process of implementation (dynamic time complexity).
  - **Description:** Time windows for traffic accessibility (e.g., rush hour opening, weekly maritime passages), follow from agreements with regional stakeholders. However, they impose strict scheduling constraints, primarily for the contractor. It effectively reduces their time available to work, therefore requiring comprehensive approaches to complete tasks within limited amounts of time. Because these requirements change, based on stakeholder negotiations and evolving priorities, the uncertainty residing in this complexity is epistemic.
  - **Uncertainty source:** Epistemic.

C.3.3. Executing project under nitrogen regulations

Following the Council of State's ruling on May 29, 2019, concerning the Nitrogen Approach Program, it became difficult to issue nature permits for nitrogen emissions in many areas across the Netherlands. This effectively brought permit procedures to a halt and marked the beginning of the current "nitrogen crisis" (Vink et al., 2021). This crisis, and the corresponding issues, are seen as a pressing constraints for all types of construction projects.

Practitioner insight

Construction projects for new infrastructure, approached through the MIRT framework, must abide by nitrogen regulations (R1, R3). Designated nature areas (Natura2000) may not be harmed by nitrogen deposition. If deposition, as a result from construction activities, is calculated to be above a predetermined threshold, then additional (compensation) measures are required in order for an environmental permit to be obtained. For R&R projects, there is a different set of guidelines and regulations with regards to nitrogen deposition in order, as explained by one respondent (R4):

> For some projects, under the M&M umbrella [including R&R activities], it is not needed to take nitrogen regulation for the replacement [such as the construction of a replacement bridge] itself into account. However, rerouting traffic via alternative (motor)ways does require consideration of the nitrogen deposition incurred. Large-scale detours can therefore have significant consequences for a project's feasibility or permitting.

From the insight it can be concluded that the construction activities in R&R projects are are excluded from nitrogen restriction. However, traffic disruption mitigation, i.e. the rerouting of traffic via alternative routes, is. This is also presented by another respondent (R7):

> Permits always remain a potential risk. For example, with nitrogen emissions, the project team is focused on minimizing this risk as much as possible. There have been no specific issues related to nitrogen in my recent project in RWS, as it was classified as maintenance [M&M umbrella], which means it does not fall under the nitrogen regulations. However, many projects are affected by this. Special attention must be paid to detours of traffic, as nitrogen deposition needs to be calculated for these.

Complexity identification

Within this challenge, the following complexities have been identified:

- **Nitrogen-restrictions constrain the range of technical solutions available to PM teams**
  - **Categorization according to complexity categorization framework (Table 4.1):** Comprehensive legislation and policies have a significant impact on the content and process (detail legal complexity).
  - **Description:** The Council of State's (*Raad van State*) ruling on nitrogen emission imposes a strict legal constraint on projects, especially those in the vicinity of Natura2000-areas (European network of nature areas). The ruling restricts the deposition of nitrogen in these areas, forcing PM teams to develop approaches which minimize nitrogen emissions, thereby limiting the available solutions within projects. Examples include not being able to reroute traffic via alternative highways, or using fossil-fuel powered construction equipments, due to the associated emission. The implications of these developments may be fully planned out by a PM team, but require additional efforts and therefore complicate the planning.
  - **Uncertainty source:** No uncertainty present
- **Developments in nitrogen restrictions potentially lead to a suddenly changing legal environment**
  - **Categorization according to complexity categorization framework (Table 4.1):** Changeable, non-existent, and conflicting laws (dynamic legal complexity).
  - **Description:** Nitrogen regulations are currently stabilized, but underwent major changes in recent years. Possible future adjustments to the rules may again change what impact the regulations pose for R&R projects. It is epistemic uncertainty, as project scope, project approach, and other fundamental dimensions cannot be fully anticipated.
  - **Uncertainty source:** Epistemic.

C.3.4. Acquiring Environmental and Planning Act permits

The Environmental and Planning Act *(Omgevingswet)* consolidates legislation and regulations concerning spatial planning, housing, infrastructure, the environment, nature, and water management. The act governs the management and development of the physical living environment (Jansen, 2016). It is currently the prevailing act, thus meaning that infrastructure project now must abide by it. For the PM teams that are now or in the future working on R&R projects, this knows deep implications. In R&R projects, the PM teams are especially dependent on the municipalities. As Jurable (2020) states, a municipality may issue an Environmental Planning Act permit with the purpose of deviating from the zoning plan. Having this permit is critical, because without it, it will not (legally) be possible to start works.

Practitioner insights

During the replacement of a bridge, a temporary situation will develop in which a new bridge is being built, while the existing one will remain operational until its demolition (R1, R4). As can be derived from this, additional ground are required for building this new structure. This also provides a PM team with a different reality with regards to legal requirements, as is described by a respondent (R4):

> In these [R&R] projects, the 'regular' environmental permits (omgevingsvergunning) are applied for. Additionally, the existing environmental permits must sometimes be altered through applying for a zoning plan deviation (buitenplanse afwijking). However, before these can be applied for, preparatory calculations, designs, and measurements must have been produced. It is in the critical path of the project planning, and can only be finalized when these preparatory efforts have been finalized.

The preparatory activities that must be undertaken before an application for permits can be made is also described by another respondent (R7):

> When the project is handed over to the implementation team, the preparation phase is, of course, not yet fully complete. The contractor must still prepare various drawings, permits must still be applied for, and so on. Permit applications are only submitted once the drawings are available and the structural calculations have been fully completed.

From the insights it can be noted that preparatory activities have to be undertaken in order to apply for the permits needed in the project. These permits, issued by municipalities, are of vital importance. Additionally, the dependency on their permit approval again highlights why it critical to maintain political-administrative support.

Complexity identification

Within this challenge, the following complexities have been identified:

- **Permit applications under the Environmental and Planning Act require extra preparatory activities**
  - **Categorization according to complexity categorization framework (Table 4.1):** Comprehensive legislation and policies have a significant impact on the content and process (detail legal complexity).
  - **Description:** The Environmental and Planning Act consolidates multiple environmental, spatial, and infrastructure regulations. R&R projects must now apply for permits under this act, e.g., zoning plan deviations, before realization can legally start. The requirements pose a significant administrative burden on the PM team, as they must conclude several preparatory researches and designs before an application can be made. These activities are on the critical path of the project planning, and are to be executed in an relatively early stage of the project, complicating early preparation.
  - **Uncertainty source:** No uncertainty present.

C.3.5. Limited tools for expropriation

To build infrastructure, such as a replacement structure for an obsolete bridge, grounds are needed. In the densely populated Netherlands, PM teams working on R&R projects are sometimes forced to utlize grounds that are not already owned by RWS. These can be owned by all sorts of parties, such as local inhabitants, businesses, or other (governmental) bodies. In the initial efforts undertaken by RWS, the land owners are approached for conversation. Their requirements are collected and analyzed. If the owner is willing to sell or lend their land, then this will be facilitated against (financial) compensation.

However, not every land owner is willing to cooperate. If negotiations fail, and no other project approach is feasible meaning that certain grounds must be acquired, then expropriation is a last resort. Expropriation is the legal procedure, in which the government takes private property for public use.

Practitioner insights

In relation to expropriation, practitioners have provided two illustrating insights. It sheds light on the fact that the legal base that is provided for new infrastructure, is absent for R&R. One respondent explains (R4):

”For MIRT projects [construction of new infrastructure] there is always a ’project decision’, which provided the legal basis for applying for permits and expropriation. In R&R projects, this is not present.”

Another respondent confirms the absence of a base or formal approach with regard to expropriation (R3):

> The boundaries [of the R&R approach] are not always clearly defined. For land that needs to be expropriated in the context of R&R, there is currently no fixed procedure. In some cases, a (temporary) solution is chosen, whereby already owned land [by RWS] is used instead.

Complexity identification

Within this challenge, the following complexities have been identified:

- **No formal expropriation procedure in R&R projects**
  - **Categorization according to complexity categorization framework (Table 4.1):** Comprehensive legislation and policies have a significant impact on the content and process (detail legal complexity).
  - **Description:** Unlike in MIRT projects (new infrastructure) that have a fixed legal basis for expropriation (project-decision), R&R projects lack a clear legal framework for acquiring (privately owned) grounds. Each project provides its PM team with a novel legal reality, forcing PM teams to design project-specific workarounds when negotiations fail. It is epistemic uncertainty as it results from a lacking legal framework, meaning that clarity could be provided through formalization of the procedures.
  - **Uncertainty source:** Epistemic.

C.4. Organizational dynamics

In this section, challenges regarding organizational project aspects are discussed, in order to identify the complexity from which they stem.

Organizational complexity concerns the project organization’s structure and its interaction with broader stakeholder networks.

C.4.1. Quality vs. cost trade-off

The ever standing trade-off between quality and cost is, as in any project, present in R&R projects. However, the exact implications of this dilemmas are ever more critical, especially when compared to the construction of new infrastructure. Dutch infrastructure is well known globally for its quality. However, for the overall R&R program, there is a severely limiting constraint present which urges RWS to rethink the quality level of their current assets: budget deficits. Due to the massive scale of the overall R&R program, in which a multitude of objects such as bridges, locks, tunnels, etc. must be renewed, there is a constricting lack of funds. As stated in the Multi-Year Plan for Infrastructure Upkeep (Ministry of Infrastructure and Water Management, 2025), a total deficit of ca. 34.5 BN euros has been found between the available and required funds in the budget of the Ministry of I&W, for the period from 2024 until 2038.

Knowing this, it is only logical that cost is a leading criteria. With such major deficits in sight, cost control is essential, urging cost effective approaches for R&R projects, with cost effectivity mainly relating to spending funds on the main objective of the overall R&R program: to renew critical infrastructure in the HWN and HVWN. This required cost effective approach is embodied in a key starting point, provided by Ministry of I&W for R&R projects: lean and cost-efficient *(sober en doelmatig)*. This objective, again, highlights why the trade-off between quality and cost is so pivotal.

Remarks about this trade-off, then in construction project for new infrastructure, were already described by (Horvat et al., 2022). In their report, which investigated cost overruns, it was noted that:

> A trade-off between cost and quality is often implicit and frequently results in a choice for quality. Within the technical teams, quality is a shared value: "We must create a solid, safe solution that meets the stated requirements." These values lead to technical solutions often receiving more attention than the budget.

Practitioner's insights

Practitioners acknowledge that cost control has proven challenging, with many R&R project becoming substantially more expensive than initially estimated (R3, R4, R5). The organizational dynamics of RWS, in which a focus on quality is often implicitly present, is one of the factors contributing why balancing the trade-off between quality and cost is challenging. This notion is shared by one respondent, as illustrated (R5):

> Within RWS, there is also a strong drive for quality. RWS is not only an implementing agency but also a knowledge organization, with specialist teams for virtually every field. This sometimes results in continued debate, even when the Ministry [of I&W] sets certain guiding principles. For example, when the basic quality level [basiskwaliteitsniveau] prescribes reduced roadside maintenance, there will be individuals who disagree with such measures. Substantively, there are often many valid reasons to deliver a higher level of quality, but decisions are frequently not made from the perspective of the overarching objective [of the R&R program]. This is detrimental to the assignment at hand: given the significant budget deficits already present, strict adherence to defined frameworks is essential.

The drive for quality against cost effectiveness was also described by another respondent (R7):

Project ownership is sometimes assigned to individuals who operate at a distance but provide clear guidance based on specific parameters (e.g.„ from the Ministry). One of these parameters, of course, is cost. On the other hand, within RWS there are many individuals who strive for excellence in quality, who aim for a 'ten'. Moreover, the standards applied in the Netherlands are relatively high, especially compared to those abroad. The Eurocodes primarily govern [European] structural design. Road design aspects (such as widths, emergency lanes, etc.) are defined in the ROA, which sets a high benchmark.

Complexity identification

Within this challenge, the following complexities have been identified:

- **Cost vs. quality trade-off is under organizational pressure from multiple stakeholders**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of decisions with uncertain best solution (dynamic organizational complexity).
  - **Description:** The inherent trade-off between cost and quality in R&R projects creates a continuous field of tension. These tensions are driven by major budget deficits in the coming period decades, which again address the need for a cost-effective approach. However, as RWS is also knowledge-rich organization consisting of many experts in various field, it values technical quality and innovation, with specialists advocating for high standards. As a result, it remains difficult to arrive at objectively cost-effective solutions. This complexity follows from epistemic uncertainty, as a clear framework for balancing cost and quality is currently lacking. This framework is the Base Quality Level (*Basiskwaliteitsniveau, BKN)*, which is supposed to guide practitioners in their decisions, but is still under development. However, even with such a framework in place, PM teams will still decide to which extent it will be utilized in specific cases.
  - **Uncertainty source:** Epistemic.
- **Development of the Base Quality Level (BKN) framework impacts projects in active development**
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).

- **Description:** The Ministry of I&W is currently developing the BKN framework, in an effort to establish guidance for determining the future quality and performance of infrastructure. As developments are currently ongoing, the exact implications for R&R projects currently in active development and in the future remain uncertain. This uncertainty is of an epistemic nature, as it stems from the lack of a baseline, thus creating ambiguity regarding project requirements and scope.
- **Uncertainty source:** Epistemic.

C.4.2. In-house technical know-how

Between 2002 and 2011, RWS has reduced its workforce by around 20%, which totals to approximately 2100 FTE (Full Time Equivalent) (Algemene Rekenkamer, 2013). Half or this reduction was achieved through transferring activities (and responsibilities) to market parties, i.e. outsourcing. The other half downsizing of the organization, i.e. the remaining responsibilities distributed over less employees (Algemene Rekenkamer, 2013).

To keep up with the ever growing number of assets in need of intervention through R&R projects, i.e. the production capacity of RWS, now requires additional employees. However, RWS finds it challenging to hire skilled personnel, for almost every type of function within their departments. (Rijkswaterstaat, 2023b). Similar struggles are felt across the Dutch construction sector as a whole, due to severe labor shortages. The scarcity of skilled personnel on the market, makes finding new employees an ever increasing struggle. To illustrate the current development, it was estimated that the construction sector had approximately 50.000 outstanding job vacancies (UWV, 2024), across the sector as a whole.

Practitioner insights

Many of the the interviewees acknowledge the difficulty in finding skilled personnel (R1, R2, R3, R6). The lack of skilled workers affects the organizational capabilities of RWS on various aspects. The current lack can partially be attributed to historical developments, in which RWS had a downsizing of their workforce. These developments are illustrated by two practitioners, who share similar experiences. The first respondent remarks that (R1):

> There is a shortage of skilled Dutch workers, which can lead to language barriers [due to use of foreign contractors] and lower quality of the work delivered. Moreover, many of the experts who previously worked at RWS are now employed by the contractor. These individuals left the organization due to workforce reductions.

Another respondent comments that: (R2):

Due to the downsizing of the RWS workforce, many experts have left the organization and are now working for, e.g., a contractor. Many of the experts working on RWS projects now, are being hired from external parties.

As can be concluded from these converging viewpoints, a shift in the allocation of technical know-how has taken place. This new distribution has proven problematic, as one respondent elaborates (R3):

> There is a lack of design expertise within RWS. In the past, this knowledge was in-house: design, directorship, and supervision were all managed internally. Nowadays, much more of this is outsourced to the market, as RWS had to reduce its staff. This creates difficult situations from time to time, since ultimately, RWS remains responsible and must therefore still be able to properly assess the provided designs [when these have been provided by a contractor/engineering firm].

An insight provided by another respondent describes a similar pattern of thought (R6):

> There is a shortage of people who can determine the as-built condition from the starting situation and then develop execution plans. This work is now also outsourced to engineering firms. However, as these parties operate in a relatively independent role, they are only minimally liable, at most up to the value of the contract, and only if it can be proven that they were at fault. This is extremely difficult to prove and often involves lengthy legal proceedings. engineering bureaus are also brought in to review the designs produced by other engineering bureaus. In doing so, they mainly assess the process aspects, rather than the

> technical content. As a result, design verification is a type of knowledge that, regardless of the project or contract form, must be available in-house at RWS. However, it will be difficult to regain this knowledge within RWS.

The lack of technical expertise has also led to requirements which are deemed unrealistic or unfeasible, resulting in negative reactions from those who have to abide by them. One respondent remarks (R3):

> Several challenges exist in the collaboration with market parties. Technical requirements are frequently defined unilaterally by RWS; it would be preferable to involve these parties at an earlier stage in order to establish requirements jointly. In one project, an excessive share of the risk was allocated to the contractor, which ultimately resulted in only a single bidder remaining. Furthermore, there are significant discrepancies in pricing between contractors: in one case, a contractor submitted a steel price that was twice as high as that of competitors within the same tender procedure. Whereas such matters could previously be addressed at a high level with executive management, opportunities for such interventions have been limited or entirely absent since the construction fraud scandals. Other contractors, however, submitted bids with prices consistent with the estimates. A recurring pattern of misalignment appears to exist between RWS and contractors, which is insufficiently addressed in an open and structured manner. Despite the continuous identification of these issues, effective mechanisms to manage them strategically are lacking.

The practical implication of not aligning these requirements have been described by another respondent (R2):

> The feasibility of the contract being put out to market can be a point of concern. The contract includes work to be carried out on an existing civil structure, for which specific requirements have been defined in advance, such as the types of work needed and how they are to be performed. However, in practice, it sometimes turns out that the work cannot be executed as initially planned. Additionally, the analysis of the contract requirements can, in some cases, take three to six months, as the submitted contract is not always practically feasible. Translating these requirements into workable, SMART formulations demands significant effort from the contractor's project team.
>
> As a result of the aforementioned points, various project activities now often run in parallel within the same phase. While this may be workable for certain tasks, the volume of concurrent activities increases the complexity of the project, making it progressively more difficult to execute.

Complexity identification

Within this challenge, the following complexities have been identified:

- Acquiring and leveraging in-house expertise for alignment and risk embracement
  - **Categorization according to complexity categorization framework (Table 4.1):** Find and keep motivated people adequate to the challenge (dynamic organizational complexity).
  - **Description:** RWS, among many other organizations active in the construction sector, faces a significant challenge in finding and retaining the professionals adequate to deal with the (technical) complexity of R&R projects. Due to downsizing of the organization in recent years, many formerly in-house experts now work for private firms. As many processes still rely on expert judgment, being able to leverage technical expertise remains of pivotal importance. Technical expertise lays the foundation for substantiated decision-making required to align project approach with the contractor, which must be able to rely on the boundary conditions and assumption provided by RWS. This complexity stems from epistemic uncertainty, as expertise forms its core.
  - **Uncertainty source:** Epistemic.
- **Feasibility of project requirements under pressure due to client-contractor misalignment**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of contracts with numerous interfaces (detail organizational complexity).

- **Description:** Issues manifest themselves in the contracts between RWS and their contractors, who provide that these contracts often hold requirements that are not realistic or prove unfeasible, leading to delays, conflicts, and possible redesigns. With RWS's move towards functional specification (providing requirements rather than in-house developed structure designs), the requirements and specification they establish have become more critical. Misalignment occurs in the interfaces of these contracts, as it is provided that early-on cooperation and executive-level negotiation is often lacking.
- **Uncertainty source:** No uncertainty present.

C.4.3. Shift toward integrated contracts

The developments in risk allocation take place in a time in which a shift towards functional specification is happening: RWS moves away from providing (preliminary) designs and more towards setting the boundary conditions of a design, which a engineering firm or contractor will then develop further. The shift is described as Buscher et al. (2022) and Rijkswaterstaat (2019), who states that after the the introduction of integrated contract forms and the shift of design responsibility to the market parties, Rijkswaterstaat, based on the "market, unless" principle *(markt tenzij agendium)*, has reduced its internal knowledge of design, design management, and technical quality control of designs. This design knowledge should now reside with engineering firms, knowledge institutes, and construction companies." With regard to these changes, TNSnipo (2008) provided that by shifting design responsibility to contractors during the tendering phase, RWS is required to define the liability for both the proposed design and its execution in the contracts. It results in significantly more legal work is.

A notable problem that this approach posed, was that risk allocation was experienced as unfair by market parties. At the start of the century, the traditional starting point was market, unless. In this procurement and collaboration strategy, Market parties would handle a significant proportion of RWS their responsibilities, unless there is a good reason to do it in-house. In this approach, the allocation of risks associated with designing and constructing infrastructure, was also been allocated at the party that undertook these activities. However, it was noted that, according to market parties, knowledge and expertise from the market are utilized too late. As a result, risks are identified too late and are then allocated to the market, even when the market is not well equipped to manage them (Ministry of Infrastructure and Water Management, 2024).

Before proceeding to the practitioner insight, an overview has been provided of the most relevant contact types and approaches mentioned in the interviews:

- **Cost-reimbursable *(regiecontract)*:** A contract in which the contractor gets compensation for their actual costs incurred during the initial phases of the project, with a predetermined markup for general costs, profits, and risks.
- **RAW-specifications *(RAW-bestek)*:** A standardized document for providing detailed requirements and standards for materials, methods, and quality that the contractor must meet, describing the assignment of the project.
- **Engineer & Construct (E&C):** A contract where the contractor is responsible for both the engineering (from the definitive design) and construction.
- **Design & Construct (D&C):** Similar to E&C, but the contractor is involved earlier in the design process, thus being responsible for establishing the preliminary design.
- **Construction team *(bouwteam)*:** Not contract type strictly, but rather an approach that can utilize one or more contact types. It is a collaborative approach in which the commissioning party and contractor work together from early design stages to jointly develop and optimize the project before construction starts. In this, the assumption is that the contractor involved in the early design, will also execute it in construction. This is, however, not necessarily the case, as the commissioning party can still set up a tender for the realization phase, so that the design can be executed by a different contractor.

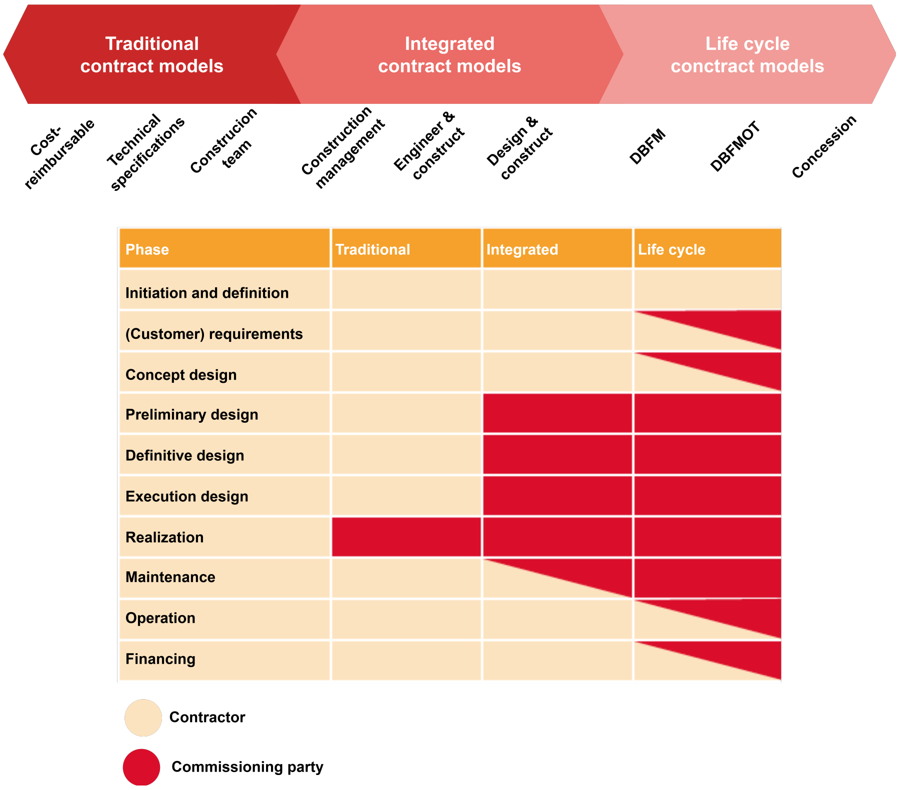

Figure C.1: An overview of common contract types in the Dutch construction sector (top), along with the allocation of responsibilities (bottom). Translated by the author, retrieved from: www.twynstragudde.nl

Practitioner insights

As previously mentioned, risk allocation is largely defined in the contract type adhered to for a project. Formerly, a prominent contract type was the RAW-specification. In this contract form, the commissioning party, i.e. RWS, produces and details the design to a level that it can be transferred to the, which can execute it and start construction. This working method implies that risks, identified during the detailing process of the design, remained allocated to commission party, i.e. RWS. This method of approach is particularly suitable for low-risk projects, for more complex project a construction team is an appropriate approach, as provided by one respondent (R6):

> Only once a project has been developed to a construction-level design, then risks can be properly assessed. If this is not done, everything remains rather generic. Careful consideration must be given to the as-built drawings, the execution risks, and their potential magnitude. Based on this, an appropriate contract type can be selected, possibly even a combination of different contract types. For instance, relatively low-risk projects could be offered at a fixed price [RAW-specification], while more complex situations might be better suited to a collaborative construction team approach.
>
> RWS has moved towards functional specifications, thereby moving away from the traditional RAW-specifications. However, the RAW-specifications compelled parties to work out the details thoroughly, thereby also exposing potential risks. It is often at this detailed level that potential problems become apparent. To make a realistic assessment of costs and risks, it is therefore essential to go beyond merely defining high-level specifications. In R&R projects, where the initial situation is highly uncertain, a detailed elaboration forces parties to identify potential risks. Based on this information, an appropriate contract form can then be selected. This approach closely resembles the 'traditional' way of developing projects, as was common practice in the past.

Nowadays, integrated contract types are also common for infrastructure project, including R&R projects. In this type of contract, early collaboration between the RWS and market parties must lead to better solutions (R1). The rationale of this approach, is that, through early collaboration, project approach and risk identification can be optimized through utilizing market expertise. However, several insight were provided with regards to how integrated contracts are used, and what implications this holds for the projects. One respondent described why integrated contract are winning territory (R1):

> Multi-phase contracts and portfolio contracts are now widely used. As today's projects have become increasingly complex, there is a growing emphasis on collaboration between the commissioning party and the contractor.

Despite the emphasis on increased performance through early collaboration, it does not always lead to the intended results as another respondent illustrates (R2):

> In a bridge project, a two-phase contract was used in which the contractor contributed to the design. However, the submitted design ultimately proved to be insufficiently feasible, causing the schedule to be delayed by approximately five years. RWS had limited control over the contractor's planned activities, resulting in the schedule slipping without a clearly documented justification.

A different experience on early collaboration was provided (R2):

> From the moment the contractor becomes involved in the project (in the case of a two-phase contract), the estimated costs tend to rise sharply. Initially, the contractor agrees to the contract terms and the target price, but after the final signing, they often seek to increase the target price rather quickly. This makes it easier for them to meet the contract requirements. The target price, however, should only be adjusted if, for example, certain deliverables were not provided correctly.

However, it is important that in this collaboration, the commissioning party stays in control. The two insights signal the importance of staying in control as commissioning party. Failing to do so may result in cost or schedule escalations, feasibility problems, or other risks for the project. Control however, such as a check and validation of design, is sometimes also outsourced to external parties (R3):

> Within RWS, there is currently a lack of in-house design expertise. In the past, this knowledge was readily available: design, project management, and supervision were all handled internally. Today, much of this has been outsourced to the market, as RWS has had to reduce its workforce. This sometimes creates a difficult situation, as RWS remains ultimately responsible and therefore must still be able to thoroughly review and assess the designs produced by other parties.
>
> Engineering firms involved are often liable only up to the amount of their contract sum. This underlines the responsibility that Rijkswaterstaat (RWS) or the consortium itself continues to bear. For consortia, engineering firms can sometimes be included as risk-bearing parties, but this rarely happens. Typically, engineering firms act as subcontractors and are therefore not held responsible.

Conclusively, using integrated contract forms cannot be considered the holy grail of project management. Whatever the chosen contract form may be, it never takes away the responsibility of the commissioning party for possessing the expertise and capacity required for verifying the feasibility of designs and project approach developed by the contractor.

Complexity identification

- **The decision-making process for choosing a contract type or approach is obscured by an array of factors**
  - **Categorization according to complexity categorization framework (Table 4.1):** Large number of decisions with uncertain best solution (dynamic organizational complexity).
  - **Description:** RWS may choose from a large number of contractual and billing approaches, each with their own trade-offs in risk-ownership, project control, and financial incentives. A single best choice may be difficult to determine if project preconditions are ambiguous. It is epistemic uncertainty, as preparatory efforts and experiences from other projects will aid PM teams in choosing an appropriate contract form for delivery of the project.

    - **Uncertainty source:** Epistemic.

- **Integrated contracts leading to shifts in procurement and risk allocation between parties involved**
    - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
    - **Description:** The move towards functional specification and integrated contracts redistributes risks between RWS and contractors, introducing new forms of collaboration and procurement. Although integrated contracts have been around since the 2000s, the exact implication of this contractual approach remain unsure in R&R projects. Experience with these contracts in R&R projects will allow for best practices to be established, but as of now, lacking knowledge results in epistemic knowledge.
    - **Uncertainty source:** Epistemic.
- **Integrated contracts introduce overlapping responsibilities and complicated collaboration**
    - **Categorization according to complexity categorization framework (Table 4.1):** Numerous working processes that interfere (detail organizational complexity).
    - **Description:** The utilization of integrated contracts introduces overlapping responsibilities between RWS, contractors, engineering firms, etc. The interdependency between parties and the additional coordination this requires complicates planning, design validation, and risk management efforts. It remains as a detail complexity, however, as the process can ultimately be fully mapped out through planning efforts.
    - **Uncertainty source:** No uncertainty present.

C.4.4. Evolving cooperation models in contracting

While the supply of R&R projects will continue to grow in the coming decades, market parties are showing a decreasing interest in them. It follows from the current market dynamics, and how the risks of (large-scale) projects are managed. Parties are becoming more critical about their participation, with RWS seeing the average number of bids per tender for project above 250 MLN. decline (Rijkswaterstaat, 2019). Particularly for large, complex project, the profit and risks margins priced in by construction have been insufficient to cover the realization of major risks, resulting in occasional significant financial setbacks that puts pressure on their financial position (Rijkswaterstaat, 2019). Contractors in the infrastructure sector relatively face a low profit margin, averaging approximately 2.6% (ING, 2023). This is the lowest average of all sub-sectors within the construction sector as a whole (see Figure C.2). If substantial risks are faced, then profitability is immediately affected, as there is only a limited buffer. These are especially critical to R&R projects, are these are characterized by uncertainty in many aspects of the projects.

In an effort the increase market interest for infrastructure project, novel contractual approaches are utilized to a growing extent. These approaches are chosen for making use of market expertise and the billing of costs made by contractors through early collaboration. In this, the latter is a development driven by the fact that it is becoming increasingly difficult to award a contract based on a fixed price (AT Osborne, 2025; Rozemond Advocaten, 2024). Cost+ allows for a contractor to be compensated for their actual costs incurred, with markup for certain costs, e.g., general costs, profit, risk, etc. Based on the exact contract, other financial incentives may also be incorporated, changing the dynamics of the collaboration between the commissioning party and the contractor. As actual costs incurred are compensated, helping the contractor to deal with the financial consequences of uncertainties.

Another development is the implementation of portfolio contracts. Rijkswaterstaat can introduce a portfolio approach for projects with a repetitive nature or projects within a development trajectory, allowing for a contractors ability to recoup investments in innovations across multiple projects (Rijkswaterstaat, 2019). Additionally, by working in a cross-project manner, where both clients and contractors generate deal flow by establishing portfolios of tasks that can be carried out efficiently and effectively through repetition and standardization. By avoiding unnecessary transaction costs and immediately applying lessons learned and innovations in the next collaboration, productivity gains can be expected (Ministry

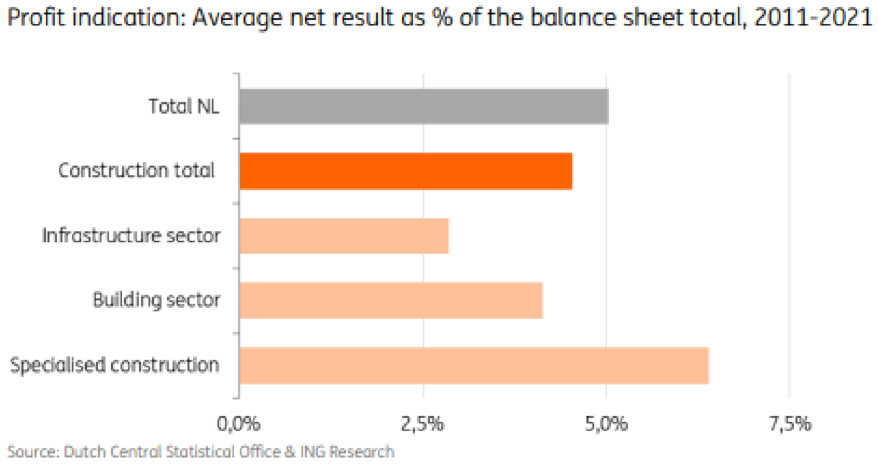

Figure C.2: Profit margins of selected sub-sectors within the construction sector (ING, 2023).

of Infrastructure and Water Management, 2024). This can be done in a serial manner by having the same parties carry out tasks on objects from a specific portfolio in succession: if the first contract or project is completed satisfactorily, the same partnership can start on a new assignment (Ministry of Infrastructure and Water Management, 2024).

This approach focuses on bundling object of the same type, allowing for a specialized workflow. Other development in this approach are the so called "yards" (*werven*). These yards are specialized in a certain object type, e.g., bridges.

Practitioner insights

One of the main reasons why maintaining the interest of market parties in infrastructure projects in these times, is explained by one respondent (R4):

> It is important to maintain market interest in infrastructure projects. Despite the increased attempts to tackle the difficulties in modern infrastructure projects, including R&R projects, a string of failed projects has lead contractors to select their projects more carefully. There is also competition from other sectors, such as home construction and the energy grid, stressing that projects must stay viable and thus also attractive for contractors.

Two main development are now taking place for R&R projects, in an effort to better manage the implications of the uncertainty and potential risks, which have sometimes proven to be hard to control. One is the emergence of the utilization of Cost+ contracts. Practitioners noted several points regarding the use of Cost+. One practitioners provides an insight into the practical application of the contract (R2):

> In Cost+, a design is provided that must be executed, and this is priced down in a sort of tender-like procedure. The work is divided into small work packages: foundations, steel structures, facades, sewage systems, etc. This is a typical English way of working, with which Dutch contractors have less experience.
>
> Within Cost+, several, smaller tenders thus run simultaneously, for example, for the foundation and for the floor layout. As an example, it was mentioned that while the construction of the foundation was already underway, the floor plan ultimately turned out to be different, changing the floor load requirements and thus requiring a different foundation (more piles and/or heavier execution). In the Netherlands, in a similar situation, work would be halted until the issue is resolved. The English/American preference, however, is to keep working and implement an ad hoc solution.It should be noted that this contract type is mainly used for new construction, where unexpected issues are less likely to arise. Notwithstanding, after breaking down the work into packages, it must also be "stitched back together," which also incurs costs.

Conclusively, it poses a novel way of working, emphasizing transparent collaboration, but at the expense of potential inexperience and cost inherent to the contractual approach itself. Another warning for this type of contract was also provided (R1):

> Cost+ is something that will be utilized in the Van Brienenoordbrug R&R project. A warning here is that the commissioning party may be vulnerable to market power. RWS must have sufficient technical expertise to assess, for example, cost estimates or schedules, in order to provide adequate counterbalance.

Another prominent development is the introduction of portfolio contracts. Practitioners indicate that multiple objects, e.g., bridges, are bundled within a portfolio. One respondent remarks (R3):

> Within the portfolio, there are multiple bridges, giving the contractor a kind of repeat assignment. The aim is to ensure that lessons learned are applied in the repeat projects and that financial control is maintained.

Their insight is complemented by another respondent (R6):

> The portfolio approach follows a similar principle: the same types of work are grouped together, concentrating specialization within a specific workflow. In the past, Rijkswaterstaat also had directorates that were specialized in certain types of objects, such as the Bridge Directorate.

Conclusively, the repetitive nature of project can be utilized to capture learning effects, reducing potential risk and better providing a contractor the opportunity to turn a profit. For bridges in specific, a general development has emerged, for the three subtypes of bridges in the RWS asset base. This is explained by one respondent (R3):

> The “bruggenwerf” (bridge yard) is an initiative by Rijkswaterstaat; it is a physical location where the renovation or demolition of bridges can take place. Three [headline] portfolios have been designated: fixed steel, movable steel, and concrete bridges. Each will have its own portfolio, with dedicated teams from both Rijkswaterstaat and the contractors.

Efforts are made to, again establish specialization of teams, allowing them to apply lessons learned in next projects. However, while allowing for efficiency, will also introduce new hurdles in the processes (R4):

> There is a shift away from the current geographically focused approach toward an object-focused approach, which allows for the bundling of workflows. However, these objects remain geographically dispersed across multiple provinces, meaning that their management falls under different regional divisions of RWS. The reality this creates for the coordination and management of the R&R program is that, while the objects may be bundled, the stakeholder management is not. Collaboration is required with multiple regional divisions simultaneously, each operating within unique environments and involving a variety of regional stakeholders. RWS is currently not structured to operate in this way, as the geographically focused approach previously had the advantage of avoiding the need to work with multiple regional divisions at once.

Complexity identification

Within this challenge, the following complexities have been identified:

- **Object-focused approach forces collaboration with multiple regional divisions**
    - **Categorization according to complexity categorization framework (Table 4.1):** Large number of stakeholders (detail social complexity).
    - **Description:** The shift towards object-focused workflows in R&R projects, i.e., incorporating objects project into a single portfolio-project, provides the PM team responsible for these portfolios with novel a stakeholder network. Instead of working within one region and thus having one RWS regional division as a stakeholder, spatially fragmented objects incorporated into a portfolio-project may result in multiple regional divisions being a stakeholder. PM teams must collaborate with multiple regional divisions, which all represent unique environments and local stakeholders. This complicates the overall stakeholder management, as more actors and relationships must now be accounted for.

  - **Uncertainty source:** No uncertainty present.
- **Shifting collaboration dynamics under novel contracting approaches (Portfolio, Cost+, etc.)**
  - **Categorization according to complexity categorization framework (Table 4.1):** Changes in co-operation (dynamic social complexity).
  - **Description:** The adoption of novel contracting approaches, such as Cost+ and portfolio contracts, fundamentally alters the dynamics of cooperation between Rijkswaterstaat and contractors. Where traditional contracts emphasized transactional relationships, these new approaches encourage a transparent and trust-based approach, in which shared financial incentives must increase project performance during long-term collaboration. At the same time, they increase RWS's dependency on market parties. This reinforces the need for internal expertise, to balance out market power. This evolving mode of cooperation introduces dynamic social complexity, as collaboration forms are not stable but shift over time in response to developments within projects and market dynamics. The uncertainty regarding this novel collaboration is epistemic as it results from the inability to fully anticipate the resulting project performance, as this may only be obtained through experiences following application within projects.
  - **Uncertainty source:** Epistemic.
- **Integrating multiple project into a portfolio (contract) requires alignment between individual projects**
  - **Categorization according to complexity categorization framework (Table 4.1):** Numerous working processes that interfere (detail organizational complexity).
  - **Description:** The bundling of multiple projects into a portfolio is not without effort for RWS, as it requires the alignment of multiple schedules, contracts, etc. It complicates the planning of underlying individual projects, as these have an increased interdependency on one another. Once processes and interfaces are mapped out, it the process remains ultimately deterministic.
  - **Uncertainty source:** No uncertainty present.

C.5. Control and estimation of costs

In this section, challenges regarding financial project aspects are discussed, in order to identify the complexity from which they stem.

Financial complexity involves challenges in cost-benefit estimations, financial control, and stakeholder cost allocations.

C.5.1. A different approach in project accountability and cost control

A call for increased productivity through less, audits, (internal) frameworks, is called for. It is deemed required for increasing the productivity of the RWS supply chain, so that a focus on substantive results and efficiency can be achieved, and less on processes and compliance. While this focuses primarily on project content, similar developments are already taking place for the cost control of R&R projects.

Cost control is formed by the checks and balances that are performed on the developments of cost within a project. As Ejekwu et al. (2025) describes, the concept of cost control has to do with various means by which management ensures that their cost element do not get out of hand. For infrastructure renewal, i.e. the overall R&R program, a governance arrangement has been developed. In this, the core idea is that Rijkswaterstaat will have more autonomy to define, plan, and execute the activities covered by the infrastructure renewal budgets. As of January 1, 2024, Rijkswaterstaat will work with an eight-year policy mandate, moving away from project-based steering on renewal and instead managing Operations, Maintenance, and Renewal as one integrated whole: Infrastructure upkeep (Ministry of Infrastructure and Water Management, 2024).

Practitioner insights

On the project level, developments have also taken place with regards to how project steering, including cost control, takes place.

It is provided that (R1):

> It is also important to organize the project team effectively and ensure that necessary work is carried out. The process requirements specifications (*Vraagspecificatie Proceseisen, VSP*) impose many process-related requirements: monthly reports must be produced, and dossiers are to be updated. On top of that, these are then bundled quarterly. All in all, there is a heavy accountability burden, resulting in a lot of (administrative) work for the project organization. And this does not necessarily contribute to project steering, as it mainly looks back at what has already happened.

The approach in acquiring control through more reporting, is also encountered by another respondent (R5):

> Within the current approach, the reflex for improving project control seems to be an intensification of reporting on project status. When projects face setbacks, the response from political leadership is often a desire to avoid unpleasant surprises. As a result, the request for more frequent or detail reporting increases. However, this shift toward tighter control and greater accountability rarely leads to actual cost control. Instead, it reinforces incentives that, according to the literature, are known to contribute to cost increases.

The quest for control is thus only answered by additional administrative burdens, and not by actual control. For cost control in the context of R&R projects, the dynamics are different than those that traditionally played in projects for the construction of new infrastructure. Construction projects, approached through the MIRT framework, were supervised the Ministry of I&W had, alongside RWS, a direct involvement in the steering group of those projects. However, the role and responsibility of both the Ministry of I&W and RWS has shifted within the R&R program, as is illustrated by one respondent (R5):

> 1-to-1 replacement projects are carried out independently by RWS, in principle, the Ministry of I&W has no role in them. This category of project covers the vast majority [of R&R projects]. Next to this category, there are policy-intensive projects which involve important or sensitive trade-offs, for which RWS and the responsible policy directorate [(Ministry of I&W)] make joint decisions the fundamental project starting points. Overall management and steering of the project remain the responsibility of RWS. The final category are the specials. There is currently no clear description of the criteria that define this type of project. Labeling a project as a “special” is based on expert judgment from both RWS and the Ministry of I&W. These projects are managed by a joint steering committee consisting of representatives from both RWS and the responsible policy directorate.
>
> Historically, the role Ministry of I&W was to supervise projects: they were responsible for the checks and balances in terms of costs, plannings, and quality. In practice, this meant that when a PM team entered a new design phase, for example, moving from a sketch design (*schetsontwerp*) to preliminary design (*voorlopig ontwerp*), they would present a new cost estimate to the steering committee. Often, this was yet another moment where it was reported that the required budget had increased again. In such cases, it was often the Ministry that insisted not only on presenting an option that required more funding, but also one including a variant that involved cuts to keep the project within the originally approved budget. In the past, the Policy Department thus acted as a system of checks and balances in terms of cost control.

From this, it can be concluded that the checks and balances previously facilitated by the responsible policy directorate of I&W for the vast majority of R&R projects, the 1-to-1 replacements, are now in the responsibility of RWS themselves. Implementation does still not always run smoothly, as overprogramming (*overprogrammering*) is now utilized as a managerial approach. This phenomenon is illustrated by one respondent (R4):

> Rijkswaterstaat currently operates under a policy agreement that allows overprogramming of the investment portfolio by approximately 10 to 20% annually. This means that more funds may be allocated in the financial planning than can realistically be spent within the fiscal year. The rationale is that project execution is frequently subject to delays and unforeseen developments, making it necessary to anticipate underutilization of budgeted funds.
>
> This arrangement was introduced after continuous monitoring showed that, despite receiving additional annual budget increases, the actual expenditure consistently reached only around 70% of the allocated funds. The discrepancy reflects the inherent difficulty of timely project implementation, driven by changing insights, procedural delays, and capacity constraints within both Rijkswaterstaat and the market.
>
> Consequently, overprogramming is now formally accepted as a management instrument to maintain progress across the investment program. Previously, such an approach was considered inappropriate, but it is now recognized as necessary given the tension between the urgency of the national infrastructure task and the practical limitations in budget absorption and available capacity.

However under-expenditure also leads to situations that are difficult to justify. It understandably raises questions about whether these funds can actually be utilized. This is not a sustainable situation (R5). In this way, it undermines the actual necessity for having additional funds for infrastructure renewal.

Complexity identification

Within this challenge, the following complexities have been identified:

- Insufficiently formalized financial governance under novel strategic arrangement
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
  - **Description:** Responsibility for the cost control checks-and-balances has shifted from the Ministry of I&W towards RWS, in an effort to improve operational flexibility. Previously, the Ministry acted as a counterweight, approving cost estimates, and enforcing more cost-cutting solution in infrastructure projects. The dynamics between these two organizations have shifted, especially with regards to the projects executed under the 1-to-1 replacement project. It makes RWS now both the implementer and controller, with no independent overseer for the majority of projects. It is epistemic uncertainty, in the sense that PM teams face unclear expectations in cost control outcomes, due to the evolving responsibilities within RWS as an organization.
  - **Uncertainty source:** Epistemic.
- **Mismatch between intervention urgency and realizability within available budget and capacity**
  - **Categorization according to complexity categorization framework (Table 4.1):** Future developments impact the organization delivering the project (dynamic organizational complexity).
  - **Description:** As a growing number of structures reaches the end of its expected service life, the need for large-scale continues to rise. However, the capacity of RWS to identify, develop, and execute R&R projects is already under pressure. As a result, a field of tension arises between the urgency of interventions and the practical realizability of renewal projects, i.e., the degree to which projects can actually be executed. Additionally, The Ministry of I&W, and thus RWS, faces major budgetary deficits in the near future, meaning that projects will have to be prioritized as there simply is not enough funding to execute all of them. The uncertainty in this complexity stems from the unavailability of knowledge regarding future budgets, prioritization outcomes, production capacity (realizability), etc.
  - **Uncertainty source:** Epistemic.
- **Political-administrative reporting pressure results in administrative burden**

- **Categorization according to complexity categorization framework (Table 4.1):** Numerous working processes that interfere (detail organizational complexity).
- **Description:** The shift towards intensified reporting, especially called for by higher executives, creates an additional burden while failing to deliver the intended control benefits. Reporting is mainly done ex ante, meaning that it remains to steer ongoing processes. It creates a tension field between the predictability demanded by politicians and executives, while it hampers the flexibility required by PM teams to operate. The administrative burden of multiple reporting streams, combined with evolving governance arrangements, complicates the internal processes. The pressure to produce various reports to demonstrate compliance is experienced as cumbersome, while not providing what is actually wanted, which is an increased level of control to efficiently steer project.
- **Uncertainty source:** No uncertainty present.

C.5.2. The accuracy of cost estimation methodology

Estimating costs, in order to determine the required budget, is an essential part of every infrastructure project. In the end, every decision made within a project will eventually translate itself into costs, which converge in the cost estimate. The costs included in the estimate, collectively form the required funds that must be invested to renew an object. Knowing this is of importance for the Ministry of I&W, so costs are known on the level of the R&R program as a whole. The insight of the total cost of the R&R program where first determined in a prognosis report (Rijkswaterstaat, 2022), and later further specified in the overall plan for infrastructure upkeep (Ministry of Infrastructure and Water Management, 2025).

Despite the efforts of RWS, accurately estimating costs has proven to be a major challenge in R&R projects. In a recent report, an analysis has been made with regards to the cost estimation methodology that RWS utilizes for determining what budgets are required for all of the R&R projects. PwC and Rebel (2020) concluded that the quality of cost estimates varies between asset categories. Moreover, unit rates for 1-to-1 replacements are not only scarce, but due to the lack of central quality assurance (validation) for these estimates, no uniform cost data is used: different sources, price levels, and assumptions are applied. As a result, the range (or uncertainty) of these cost estimates is very large.

The uncertainty, risks, and other difficulties for accurately estimating costs in R&R projects has widespread implications. These are far reaching, not only spanning the project itself, but also on the level of the entire R&R program.

Practitioner insights

Many practitioners recognize that much of the experience that has been gained through the years, originates from construction projects (R1, R3, R4). But as has already been established, these differ significantly from R&R projects. The distribution of costs over the different cost categories in R&R projects are generally not the same as in construction projects. One respondent remarks the following (R1):

> The direct costs within a project are generally quite stable; it is unlikely, for example, that suddenly 20% more concrete will be required. Indirect costs, on the other hand, are less predictable, with the project's duration being a major determining factor.

Since R&R projects regularly face delays, indirect cost often turn out higher than initially expected. For the distribution of costs between other cost categories another respondent indicates that (R5):

> Much of the cost estimation experience for infrastructure projects stems from new construction projects, which is reflected in the typical cost breakdowns. However, this distribution can differ significantly for renovation projects. For example, environmental complexity tends to be much higher in renewal projects. Since the asset is already in use, the anticipated disruption [of traffic] during the works has a price-increasing effect. In general, there are simply more obstacles to account for, such as the inherent uncertainty regarding the actual condition of the existing asset.

While the experience gained from constructing new infrastructure acts as a foundation for further projects, it cannot be reliably relied on for approaching R&R projects. Since these projects have a completely different nature, practitioners must be wary of the novel and additional obstacles faced.

The same applies for the way that cost are estimated. The cost estimation methodology currently used makes use of unit prices and markups to calculate certain cost elements. Some elements, e.g., the prices for the amount of concrete required in a object, are calculated based on a unit price per square meter (R4). Some cost elements are calumniated as a percentage, i.e. a markup, of other costs. These have been based on historical numbers, embodying the many years of experience that those active in the infrastructure branch have gained. Nonetheless, the conditions under which R&R projects remotely different. One respondent notes (R1):

> From a cost perspective, it is crucial that commissioners do not rely solely on historical unit rates when estimating costs. The circumstances surrounding replacement and renovation (R&R) projects have changed significantly.

Using inaccurate unit prices, or having changing scope, can prove problematic as the following example illustrates (R3):

> As a cost estimator [cost expert], for example, [on a highway] project, the required square meters of viaduct or bridge is calculated to which an unit price is applied. If it later turns out that these structures need to be wider than initially assumed, this immediately results in the first cost increase.

Finally, much uncertainty is present in cost estimates. Although it is known by practitioners, it remains difficult to fully acknowledge and incorporate it into cost estimates. On the level of the R&R program, the question posed earlier by PwC and Rebel (2020) with regards to how uncertainty the in the assumption for cost estimation take their form, is shared by one respondent, who explains (R5):

> The uncertainty is acknowledged, as evidenced by the fact that [uncertainty/reserve] margins are being calculated. However, the question remains whether this is sufficiently reflected in the final budget. It currently appears that the budget, which is based on the R&R forecast report, does not adequately account for the nuances (such as additional markups and uncertainties) associated with a 1-to-1 replacement. This is also very complex: what value should be assigned to such uncertainties? These uncertainties become more visible in projects that are currently under development, as active cost estimates are being made for them. As a result, these projects receive a different estimate (with more visible costs) than projects scheduled further in the future, which are still based on the R&R forecast report.

This notion of uncertainty is shared by another respondent (R4):

> Extensive discussions have taken place to reach alignment on a more realistic cost estimation, based on prior experiences with replacement and renovation (R&R) projects, which have frequently encountered cost overruns. R&R projects are relatively new in nature and therefore difficult to estimate and benchmark. For projects, it is common practice to use the P50 value of the confidence interval. However, a recent discussion proposed adopting the P85 value instead, in order to better account for potential setbacks. To justify maintaining the P50 value, it is important that cost estimates are calibrated to this new type of project, for example, by acknowledging a higher risk profile. Currently, there remains a gap between theory and practice.

Complexity identification

Within this challenge, the following complexities have been identified:

- **Uncertain distribution of direct and indirect costs**
  - **Categorization according to complexity categorization framework (Table 4.1):** Costs and benefits are difficult to calculate and are not equally divided (dynamic financial complexity).
  - **Description:** It remains difficult to accurately estimate direct and indirect costs, as there is a high degree of uncertainty present in several cost elements and categories. This uncertainty is further reinforced by project developments such as project scope changes, delays, and other disruptions. Moreover, the share of indirect costs in R&R projects has grown relative

to greenfield construction projects, in some cases being more than halve of the total project cost. The uncertainty residing in this complexity is a mix of both aleatory and epistemic uncertainty. Aleatory, because prices fluctuate as they are subject to market developments. Epistemic, as uncertainty can and will be reduced through experience with R&R projects allowing for accurate cost breakdown and better reference figures.

– **Uncertainty source:** Aleatory and epistemic.

C.5.3. Strategic behavior over scarce funds

Strategic behavior with regards to determining cost is a reoccurring subject in many researches involving LIPs. As (Flyvbjerg, 2009) has noticed, strategic misrepresentation can be traced to agency problems and political and organizational pressures such as, for instance, competition for scarce funds. It raises the question, if such mechanism such as described by Flyvbjerg are also at play in infrastructure renewal projects. These project are of a fundamentally different nature than projects which encompass the construction of new infrastructure: The infrastructure is already existent, so in principle, it is not that there will be any novel benefits to the direct surrounding. Of course, benefits such less malfunction, of a faster opening and closure of a bridge are welcome effects, but the new situation will in most cases be more or less functionally identical after renewal as before.

Practitioner insights

Despite the different playing field for infrastructure renewal projects, the scarce funds for infrastructure renewal and the resulting competition for it has been identified by one respondent as an example of strategic behavior (R5):

> The regions are aware that there is not enough funding available for all [R&R] projects, and they primarily have an interest in their own projects. In my view, this creates a strong incentive to present their projects in a more favorable light than they actually deserve: the problems are portrayed as more severe, and the solutions [required for renewal] are easier to implement [and thus preferable to execute]. This, combined with the fact that once a project has started it becomes very disadvantageous to halt it, creates a problematic dynamic.

These dynamics inevitably go hand-in-hand with an optimistic bias. It has been noted that the transferring of a project from the development phase which is facilitated by the regional divisions, to the national divisions that detail them. The PM team is often the first that needs to address issues, such as that the scope as proposed in the development phase is not complete or not feasible (R4). It also play in the manner that uncertainty is paid attention to, as provided (R5).

> In addition, there is a tendency towards optimism, as uncertainty is given little to no consideration in decision-making at the project level. The approach relies too heavily on corrective measures after the fact. Accomplished facts appear to be the most effective means of compelling decisions. Ultimately, these issues also resurface at the ministerial level.

As can be implied from this setting, which is formed by the current urgency for a multitude of renewal projects to be executed while budgets are not sufficient, strategic behavior is at play. Another respondent illustrates why the high cost associated with R&R projects prove problematic (R3):

> R&R projects that spiraled out of control were subjected to financial analysis, which revealed that if one calculates the [initial] costs at 100%, a budget provision of 250% would be required [for the costs actually incurred]. Alternatively, the risk contingency could simply be doubled. The problem with either approach, however, is that the projected costs become so high that no one within the organization is willing or able to accept them.

The implication from this, is that costs have a tendency to be suppressed, because they are too high for the organization to accept.

Complexity identification

Within this challenge, the following complexities have been identified:

- **Strategic misinterpretation due to competition over the limited renewal funds**

- **Categorization according to complexity categorization framework (Table 4.1):** Strategic misinterpretation (dynamic financial complexity).
- **Description:** Regional divisions of RWS present projects as more favorable, such as by downplaying costs, risks, or complexity, in order to secure funding over competing projects. Unlike inherent variability, this uncertainty arises from intentionally biased information, which thus lacks a transparent and complete profile. It is a form of epistemic uncertainty in projects, as stronger checks and improved governance may reduce it.
- **Uncertainty source:** Epistemic.

• Optimistic bias in early project scope and budget undermines scope-stability and feasibility

- **Categorization according to complexity categorization framework (Table 4.1):** Optimistic/pessimistic bias (dynamic financial complexity).
- **Description:** The practice of underestimating costs is encouraged by organizational developments, as the estimated 'true' costs of projects, resulting from significant contingency reserves or other cost-driving elements, are often perceived as being too high to secure project approval. This is further compounded by the fact that early project scope is frequently underdeveloped. This leads to plans that prove unfeasible once a project progresses and is handed over between internal PM teams that work on them. These dynamics introduce epistemic uncertainty as the overly favorable assumptions stem from gaps or distortions in the available knowledge.
- **Uncertainty source:** Epistemic.

• **Persistently distorted perceptions of costs throughout various project phases**

- **Categorization according to complexity categorization framework (Table 4.1):** 'Cascade of distortion' effect (dynamic financial complexity).
- **Description:** When costs are misrepresented from the start, all subsequent cost estimation processes inherit this initial bias. An artificially low baseline anchors later estimates, forecasts, and performance assessments, causing the project to appear as if it is continually experiencing financial setbacks. This constitutes epistemic uncertainty that propagates through the project life-cycle, as the consequences downstream cannot be fully anticipated in advance.
- **Uncertainty source:** Epistemic.

D
Additional case information

This Appendix provides additional information which has been collected for the case study in Chapter 6.

D.1. Approach and phasing of the project

In this section, project features related to the phasing of the project are discussed.

D.1.1. Approach

The design includes two bridges with multiple spans due to soil and dike conditions, reuse of girders a previous highway project, and a bascule bridge between a support pier in the waterway and a basement structure on the west bank. On the east side, a fixed span and support will also function as a flood barrier, integrating with the exist system. Additionally, a local control room will be provided for bridge operations. Furthermore, the new Kaag Bridge will be operated jointly with the nearby railway bridge, to streamline operations.

D.1.2. Project delivery framework

This project is classified as an infrastructure renewal project, and is thus approach via the R&R approach, which is the project delivery framework. As the project entered the start-up phase, the this R&R approach was still under internal development of RWS. Therefore, the exact structure in which it all was followed remained unsure.

In the project, the regular decision points (DP1 and DP2) were passed through. However, an important additional decision point was utilized in the process, which is referred to as the Interim Decision (*Tussenbesluit)*. This additional decision point was established in an effort to reach a stable scope more quickly. It primarily consisted of an analysis of all seventeen objects in the initial scope (all civil structures in the A44 highway), to determine which of them were in need of urgent intervention. From this it was concluded that five objects were to be prioritized, in order for them to be replaced as soon as possible.

D.2. The project

D.2.1. Risk ownership and contract

During the pilot phase of the project, RWS has chosen to develop a preliminary design in collaboration with an engineering firm. Under a D&C contract, the tendering procedure and competition-oriented dialogue are further executed. It is an integrated contract form, as it allows for earlier cooperation between the PM team and the contractors. In this early collaboration, collective efforts are made to ensure better results. In this approach, the contractors is also ultimately responsible for providing the design of the structures that are to be constructed.

The D&C contract was chosen, as it was deemed most fitting for the project at hand, taking into account the risks, scale, and nature of the project. It emphasizes the design efforts that must be made by the contracted party. Moreover, parallel to the replacement project for the Kaag Bridge, another contract is to be executed for the other objects in the total scope of the R&R Civil Structures A44 project.

As for risk ownership, the PM team was aware of the current developments in the construction sector as a whole. This being that in recent years, it has become more clear that the approach which RWS had previously adhered to proved to be feasible no more. In this approach, most project risks were allocated at the contractor, which proved to be problematic, as it was deemed unfair. For this project, several efforts were made to promote fair risk ownership, ensuring that there were sufficient bidders during the tender of the project. This is of major importance, especially in the current times due to competition of other sectors such as residential construction and the energy transition.

In order to ensure balanced risk distribution, multiple measures were taken. While the tender process was still underway, the technical guidelines (ROA/ROK), were subject to change. As these developments took place, it remained uncertaint what the exact implication would be for the project, making it difficult for a contractor to adress them. RWS has provided certainty for these parties by stating clear starting points, and indicating that these would be further developed after the tender.

Another example are the soil conditions. RWS carried out several studies and also provided clear assumptions on which the contractors were to basis their bid. If the situation would turn out to be different in practice, then RWS would be responsible for the consequences. These efforts were in the line with the principle that risks are to be allocated at the party who is best able to manage and influence them. The efforts in establishing a more balanced risk ownership have proved to be a delicate trade-off in projects. This trade-off revolves around adhering to the frameworks established vs. serving the project. As RWS takes accountability for more risks, possibly also adding cost to the project, it helps the project move forward by deterring negative developments such as conflicts or failed tenders.

D.3. Technical features

D.3.1. Replacement of severely outdated bridges

The Kaag Bridge were constructed before the Second World War, as construction finished in 1937. These civil structures were constructed in a time were technical guidelines were not as strict as nowadays. As a result, the bridges are narrow and have no emergency lanes. Moreover, the construction techniques using at that time differ significantly from now.

As with many R&R projects, in which the choice is made to replace an asset entirely, the requirement of keeping the functionality level the same has been given by the Ministry of I&W. However, ambiguity is present in this prerequisite, as it is something which can be achieved in terms of functionality, but not technically. Construction of the Kaag Bridge finished in 1938. At that time, technical standards were significantly different then they are now. Currently, the Kaag Bridge are perceived as notoriously narrow by road users, also lacking emergency lanes.

The relevant standards for this project are primarily the ROA and ROK. These design guidelines, based on the prevailing European guidelines, are developed by RWS. In general, these guidelines demand higher quality/safety levels for Dutch infrastructure than their European counterparts. As a result of the development in technical guidelines, it became clear in the initial phases that an exact replacement of the original structure is simply not possible, as this does not comply with modern requirements. For the Kaag Bridge, a practical implication of this was that the replacement brides would have to be wider than the existing structures. This space is needed to construct a sufficient shoulder width and emergency lanes.

D.3.2. Connection to the railway bridge

As Figure 6.7 shows, the Kaag Bridge are in the vicinity of a railway bridges, which is under the management of ProRail. In this project, a requirement given was for the Kaag Bridge (road vehicles) and the railway bridge to be operated jointly. In practice, this means that the control systems of the objects must be connected.

D.4. Sustainability and emission

D.4.1. Reuse of girders

An unique feature of the replacement of the Kaag Bridge, is that is makes uses of a vast amount of reused girders. In another project that RWS is currently working on, the widening of the A9 highway between Badhoevendorp and Holendrecht to better accommodate increased traffic volumes. From this project, ca. 360 girders, which are long concrete beams that support the road, have been 'harvested'. Around 220 of these girders will be reused in the construction of the new Kaag Bridge.

Within the context of reuse of structural elements within RWS, this is an innovation. It is one of the first times that girders are being reused, with the scale of this reuse, also being a novelty. As concluded in the previous chapter, reuse of structural elements can be a challenging feature of R&R projects. RWS has consolidated its approach toward this, as can be concluded from the methods in which reuse of the girders was facilitated.

RWS has facilitated reuse through providing dedicated team responsible for reuse in the project. This team identifies potential structural elements suitable for reuse, checks their integrity, executes the necessary calculations, and brings them up to the required specification through renovation/adjustments. These structural elements are then supplied through a direct delivery, meaning that RWS provides them, also retaining ownership of risks associated with reuse.

reuse was discussed during the initial phases of the project, such as the market consultation (voluntary, transparent exchange of information with market parties before the tendering process) and the tender dialogue (structured conversation between the contracting authority and potential contractors during the tendering process). It is important to discuss it among the potential contractor(s), as they will have a responsibility for integrating the reused elements in the designs the develop. Risks associated with this integration are allocated at the contractor.

D.4.2. Nitrogen and emission-free construction

In this project, it is not required to work completely emission-free, it is however, required to work emission-reducing. The project location is not near protected nature areas (Natura2000). The requirement states the need to utilize sustainable construction equipment, which often comes down to using electrical equipment.

D.4.3. Other sustainability efforts

Besides the aforementioned points, the PM team undertook various other measures in order to increase the sustainability of the project. These include:

- **Utilization of sustainable concrete:** All concrete procured, used, repaired, or demolished in RWS projects is handled in accordance with the RTD 1033 framework. guiding both project-level and material-level sustainability.
- **Application of environmental cost indicator:** In the tender procedure, an environmental cost indicator was adhered to.
- **Mandatory application of energy saving measures:** The application of utilizing energy saving measures is mandatory, having a payback period of five years.
- **Sustainable dismantling of guard rails:** Guard rails are to be removed sustainable, i.e. dismantled in a manner to allows for reuse.
- **Requesting an option dossier for sustainability measures:** A dossier is to be requested after the contracted is awarded, presenting the PM with additional opportunities to increase sustainability.
- **Application of front-runner requirements for emission free construction equipment:** In the project, so called front-runner *(koplopereisen)* requirement were instated for the use of emission-free construction equipment. The front-runner requirement refer to pioneering projects, that go beyond standard practice.

D.5. Regional stakeholders and regulatory landscape

In this section, project dimension related to the regional stakeholders and the regulatory landscape are presented.

D.5.1. Legal basis of the project

In R&R projects, there is no formal legal project decision which backs up the legality of the project. In contrast to the construction of new infrastructure, as in these projects, such a legal basis is present. Not having this legal basis has presented the PM team with a novel legal playing field. The lack of legal basis especially concerns the process of applying for permits, and if it proves the be necessary the process of expropriation.

Acquiring the permits needed for construction works concerns primary those under the management of the Environmental and Planning act. A prominent permit for which the PM must apply under this act, are zoning deviations (*buitenplanse afwijking*). These are needed as a legal permission to deviate from the original zoning plans as instated by the relevant competent legal authority.

To apply for such a permit, preparation is needed: Several researches, calculations, and (preliminary) designs must be completed before an application can be submitted. Acquiring the permits is essential, as construction cannot start without it, meaning that is part of the critical path of the project planning. The legal preparation in order would ideally be completed in an earlier stage, but the current legal reality forces a PM team to complete this as the project, including the tender, is already underway.

D.5.2. Reducing traffic disruption

As with any R&R project, the project revolves around an asset that is currently functioning, i.e. it is used by road and/or waterway users. Bridges that are a part of the main transportation networks in the Netherlands, that being the HWN and the HWVN, serve as an important link, that cannot be taken out of service without major disruption of traffic. Even more so, it could possibly lead to inaccessibility of homes, businesses, or critical facilities such as emergency services. All in all, it emphasized the need for measures that seek to reduce disruption, e.g., through keeping bridges partially opened, or rerouting traffic via temporary/replacement structures or alternative routes. This is also the case for the A44 highway: completely closing down this connection would lead to unacceptable inaccessibility of the surrounding region as a whole. However, within the context of an ever growing need for R&R projects as more and more structures reach their technical EOL, it will not always be possible to maximize efficiency of disruption mitigation measures. Furthermore, taking these measures is not without significant cost.

The PM team of the project R&R Civil Structures A44 also found themselves in this situation. Since the A44 highway is such an important traffic corridor, adequate measures were in order to promote accessibility of the region while the R&R projects are underway. For regional stakeholders, among them also local authorities such as the municipalities (which the highway crosses), this accessibility is a key demand. However, as the PM team noticed, demands are subject to continuous change, making it difficult to make lasting agreements up front. However, there is a major dependency on these stakeholders, as they issue the permits required for the project. Not taking into account and actively managing these developments would negatively affect the political-administrative support for the project.

The efforts of the PM team in managing the previously mentioned matters included early cooperation with regional stakeholders, allowing for the discussion of project scope, phasing, dealing with the limited space available, and what measures would be taken in order to mitigate traffic disruption. Rerouting traffic proved unfeasible, meaning that existing traffic flows were to be maintained. At first it was though that the nearby A4 highway could alleviate some of the problems, but after closer analysis, this option was off the table. This was due to the fact that rerouting significant traffic volumes via longer alternative routes would lead to increased nitrogen depositions. In the current nitrogen crisis in the Netherlands, this would have significant consequences for the project. Ultimately, an project phasing was chosen in which a one of the replacement bridges is to be constructed first (as explained more detailed in Section D.1) , allowing for rerouting of traffic via this structure.

E

HREC informed consent form

This appendix displays the informed consent form that has been utilized to gain formal approval from individuals taking part in the interviews. Since these interviews were conducted among practitioners in the Dutch infrastructure sector, the forms provided are in Dutch.

Introductie tot het geïnformeerde toestemmingsformulier:

U wordt uitgenodigd om deel te nemen aan een interview, om hiermee input te leveren voor de afstudeerscriptie genaamd "Uncovering causes of financial setbacks in bridge renovation & replacement: Enhancing project delivery for public commissioners". Dit onderzoek wordt uitgevoerd door Jesse Mathôt, student aan de TU Delft van de masteropleiding Management of Technology. De afstudeerstage (master thesis) wordt uitgevoerd bij Horvat & Partners te Delft.

Het doel van dit onderzoek is informatie/data te vergaren wat betreft de factoren die de complexiteit en kostenontwikkelingen beïnvloeden in renovatie- en vervangingsprojecten van grote bruggen in Nederland. Het interview zal zo'n 60 minuten in beslag nemen. De data zal gebruikt worden in het kader van het schrijven van de master scriptie (afstudeeronderzoek). Dit onderzoek zal na afronding van het afstuderen op de TU Delft Repository (openbaar publicatieplatform) worden gepubliceerd. Indien informatie door u als vertrouwelijk wordt bestempeld, dan dient dit schriftelijk kenbaar te worden gemaakt, en bij voorkeur ook mondeling.

Informatie/data uit het interview zal verwerkt worden in een geanonimiseerde technische samenvatting. Deze samenvatting bevat de belangrijkste resultaten van het interview. Deze worden na het opstellen volledig geanonimiseerd en aan u teruggelegd ter review. Op deze manier geven wij u de mogelijkheid om feitelijke onjuistheden te corrigeren en gevoelige/geheime informatie die niet gedeeld mag worden aan te passen of te verwijderen. Na uw akkoord zal de informatie uit deze samenvatting als input dienen voor het schrijven van de afstudeerscriptie.

Zoals bij elke online activiteit, waaronder email uitwisselingen of gesprekken via online services, is het risico van een databreuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico's door verzamelde data na het ontvangen te anonimiseren. Data is alleen toegankelijk voor de afstudeerder en de begeleiders vanuit de TU Delft (onderzoeksteam). Dit wordt gefaciliteerd door de data op te slaan op de TU Delft OneDrive.

Uw deelname aan dit onderzoek is volledig vrijwillig, en u kunt zich elk moment terugtrekken zonder reden op te geven. U bent vrij om vragen niet te beantwoorden.

J.J. Mathôt (TU Delft studentnummer 5655420)

Datum van opstellen: 21-04-2025

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. Ik heb de informatie over het onderzoek gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	☐	☐
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	☐	☐
3. Ik begrijp dat mijn deelname aan het onderzoek de volgende punten betekent (zie de onderstaande punten): • Informatie uit interviews zal via audio-opnames worden vastgelegd, waarna deze wordt getranscribeerd. • Informatie uit deze gegevens zal verwerkt worden in een geanonimiseerde technische samenvatting, die ter review aan u voor zal worden gelegd. • Persoonsgegevens (naam, email, functie) zullen op de TU Delft OneDrive bewaard worden en zijn alleen toegankelijk voor het onderzoeksteam. In de scriptie en overige communicatie richting de TU Delft zullen deze persoonsgegevens nooit worden gedeeld.	☐	☐
5. Ik begrijp dat de studie (afstudeeronderzoek) per 15-09-2025 eindigt. Na het voltooien van het afstudeeronderzoek zal de informatie en gegevens van de interviews permanent worden verwijderd. Dit geldt niet voor de geanonimiseerde informatie opgenomen in de scriptie.		
Please add the anticipated timing or how the date will be determined		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt: • Het delen van (potentieel) bedrijfsgevoelige informatie. • Het (per abuis) delen van informatie die tot reputatieschade van de persoon of organisatie in kwestie leidt (bijvoorbeeld in het geval van her-identificatie). • Een lek van persoonlijke gegevens. Ik begrijp dat deze risico's worden geminimaliseerd door: • Informatie uit interviews zal verwerkt worden in een geanonimiseerde technische samenvatting, die ter review aan u voor zal worden gelegd. Deze samenvatting bevat de belangrijkste resultaten van het interview, welke ter review naar u terug gestuurd zal worden. Indien er aanpassen nodig zijn op uw verzoek, bijvoorbeeld ter borging van u privacy of ter voorkoming van het delen van gevoelige/vertrouwelijk informatie, dan zullen deze worden verwerkt. Na uw akkoord zal de informatie uit deze samenvatting als input dienen voor het schrijven van de afstudeerscriptie.	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
• Persoonsgegevens (naam, email, functie) zullen op de TU Delft OneDrive bewaard worden en zijn alleen toegankelijk voor het onderzoeksteam. In de scriptie en overige communicatie richting de TU Delft zullen deze persoonsgegevens nooit worden gedeeld.		
7. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld, met het risico dat ik hieruit geïdentificeerd kan worden.	☐	☐
8. Ik begrijp dat binnen de Algemene Verordering Gegevensbescherming (AVG) een deel van deze persoonlijk identificeerbare onderzoeksdata als gevoelig wordt beschouwd, namelijk: • Naam • Email • Functie(titel)	☐	☐
9. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een databreuk te minimaliseren, en dat mijn identiteit op de volgende manieren wordt beschermd in het geval van een databreuk: • Data wordt op een beveiligde server bewaard, de TU Delft OneDrive. • Data wordt preventief bescherm door personen uit de interviews en overige data (bijvoorbeeld projecten indien nodig) te labelen middels een anoniem volgnummer. • Mocht een databreuk zich voordoen, dan zullen de getroffen personen hiervan onmiddellijk op de hoogte worden gesteld.	☐	☐
10. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals naam, email, of functie niet gedeeld worden buiten het TU Delft onderzoeksteam.	☐	☐
11. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt op 01-10-2025. Dit is onder voorbehoud dat op deze datum het afstudeeronderzoek succesvol is afgerond, als dit niet het geval is zal de data zo spoedig mogelijk na het afronden alsnog worden vernietigd.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. Ik begrijp dat na het onderzoek de geanonimiseerde informatie gebruikt zal worden als input voor het afstudeeronderzoek, bijvoorbeeld in de vorm van citaties or parafraseringen. De informatie zal fungeren als aanvulling of validatie op bestaande literatuur.	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
15. Ik geef toestemming om de geanonimiseerde data/informatie die via interviews over mij verzameld worden gearchiveerd worden in de TU Delft Repository (openbaar toegankelijke opslag) opdat deze gebruikt kunnen worden voor toekomstig onderzoek en onderwijs.	☐	☐

Signatures

_____________________________ ____________________________ _________

Naam deelnemer Handtekening Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

J.J Mathôt

___________________________ ____________________ _________

Naam onderzoeker Handtekening Datum