Prioritization of Infrastructure Renovation and Replacement works

MSc Construction Management and Engineering

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TU Delft

Witteveen + Bos

Prioritization of Infrastructure Renovation and Replacement works

by

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In partial fulfillment of the degree of **Master of Science** in Construction Management and Engineering at Delft University of Technology

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Preface

I am pleased to present the final piece of my Master's study in Construction Management and Engineering, dedicated to the relevant topic of Infrastructure Renovation and Replacement. I hope that this research will be helpful to the organizations responsible for this critical task and, consequently, to everyone who benefits from the built environment.

This last phase of my study has been an incredible journey, and I am deeply grateful for the guidance and support of such outstanding professionals. First, I want to thank my evaluation committee at Delft University of Technology. Dr. Ir. Erik-Jan Houwing, your willingness to listen and discuss new ideas has been invaluable. Thank you for our weekly meetings and the challenging questions you posed, which were eye-opening for me. Ir. Leon Hombergen, thank you for your comments and suggestions that pushed me to explore further. Dr. Ir. Ad Straub, thank you for your diligent help in defining my research topic and for providing valuable insights throughout the development of my thesis. I also want to thank my supervisor at Witteveen+Bos, Ir. Xaief Ezechiëls, for your support in the progress of my thesis, backing my academic goals, and connecting me with the right people. I extend my gratitude to all the interviewees; your experiences and knowledge were inspiring and central to this research.

Lastly, I want to thank my parents for their unwavering love and support, which make everything possible. To my sisters, who constantly inspire and teach me by their example. And to my friends, both those who have stayed close despite the distance and those I've met here who have made this journey joyful and memorable.

Laura Isabel Loaiza Osorio
Delft, August 2024

Summary

The civil engineering sector in the Netherlands faces significant challenges, particularly in the Renovation and Replacement (R&R) of infrastructure built in the 1950s and 1960s. Rijkswaterstaat (RWS), part of the Dutch Ministry of Infrastructure and Water Management, highlights three primary issues: the growing demand for R&R, the need to achieve climate neutrality and adopt circular practices by 2030, and a shortage of skilled personnel, which leads to delays and increased costs. These challenges complicate the management of R&R projects, with municipalities overseeing over 80% of civil structures and bearing the majority of R&R costs.

This research aims to develop a Roadmap that enables municipalities to effectively prioritize R&R tasks, addressing stakeholder demands while optimizing resources. The main research question is:

How can municipalities in the Netherlands effectively prioritize infrastructure renovation and replacement works to meet stakeholders' demands and optimize resources?

To address this, the study is guided by four secondary questions that tackle understanding the challenges in prioritizing R&R works, identifying the interests and influences of stakeholders, examining the current prioritization practices of asset owners and evaluating the decision-making approaches of municipalities.

By identifying a significant gap in understanding the prioritization of infrastructure R&R projects, the study proposes using the Double Diamond model to systematically discover, define, develop, and deliver solutions, dividing the research into these four phases. The methodology includes a comprehensive review of the literature, exploratory interviews, and detailed case studies in different municipalities.

Phase I: Discover

The literature review identifies the main challenges in prioritizing infrastructure R&R, such as defining objectives, managing multiple actors, assessing infrastructure, and aligning decision areas. It also delves into the specific context of the Netherlands by quantifying the infrastructure R&R challenge.

Additionally, six exploratory interviews were conducted with various experts working on the R&R challenge, providing practical insights into the theory. These interviews identified five distinct prioritization approaches: Asset-driven, Importance-driven, Area-oriented, Capacity-driven, and Collaboration-driven. Each approach offers unique criteria and methodologies for determining the priority of R&R works. These approaches reflect varying visions and terminologies that influence infrastructure objectives and boundary conditions.

As a result of the first phase of the research, a theoretical framework was developed to encapsulate the findings from the literature review and interviews. This framework outlines the infrastructure R&R cycle, decision-making processes, and associated challenges. It underscores the importance of strategic, tactical, and operational planning in managing infrastructure assets, emphasizing the roles of stakeholders, objectives, and contextual factors in shaping R&R decisions.

Phase II: Define

The selection of case studies focuses on Dutch municipalities actively involved in infrastructure R&R. Municipalities of various population sizes, specifically Amsterdam, Utrecht, and 's-Hertogenbosch, were selected to capture diverse contextual and organizational conditions. Data were collected through semi-structured interviews with senior advisors, engineers, and managers involved in infrastructure R&R.

The findings highlight variability in R&R management among the municipalities, with differences in organizational structure, resource availability, and prioritization approaches. The key challenges identified for project implementation include market capacity, financial capital, and human capital constraints. The study reveals that municipalities employ a two-cycle prioritization process: the first cycle focuses on the technical and functional aspects of assets, while the second cycle considers medium- and long-term strategic objectives and broader stakeholder impacts.

The comparative analysis identifies common and unique strategies among the municipalities. At the strategic level, infrastructure goals are aligned with political agendas, with safety being the primary objective across all municipalities. Tactical planning highlights differences in project timelines and evaluation criteria. Programming reveals that all municipalities adopt Asset-driven and Importance-driven approaches as standard methods, while advanced strategies such as Capacity-driven and Collaboration-driven approaches face implementation challenges due to resource and information constraints.

Furthermore, the research introduces the concept of organizational maturity to classify infrastructure managers, emphasizing the need for a comprehensive assessment of capabilities beyond organizational size. Factors such as information availability, coordination levels, market orientation, risk management, and role definitions are crucial in determining a municipality's capacity to effectively manage R&R tasks.

Phase III: Develop

The Roadmap depicted in Figure 1 consolidates all information gathered and analyzed in preceding stages, proposing a structured guide for evaluating and selecting prioritization methods based on organizational maturity levels and project-specific factors. Thus, the Roadmap is designed to be flexible and adaptable across various municipal contexts.

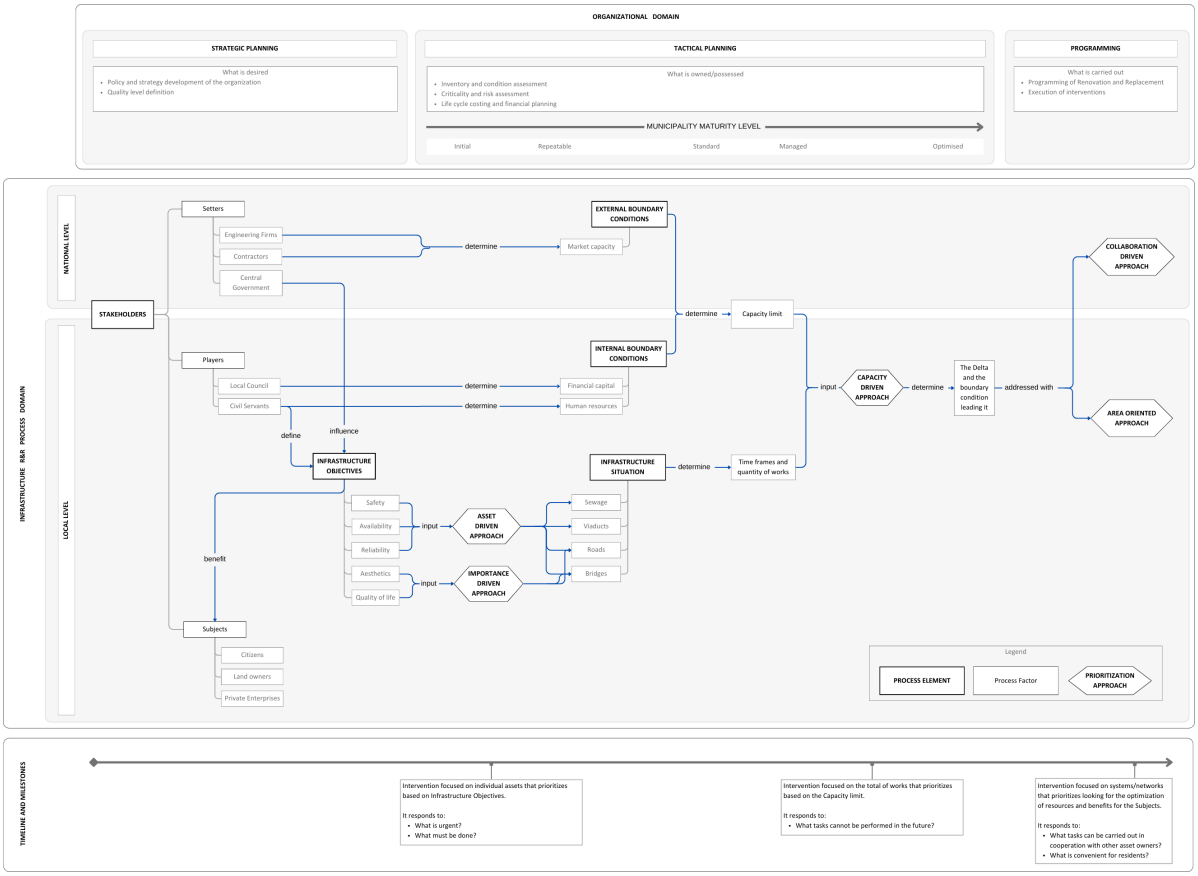

Figure 1: Roadmap for the prioritization of infrastructure R&R works.

Phase IV: Deliver

The study concludes that in addition to the challenges identified in the literature review for prioritizing R&R works, information management, internal coordination, and uncertainty must also be considered. It explains that asset owners must manage extensive and variable data sets, overcome internal disconnections, and navigate dynamic political and technical environments that are inherently part of bureaucratic structures, affecting resource allocation and asset integrity objectives.

The research proposes an optimal sequence for implementing prioritization approaches as follows: (1) *Asset-driven* for safety, (2) *Importance-driven* for cultural and historical value, (3) *Capacity-driven* for long-term compliance, (4) *Area-oriented* for resident benefits, and (5) *Collaboration-driven* to leverage market capacity. This sequence reflects municipal priorities by emphasizing the use of scalable approaches that enable proactive, collaborative, and sustainable solutions as organizational maturity develops.

This route implies that all infrastructure owners should start with the Asset-driven approach and progressively incorporate additional approaches as their organizational maturity allows. These additional approaches address various aspects of the R&R challenge and provide benefits to stakeholders.

Limitations

The study faces methodological limitations, including limited data availability on prioritization approaches for R&R projects in the literature; findings based on a small number of case studies, cautioning against broad applicability; reliance on a narrow group of interviewees, potentially biasing perspectives; and a theoretical Roadmap not yet tested in practical scenarios due to time constraints, requiring further validation before implementation.

Recommendations

Municipalities at the **Initial-Repeatable Maturity Level** should create dedicated teams to handle urgent R&R projects, freeing capacity to focus on long-term planning and asset management. For those at the **Standard-Managed Maturity Level**, formalizing the ”second cycle of prioritization” by conducting regular meetings across infrastructure teams is essential to improve communication and integrate R&R projects across all asset types.

The central government should establish an independent funding source for R&R projects, ensuring transparent and effective resource allocation free from local political influence. Additionally, a centralized public information platform should be created to facilitate information sharing and collaboration among asset managers at all levels.

All asset owners are encouraged to adopt alternative procurement criteria that prioritize innovation and improved construction performance. This approach will help shape market capacity to better support R&R projects, ensuring more effective and strategic project execution.

Contents

Abbreviations

IAM Infrastructure Asset Management

IM³ Infrastructure Management Maturity Matrix

NGO Non-Governmental Organization

R&R Renovation & Replacement

RWS Rijkswaterstaat

List of Figures

List of Tables

1

Introduction

1.1. Background

The civil engineering sector in the Netherlands is confronted with a growing array of challenges, as detailed in the 2019 document titled ”Perspectives on Challenges and Improvement Opportunities in the Civil Engineering Sector,” prepared by Rijkswaterstaat (RWS), the executive organization of the Dutch Ministry of Infrastructure and Water Management. Three primary situations have been identified. Firstly, there is a mounting demand for the Renovation and Replacement (R&R) of existing infrastructure, encompassing aged bridges, tunnels, locks, and viaducts originally built during the 1950s and 1960s (Rijkswaterstaat, n.d.). This demand is expected to persist through to the year 2100.

Secondly, the construction industry must actively contribute to sustainability efforts, especially in the public sector. In the case of the Netherlands, RWS has set ambitious goals, aiming to achieve climate neutrality and adopt circular practices by 2030. This commitment aligns with the global shift towards sustainability, marked by milestones such as the 2016 Paris Agreement and the formal commitment of the European Union in 2019 to steer its economy towards sustainability and climate neutrality by 2050 (Commission, n.d.; UNFCCC, n.d.). Third, a shortage of highly skilled personnel is a prominent concern for both the RWS and the European Construction Industry Federation (FIEC, 2023; Rijkswaterstaat, 2019). The industry faces a demand for qualified labor that often exceeds the available workforce, leading to delays and additional costs.

While these three challenges are situated at different management levels, it is found that they are all present in infrastructure R&R. This indicates that, apart from being urgent and demanding, R&R works are exceptionally complex to manage. Just as RWS conducted an assessment of the sector, similarly, for a more comprehensive understanding of the nature and scope of R&R works, TNO, the independent Dutch organization for applied scientific research, has prepared two forecast reports. In its latest report for 2023, TNO reveals that in the Netherlands, municipalities oversee more than 80% of civil structures, encompassing all sewerage, a significant portion of roads, and approximately 45% of bridges and viaducts. Consequently, municipalities bear the largest share of the projected R&R costs, amounting to approximately 55%, while 9% is allocated to provinces, 13% to water management agencies, and 23% to RWS and ProRail (Rasker et al., 2023).

Currently, infrastructure owners have initiated the planning and bidding process for infrastructure R&R projects, encountering challenges in determining the optimal timing and selection of these works. In essence, they struggle to establish a prioritization approach for R&R works that optimally utilizes available resources and addresses stakeholder interests. This aligns with the findings of Schraven et al. (2011), who highlight in their study that the primary challenges in infrastructure asset management revolve around defining infrastructure objectives, aligning these objectives with the condition of the asset and the type of intervention required, and managing diverse stakeholders with varying interests.

1.2. Problem Statement

Infrastructure asset owners in the Netherlands are confronted with a growing volume of renovation and replacement projects, expected to continue until the year 2100 (Rasker et al., 2023). However, these owners face challenges as their financial resources and access to skilled personnel and labour are insufficient to address the demands of R&R projects promptly (Rijkswaterstaat, n.d.). This indicates that asset owners not only need to prioritize which R&R projects to undertake due to limited capacity, but also to determine the most effective prioritization approach considering stakeholder interests and infrastructure objectives (Schraven et al., 2011).

Besides this primary challenge, several factors further complicate defining a prioritization approach:

- Uncertainties surrounding the purpose and functionality of the infrastructure about evolving technologies and environmental factors (Hertogh et al., 2018; Schraven et al., 2011).
- The slow start in R&R investment in the Netherlands, which is particularly evident in municipalities. An example of this is the expenditure of municipalities in 2023, who invested only 0.53 billion euros, whereas forecasts indicate that annual expenditures until 2030 should be around 1.32 billion, with a further increase to 1.8 billion annually in the period 2031-2050 (Rasker et al., 2023).
- The narrow perspective held by asset owners in the Netherlands regarding R&R tasks. Despite the lifespan of infrastructures ranging between 60 and 80 years, forecasts often extend only up to 20 years (Hertogh & Bakker, 2016; Rasker et al., 2023). This, combined with the limited capacity of asset owners to prioritize multi-year budgets.
- Changes in administration and the obligatory integration of sustainability and local development objectives into project scopes (Di Sivo & Ladiana, 2011; Hastak & Baim, 2001; Hertogh & Bakker, 2016).

1.3. Research Gap

This research highlights a significant gap in empirical knowledge on how to prioritize infrastructure R&R work, or as Di Sivo and Ladiana (2011) puts it, how to address the multiplicity of needs in investment management and planning in R&R activities. This includes the following aspects:

- The identification of the actors and factors that play a determining role in prioritising infrastructure R&R work.
- The analysis of how these actors and factors are related and how they vary depending on the context in which they develop.
- The identification and definition of the R&R prioritization approaches currently implemented by asset owners.
- The analysis of the requirements and benefits associated with each prioritization approach.

The lack of detailed records on previously executed R&R projects, as well as the scarcity of guidelines and instructions on how to make decisions related to public assets, along with the absence of theory explaining the relationship between decision-making factors and the actors involved, makes it difficult for infrastructure owners to have a comprehensive understanding of R&R work and thus to define an effective approach for prioritizing tasks.

The results of this research are relevant for future studies in this field by presenting the current practices of infrastructure R&R in the Netherlands. In addition, it contributes to the construction industry, especially owners of local infrastructure assets, by providing practical recommendations to address the challenges in prioritizing R&R work and identifying the most effective prioritization approaches.

1.4. Research Objective

This research aims to improve the understanding of the factors and conditions that play a determining role in the choice of a prioritization approach to infrastructure R&R works. In doing so, it seeks to develop a roadmap to guide municipalities on how to effectively prioritize R&R tasks to respond to stakeholder demands and optimize the use of available resources.

1.5. Research Questions

To achieve the research goal, the following primary research question is formulated:

RQ: How can municipalities in the Netherlands effectively prioritize infrastructure renovation and replacement works to meet the demands of stakeholders and optimize resources?

Additionally, secondary research questions (SQ) are defined to gather the necessary information to address the main research question (RQ):

- **SQ 1:** What are the challenges of prioritizing infrastructure renovation and replacement works?
- **SQ 2:** What are the interests and influence of each infrastructure stakeholder on the prioritization of renovation and replacement works?
- **SQ 3:** How do infrastructure asset owners currently prioritize their renovation and replacement works?
- **SQ 4:** How can municipalities decide between different prioritization approaches for infrastructure renovation and replacement works?

1.6. Research Method

Considering that part of this research is to precisely define the problem of prioritizing infrastructure R&R works before seeking an appropriate solution, the use of the Double Diamond model is proposed. This model is particularly effective because it provides a structured approach to both problem identification and solution development. The first diamond is dedicated to understanding and defining the problem thoroughly, while the second diamond focuses on creating and refining the solution. Each diamond consists of two phases: a divergent phase that encourages broad exploration of ideas and perspectives, and a convergent phase that narrows down these ideas to focus on specific, actionable insights. This approach ensures a comprehensive and methodical process, as indicated by Gustafsson (2019), allowing for a deeper and more precise analysis before moving towards solution implementation. The following explains each phase of the model and presents a synthesis of the methodology in Figure 1.1.

I. Discover, where divergent thinking is employed to explore the available information on the topic. This includes a literature review and exploratory interviews with experts in infrastructure R&R.

II. Define, which employs convergent thinking to gather the specific missing information needed for a complete understanding of the problem, thereby narrowing the scope of the solution. In this case, this phase involves conducting semi-structured interviews within case studies.

III. Develop, characterized by divergent thinking, allows for the use of different methods and the creation of solution models. In this case, a Roadmap is developed for prioritizing infrastructure R&R tasks.

IV. Deliver, with convergent thinking, the research is discussed, and the study's conclusions and recommendations are presented.

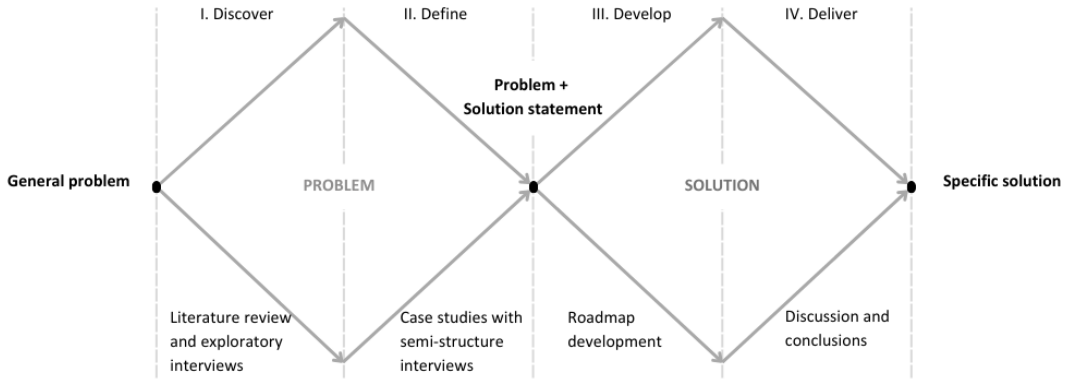

Figure 1.1: Double diamond research methodology.

The following is a description of the steps involved in each phase and how they relate to the research questions.

Phase I - Literature review and Exploratory interviews

In this initial phase, the theoretical foundations of the research are established, focusing on discovering the factors related to the problem and openness to information and inspiration (Kochanowska & Gagliardi, 2022). For this purpose, a literature review is carried out, starting with the challenges of the R&R tasks in the Netherlands, to a broader view, reaching a general picture of the infrastructure prioritization process. The literature review has the following specific objectives:

- Understand the difficulties and challenges inherent in infrastructure R&R works. This answers the SQ1 research question.
- Delve into the factors and actors involved in prioritising infrastructure R&R works. This partially answers the SQ2 research question.
- Characterize the R&R task in the Netherlands, its infrastructure assets, and its owners. This contributes to answering SQ1 and SQ2 research questions.

Once the literature is reviewed and the theoretical foundations of the R&R task prioritization process are established, it is possible to expand the research to different points of view. Therefore, exploratory interviews are subsequently conducted to complement and contrast the information collected, as well as to explore new aspects of the main topic. This type of interview offers a high degree of flexibility for both interviewers and interviewees regarding the planning, execution, and organization of questions (Gubrium & Holstein, 2002).

In this case, interview participants are selected based on their experience and knowledge in infrastructure R&R. A wide range of different types of asset owners and researchers, both at the national and regional levels, are engaged, offering diverse perspectives to the study.

At the end of the first phase, knowledge and understanding of the general process of prioritizing R&R works are achieved. Additionally, knowledge gaps that need to be investigated to achieve a specific definition of the problem are identified, which are addressed in the next phase of the research.

Phase II - Case studies with semi-structured interviews

In the second phase, the insights gained from the discovery phase are utilized to redefine the challenge of the R&R prioritization, examining all the collected data, connecting the dots, and identifying patterns (Kochanowska & Gagliardi, 2022). Information analysis is complemented by conducting semi-structured interviews framed within case studies. These are carried out in specific contexts and settings, delving in this way into the particulars of the problem.

Case studies focus on understanding the dynamics present in specific settings (Eisenhardt, 1989). Offering flexibility in its structure, allowing variations in the number of cases examined, the level of analysis undertaken, and the incorporation of diverse data collection methods such as archival research, interviews, questionnaires, and observations (Eisenhardt, 1989; Yin, 1984). Furthermore, this research methodology exhibits versatility in its objectives, encompassing activities ranging from providing detailed descriptions to testing and even generating theories (Kidder, 1982; Pinfield, 1986).

To complete the problem definition the following configuration of the case studies is proposed:

- **Objective:** Gain an in-depth understanding of how Dutch asset owners prioritize infrastructure R&R works, identifying challenges and decision-making processes. As well as, determining how different contextual settings and conditions influence the choice of a particular prioritization approach. Thus, contributing to answering the SQ3 research question.
- **Case study unit:** Dutch municipalities carrying out infrastructure R&R works.
- **Number of case studies:** Three cases, each corresponding to municipalities of different population sizes. Differentiating between metropolitan areas with populations between 500.000 and 1,5 million; medium-sized urban areas from 200.000 to 500.000; and small urban areas from 50.000 to 200.000 OECD, 2024.

The decision to have three case studies is made to facilitate a comparative study. This type of analysis is based on predicting how a system will react to perturbations in its parameters and why (Weld, 1988). Przeworski (1970) state that comparative analysis allows understanding of how a social characteristic affects the variable or relationship of interest. In this case, the social characteristic that is examined is precisely the factors that are part of the prioritization process that vary with context. Determining the effect and relationship that these particular factors have on the prioritization of R&R works.

Moreover, conducting comparative analyses not only reinforces the external validity of the research but also provides valuable insights applicable to real-world situations. This ensures that the research contributes both to academic knowledge and the development of effective prioritization approaches that accommodate contextual variations. Additionally, it generalizes the methodology, enabling extrapolation to new cases with different population densities, thereby enhancing the applicability and robustness of the findings.

On the other hand, semi-structure interviews delve into and characterize the ”nature” of human behaviour, experiences, and perceptions, offering substantial potential for hypothesis generation (Brown, 2005; DiCicco Bloom & Crabtree, 2006). Data collection through semi-structured interviews allows in-depth exploration, follow-up questions, and seeking clarification, often guided by a basic checklist to align with research objectives (Berg, 2001; Whiting, 2008). For this research, it is proposed to interview professionals in the infrastructure sector responsible for programming R&R works. Intended roles are department, project and contract managers and advisors. In this way, a rich and deep understanding of perspectives, experiences and points of view will be achieved.

It is important to acknowledge the limitations and objections associated with this data collection instrument, with a view to either mitigating them or considering their implications during data analysis. These concerns encompass the internal quality criteria of qualitative research, the potential use of vague terminology, researcher bias, and the influence of leading questions (Kvale, 1994). Addressing these concerns can involve precise definitions of terms, a comprehensive literature review to underpin interview design, and consultation with experts to discuss research findings (Kvale, 1994).

Phase III - Roadmap development

Multiple solutions are developed, explored, and refined during the third phase, fostering creativity and iterative feedback (Kochanowska & Gagliardi, 2022). Using inspiration and a new understanding of the problem from earlier phases of the research to create a decision framework. The primary aim of this roadmap is to provide structured guidance to municipalities planning R&R works. It is designed to assist these municipalities in understanding the stakeholders, factors and conditions that play a determining role in the process of prioritization of R&R works and how they relate to different prioritization approaches. As well as, establishing a clear connection between prioritization approaches and their specific benefits and the strategic objectives they support. Through the development of this roadmap, a comprehensive and systematic response to the SQ4 research question is provided.

Phase IV - Conclusions and Recommendations

The final phase involves refining the chosen solution for successful implementation (Kochanowska & Gagliardi, 2022). This phase recapitulates the research objectives, highlights and synthesizes the main findings, and discusses their relevance to both the current body of knowledge and the industry. It reflects on the implications and limitations of the study. Based on these findings, it offers practical advice for future research, suggests applications of the results, recommends changes in practice, and proposes improvements in the methodologies used. This chapter ensures that the thesis not only demonstrates what has been discovered but also how these findings can be used or expanded in future work.

1.7. Thesis Outline

Figure 1.2 provides an overview of the thesis chapters, distinguishing the four research phases and illustrating their relationship with the research questions.

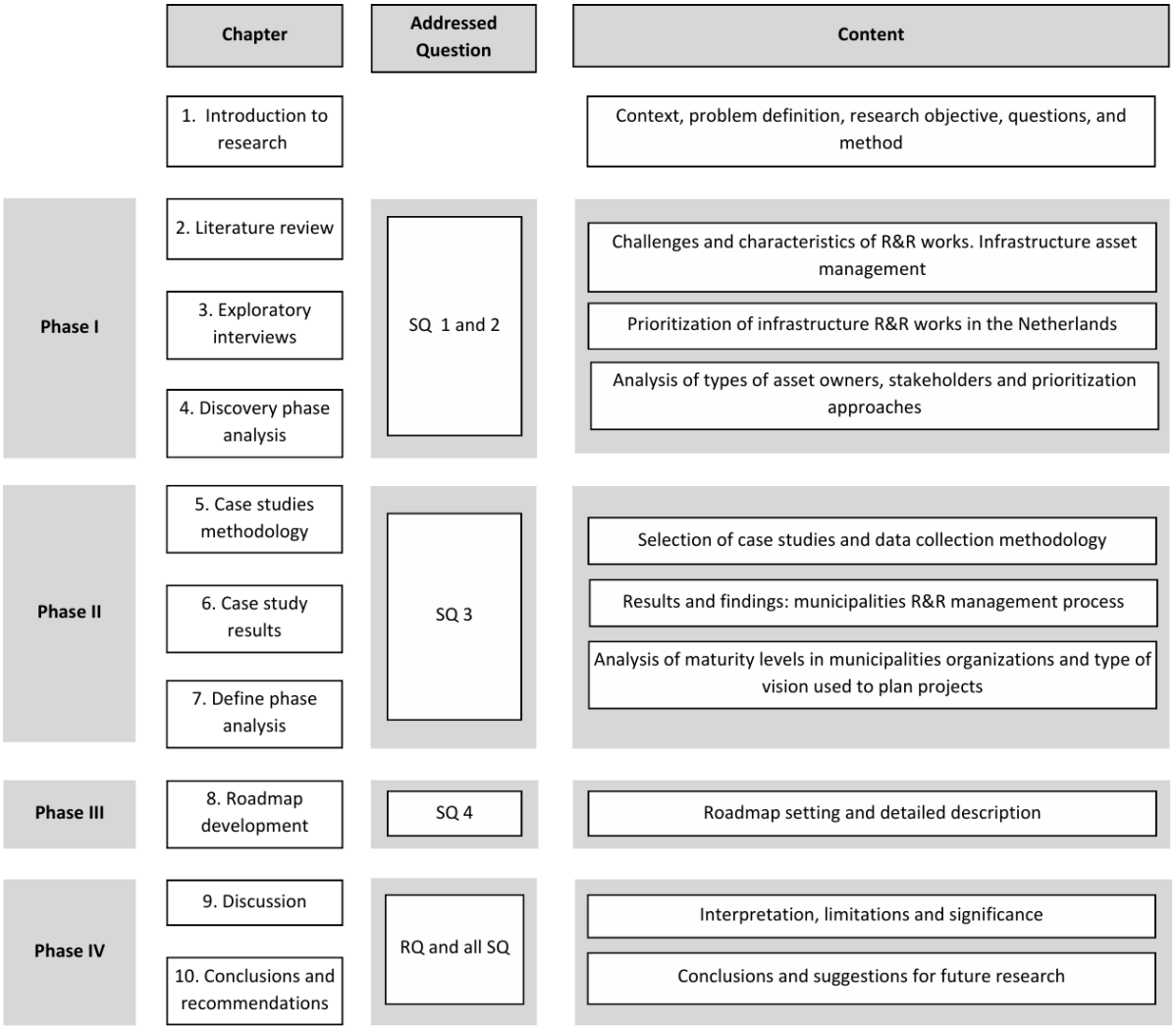

Figure 1.2: Thesis Outline diagram.

I

Discovery Phase

2

Literature Review

This chapter is divided into four sections that aim to address SQ 1: What are the challenges of prioritizing infrastructure renovation and replacement works?, and establish the foundation to answer SQ 2: What are the interests and influence of each infrastructure stakeholder on the prioritization of renovation and replacement works?

First, Section 2.1 provides a brief overview of the R&R task in the Netherlands. Second, in Section 2.2, the challenges of infrastructure R&R are identified, and related subjects are described. Third, Section 2.3 defines and explains the broader concept that encompasses all the factors and establishes a procedural order for them, corresponding to Infrastructure Asset Management. Finally, in Section 2.4, a theoretical framework is presented, illustrating the findings of the chapter.

2.1. Infrastructure R&R task in the Netherlands

After World War II, many European countries had to rebuild their infrastructures in an era of rapid population growth and increasing demand for services (Bleijenberg, 2021; Hertogh et al., 2018). In the case of the Netherlands, and according to Rasker et al. (2023), most of the post-war infrastructure was delivered between the 1960s and 1980s, implying that in the coming years, many civil assets will reach their lifespan. This considers the variation of the typical technical lifespan of each asset type (see Table 2.1).

Asset	Typical lifespan (years)			
	General	Concrete	Steel	Wood
Sewage	30-100			
Fixed bridges and viaducts	60-100	80-100	75	40
Movable bridges	60-80			40
Roads	40			
Culverts		80-100	70	
Tunnels	100			
Jetties	20-50			
Weirs		100	80-100	40

Table 2.1: Typical technical lifespan of infrastructure. Retrieved from Rasker et al. (2023).

Civil infrastructure in the Netherlands is managed by around 400 asset owners, with five distinct types located at different levels of authority: at the national level, Rijkswaterstaat and ProRail; at the regional level, provinces and water authorities; and at the local level, municipalities. Among all Dutch asset owners, municipalities undertake 80% of R&R works. Figure 2.1 shows the distribution of ownership of municipalities in relation to the rest of asset owners for the different types of infrastructure. It is important to note from the figure that municipalities manage the majority of the sewerage network and a significant share of roads, followed by jetties (Rasker et al., 2023).

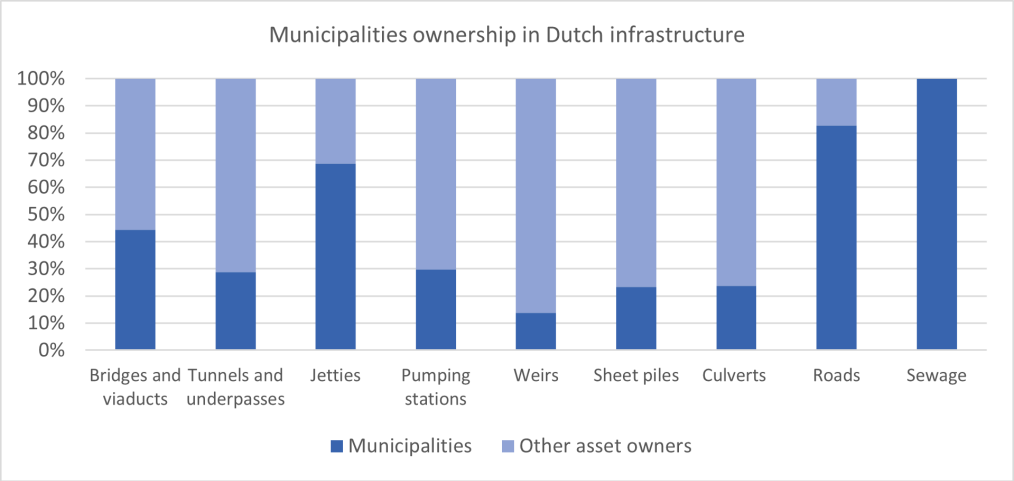

Figure 2.1: Percentage of municipalities owner in Dutch infrastructure. Based on Rasker et al. (2023).

Figure 2.2 shows the projected investment in R&R works between 2021 and 2100, differentiating between three categories of infrastructure: sewerage, road foundations and civil constructions. The latter refers to bridges, viaducts, culverts, jetties and weirs. The figure reveals a significant and steady increase in budget requirements from 2021 to 2050. In particular, variations in these numbers are mainly due to the demand for renewal projects within civil constructions. While funding for road maintenance remains stable over the years, fluctuations in sewerage investments are minimal, mainly concentrated in the 2030s and 2070s.

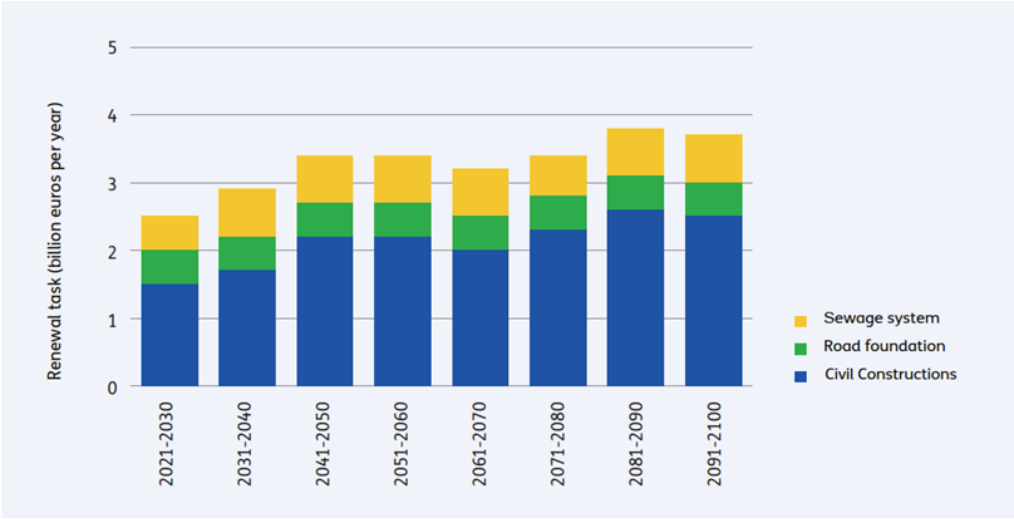

Figure 2.2: Forecast of Dutch renewal costs. Retrieved from Rasker et al. (2023).

Consequently, municipalities bear 55% of the expected R&R costs, i.e. about €147 billion of the estimated total €260 billion until 2100, while 9% is allocated to the provinces, 13% to the water management agencies and 23% to the national administrator RWS and ProRail (Rasker et al., 2023). Moreover, 84% of the municipalities' R&R investment is concentrated in four infrastructure types, as can be seen in Figure 2.3, which are: sewage (35%), bridges and viaducts (27%), and roads (22%).

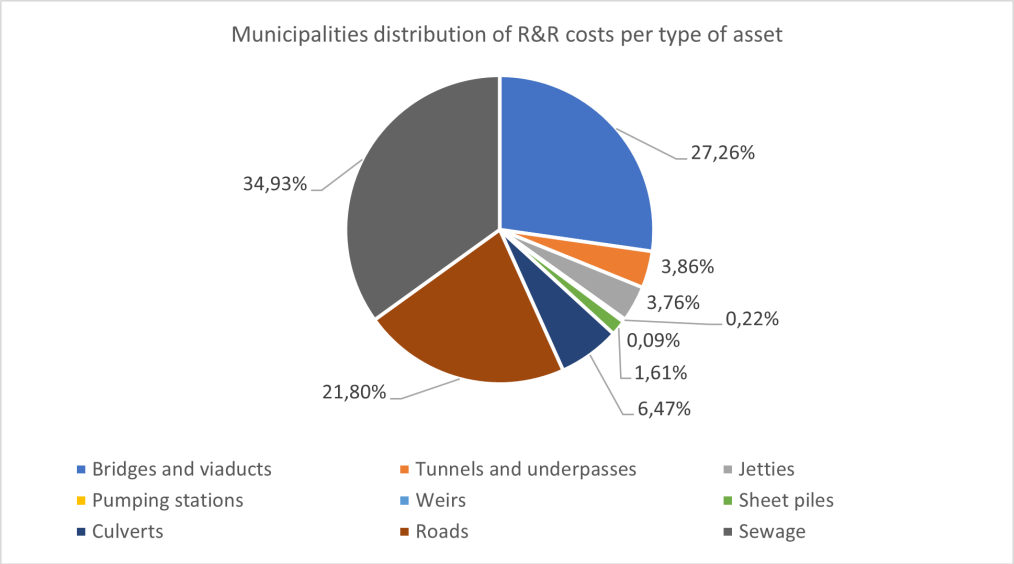

Figure 2.3: Municipalities distribution of R&R costs per type of asset. Based on Rasker et al. (2023).

Now that the R&R task in the Netherlands has been described and quantified, the next step is to define and explore it in theoretical terms. This involves uncovering the underlying theories and concepts that shape its development and explain its broader significance.

2.2. Infrastructure R&R challenges

Asset owners face many difficult decisions regarding how and when to cost-effectively repair their existing building stock, as little is known about managing public infrastructure, and there are only a few tools to assist decision-making (Schraven et al., 2011; Vanier, 2001). From the literature review, four main challenges that public agencies face when planning and programming infrastructure R&R works are identified, which are mentioned below.

- **Defining objectives:** implies the interpretation of policies, norms, and strategic goals to define the asset objectives and benefits, which provide the rationale for the evaluation of the asset condition and performance, and the prioritization of R&R activities (Dekker, 1996; Schraven et al., 2011; E. Too, 2012).
- **Managing multiple actors:** multiple stakeholders are involved in and affected by asset management decisions; therefore, their needs and expectations must be considered.(Dekker, 1996; Schraven et al., 2011).
- **Assessment of infrastructure:** knowledge about the asset's technical and functional performance is hardly possible due to poor monitoring systems and precarious information management (Foundation, 1996; Pathirana et al., 2021; Vanier, 2001). Additionally, efficient condition assessment is hampered by subjectivity, which leads to inaccuracy (Singh Ahluwalia, 2008).
- **Aligning decision areas:** involves balancing resource availability, infrastructure objectives, and the current technical and functional condition of assets when planning maintenance, renovation, or replacement activities (Schraven et al., 2011; E. G. Too, 2010). Asset owners must anticipate and adapt to contextual changes such as funding shifts, regulatory updates, and technological advancements. They also need to avoid premature convergence on solutions, ensuring a thorough evaluation of all possible options to meet strategic goals effectively (Hertogh et al., 2018).

These challenges impact society by exacerbating health and safety risks, diminishing economic competitiveness, depreciating built assets, and necessitating increased funding to uphold the built environment.(Vanier, 2001). Therefore, it is pertinent to broaden the literature review in each of these subjects to gain a deeper understanding of their characteristics and functionalities.

2.2.1. Infrastructure objectives

Infrastructure objectives are specific statements that enable quantifiable progress monitoring (Neumann & Markow, 2004; Weninger-Vycudil et al., 2015). These derive from explicit policy goals. In the field of infrastructure, scholars have pinpointed various key objectives that capture what is commonly desirable for the assets. Most of these align closely with the six objectives identified by Schraven et al. (2011), namely:

- **(1)** Safety, which is recognized as the most critical priority within infrastructure systems, emphasizing the reduction of accident risks (Leffers et al., 2022; Weninger-Vycudil et al., 2015);
- **(2)** Availability, this focuses on ensuring that the system is accessible and functional, aiming to minimize any disturbances (Leffers et al., 2022; Shami, 2004);
- **(3)** Convenience, and **(4)** Appearance, that refers to users satisfaction, perception and acceptance (Dekker, 1996);
- **(5)** Quality of life is about natural, cultural, and historic resource conservation and community character (Thekdi & Lambert, 2014); and
- **(6)** Environment, which focuses on minimizing negative impacts and damage on the natural environment (Zandvoort & van der Vlist, 2020).

2.2.2. Infrastructure stakeholders

Since infrastructure projects are large-scale and have a significant impact on society, they attract the interest of various stakeholders who can be classified as asset owners, operators, managers, and users (Parlikad & Jafari, 2016). The literature identifies the following groups as key stakeholders in infrastructure projects: asset owners, consulting and engineering firms, the construction industry, operational staff, suppliers, politicians, citizens, landowners, market parties, and non-governmental organizations (NGOs) (Vuorinen & Martinsuo, 2019).

As noted in the previous list and described by Lienert et al. (2013), stakeholders in infrastructure projects have diverse interests—economic, technical, environmental, and social. They also differ in their roles, levels of authority (ranging from local to national), and expectations (Pandi-Perumal et al., 2015). This highlights that meeting the requirements and expectations of infrastructure stakeholders is one of the greatest challenges in infrastructure management (Parlikad & Jafari, 2016). Besides their varied interests, stakeholders differ in their power and influence over achieving desired project outcomes (Pfeffer & Salancik, 2015). Aaltonen et al. (2015) explain that stakeholder power is derived from their ability to provide or withhold material, financial, symbolic, or physical resources, thus setting the project's **boundary conditions**.

Regarding the analysis of stakeholders Brugha and Varvasovszky (2000) discuss its growing importance, emphasizing that the unique characteristics of these individuals, groups, and organizations are context- and project-specific. Therefore, stakeholder analysis must be conducted and monitored continuously. The most commonly used tool for this analysis is the Mendelow (1991) matrix, enhanced by Scholes et al. (2001). This matrix classifies stakeholders based on the resources they control, their interests in the project's activities and outcomes, and their significance for various interventions.

2.2.3. Infrastructure condition

Regarding the 'end of life' of an ageing asset Hertogh et al. (2018) highlights that this is a decision, not a technical fact unless an object has completely collapsed and cannot be repaired. This is why determining whether an asset has reached its lifespan requires an assessment of the condition of the infrastructure. Concerning how to make this assessment, the authors state that in practice a replacement decision is made when repair costs are too high compared to a replacement or when performance is insufficient. They distinguish three types of lifespan. The **technical lifespan** ends due to degradation. The **economic lifespan** ends once maintenance and renovation become too costly and replacement is financially preferable. And, the **functional lifespan** ends because of changes in external influencing factors. Examples of this are changing loads, changes in political mandates, climate change, and technology innovations.

Currently, as noted by Kuijper and Bezemer (2016), infrastructure condition assessments in the Netherlands rely on the NEN 2767 standard. This standard is extensively used for buildings and is increasingly being applied to bridges, tunnels, and viaducts. It aims to objectively determine system conditions by clearly documenting defects and technical status. Additionally, the international ISO 55000 standard is also employed to complement these evaluations.

2.2.4. Infrastructure and the context

There exists a significant interdependence between infrastructure and the context. The context is dynamic, constantly evolving, and susceptible to both predictable and abrupt changes. It delineates two fundamental aspects of infrastructure that must be determined and aligned:

- **Resources:** This encompasses the availability of financial capital, time, raw materials, and people, referring to both manpower and personnel proficient in technical and managerial aspects of infrastructure. Therefore, the specific resources of the context establish the **boundary conditions** for projects, determining feasibility, scope, and timelines (Schraven et al., 2011).
- **Demands:** These reflect the diverse interests of stakeholders, ranging from utility and capacity requirements of the infrastructure to alignment with emerging technologies and transitions, as well as its impact on the physical, natural, and social environments. Therefore, stakeholder demands shape the functionality and **objectives of infrastructure**, determining the value to be delivered (Vuorinen & Martinsuo, 2019).

In response to the challenges and complexities faced by infrastructure managers, Infrastructure Asset Management (IAM) has emerged. Pathirana et al. (2021) describes IAM as the decision-making and resource allocation process aimed at ensuring that the performance of assets complies with the required standards. IAM includes a series of steps in which all relevant elements and factors for infrastructure management are defined, thereby establishing a hierarchy and the interdependencies between them.

2.3. Infrastructure Asset Management

In the public infrastructure sector, asset management has emerged with the promise of achieving more value, with fewer resources, i.e. optimizing system performance within budgetary constraints (Li & Sinha, 2009; Moon et al., 2009). According to Valencia et al. (2011), Infrastructure Asset Management is a holistic assessment that uses a life-cycle approach based on quality data to optimally manage infrastructure at the lowest cost to stakeholders. Similarly, E. G. Too (2010) defines IAM as a strategic and systematic process of optimizing resource allocation decision-making to align an infrastructure asset with corporate objectives throughout its lifecycle.

The above definitions expose the procedural and iterative nature of IAM, which can be viewed as a cycle for decision-making, optimization of resources and fulfilment of objectives. To understand the key stages of the IAM process, a brief description of each is presented below according to Neumann and Markow (2004), E. G. Too (2010), and Wijnia and de Croon (2016):

1. **Policy and strategy development:** Establishing the overall policies and strategies for asset management that align with organizational ambitions and regulatory requirements. This involves setting out the vision, objectives and principles of IAM (Neumann & Markow, 2004).
2. **Quality level definition:** Refers to the categories with which the fulfilment of infrastructure objectives/criteria is classified. In other words, the level at which the asset meets quality standards, organizational objectives and citizens' expectations (Neumann & Markow, 2004).
3. **Inventory and condition assessment:** Accurate and complete on-site data, reflecting the nature and conditions of infrastructure assets, which typically includes construction records, as-built data and inspection formularies (Gordon et al., 2011; Singh Ahluwalia, 2008; Yuan et al., 2016).
4. **Criticality and Risk assessment:** Identifying asset criticality about the quality levels and assessing risks associated with asset failure. Describes and compares infrastructure vulnerability, resilience, and potential risks (Eidsvig et al., 2017; Thomas, n.d.).

5. **Life cycle costing and Financial planning:**Estimating the whole-life costs of assets, including acquisition, operation, maintenance, and disposal costs (Swarr et al., 2011). Financial planning ensures that sufficient resources are allocated for IAM over the assets' life cycle (Ilg et al., 2017).
6. **Maintenance and Renewal planning:** Developing plans for routine maintenance, renovation, and replacement activities based on the condition assessment, risk assessment, and life cycle cost analysis (E. G. Too, 2012).
7. **Implementation and execution:** Carrying out the planned maintenance, rehabilitation, and replacement activities. Effective implementation requires coordination, resource allocation, and adherence to schedules and budgets (E. G. Too, 2010).
8. **Performance monitoring and review:** Continuously monitoring asset performance against defined service levels and objectives. This stage involves collecting data on asset condition, performance, and maintenance activities to inform decision-making (Maser, 1996).
9. **Continuous improvement:** Using performance data and feedback to refine asset management policies, strategies, and practices. Continuous improvement aims to enhance efficiency, reduce costs, and improve service delivery over time (E. G. Too, 2010; Zehir et al., 2006).

Within this broad spectrum of asset management, infrastructure maintenance, renovation and replacement represent a crucial part of the cycle (sixth step). About these three tasks Schraven et al. (2011) provide an overview, stating that routine maintenance includes short-term maintenance work (less than one year), which can be both corrective and preventive, and primarily aims at maintaining the performance of the asset. Renovation projects are planned and carried out in a medium-term period (one to five years), while replacement projects have a long-term orientation (more than five years).

Unlike routine maintenance, R&R works highlight the strategic aspect of assets, addressing long-term goals and adding value to asset owners and other stakeholders. It provides users with enhanced functionalities, opens new business opportunities for enterprises, increases livability for citizens, and contributes to societal issues such as sustainability (Hertogh et al., 2018; E. G. Too, 2012).

2.4. Theoretical framework

From the literature review, a theoretical framework for the research was developed, which is presented below in Figure 2.4. This framework summarizes the findings of the literature review, showing all the preceding actions involved in decision-making for the programming of R&R activities and their associated challenges. Likewise, it illustrates the type of relationship and linkage that infrastructure maintains with stakeholders, objectives, and the context.

The framework points out with red arrows the challenges defined earlier in this chapter. Showing that for the organization managing infrastructure assets, managing the different stakeholders, assessing the technical condition and performance of the infrastructure, and formulating infrastructure objectives are challenges. In addition, the organization is also responsible for managing the contextual boundaries within which it is framed. That is, it must manage the financial, human and time resources available.

The intervention box refers to the decision about the type of work to be carried out, which depends on stakeholders, the current condition of the asset, the objectives defined for that asset, and the resources available to the organization to carry out the intervention. With all elements of the framework taken into account, a fourth challenge emerges: aligning decisions regarding infrastructure situation, objectives, and interventions. This is depicted in the diagram as a red circle.

Finally, when the intervention has been completed, it implies a change in the condition of the asset, which will consequently be monitored regarding the objectives it must fulfil and which serve as input for the periodic evaluation of the infrastructure situation.

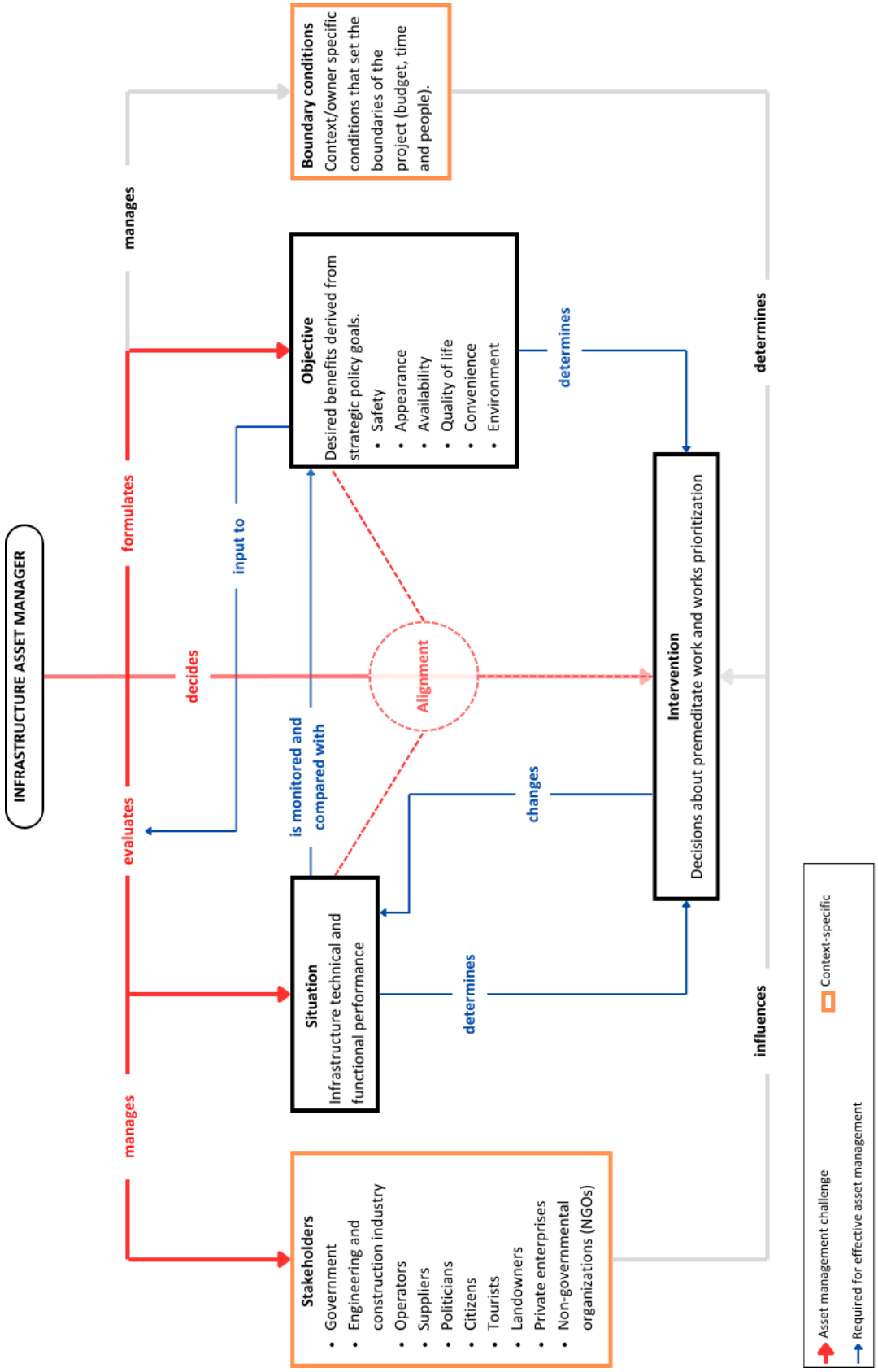

Figure 2.4: Theoretical framework: Infrastructure R&R cycle, decisions and challenges. Based on Neumann and Markow (2004) and Schraven et al. (2011).

3

Exploratory Interviews

This chapter aims to enrich and complement the findings of the literature review through exploratory interviews. These interviews served to: discover additional subjects relevant to the study, complement the theoretical framework with practical information, and understand the perspective of asset owners and contractors on infrastructure R&R works.

The chapter is divided into three sections as follows: Section 3.1 explains the procedure for conducting the exploratory interviews. Section 3.2 presents the results of the interviews, which serve as proof of evidence for Section 3.3, in which the findings are described. This last section contains the theoretical framework of the research, which shows how the elements identified as part of the infrastructure R&R planning and programming process are related.

3.1. Interview procedure

Six exploratory interviews were conducted, each lasting approximately one hour. A simple format was used, consisting mainly of three parts.

1. **Introduction:** Both parties introduced themselves, providing an overview of their relationship and experience with infrastructure R&R works.
2. **Discussion of Practices:** The interviewee described how infrastructure R&R is carried out within their organization. During this part, the interviewer asked questions to clarify and explore key topics and concepts mentioned.
3. **Discussion of the Theoretical Framework:** The theoretical framework for infrastructure R&R planning and programming was discussed.

Sampling of Interviewees

Table 3.1 summarizes the [coded] interviewees, detailing their affiliated organizations and roles in infrastructure R&R. The participants offer multiple perspectives, representing infrastructure owners at both national (RWS) and regional (Province of Zeeland) levels, alongside insights from a consulting and engineering firm (Witteveen+Bos). Roles vary from managers and leaders to advisors. This diversity enriches the research by providing a broad spectrum of insights and experiences, contributing to a comprehensive understanding of the infrastructure R&R challenge.

Code	Organization	Role	Date of interview
EI1	Witteveen+Bos	Theme leader	06/03/2024
EI2	Province of Zeeland	Quartermaster	15/03/2024
EI3	RWS	Program Manager	18/03/2024
EI4	RWS	Hydraulic Engineering Advisor	18/03/2024
EI5	Witteveen+Bos	Department head	29/03/2024
EI6	TNO	Theme leader	03/04/2024

Table 3.1: Exploratory Interview sampling.

3.2. Interview results

3.2.1. Discussion of Practices

It was decided to present the interview results in four thematic groups to facilitate understanding. These groups correspond to different aspects and elements of the infrastructure R&R planning and programming process, which were previously identified in the Literature Review. Providing in this way continuity to the research and complementing the initial findings.

The categories included are: Situation Assessment, Boundaries and Challenges, Needs, and Intervention Decision. Figure 3.1 illustrates, using different shapes, how each thematic area corresponds to different natures: rectangles represent processes that lead to decision-making, the circle can be understood as a filter or gateway, and the diamond shape demonstrates the abstract nature of the category of needs. Although the needs category is not associated with any specific activity, it can influence decisions regarding the type of intervention to be carried out.

Figure 3.1 shows how the diagnosis of the infrastructure situation before becoming a decision about the type of intervention must first be contrasted with the organization's specific constraints and challenges, a process in which the industry has identified several needs.

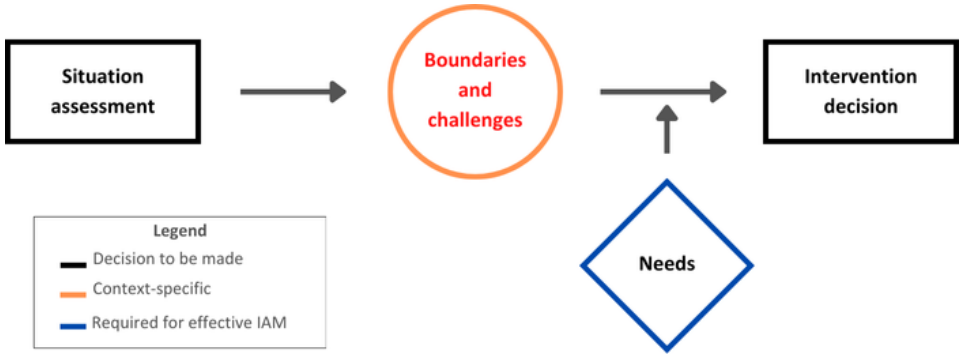

Figure 3.1: Categories of exploratory interview findings.

The results of the interviews for each topic area are presented below. The analysis of them is given in the following chapter.

Situation assessment

Below are the key activities participants identified as integral to the assessment of infrastructure:

- Identifying the owner of each asset within a specified area [EI2].
- Determining information availability (blueprints, calculation sheets, and inspection reports) [EI2].
- Conducting infrastructure inspections and sampling for laboratory studies when necessary in order to ascertain the type of damage present in the asset [EI5].
- Determining the end of the infrastructure's lifespan based on its technical and functional condition [EI3], [EI4], and therefore determining the remaining lifespan of each asset [EI2].
- Classifying assets into groups based on their lifespan and the type of problem, whether technical due to failure or regulatory changes, or functional [EI2].

It should be noted that asset owners agreed that, during the initial stage, neither the time nor all the information needed to plan R&R projects with a detailed scope is available. In this scenario, it is preferable for them to initiate projects and make adjustments as they go along; otherwise, planning could drag on for years [EI2], [EI3], [EI4], [EI6].

Regarding the impossibility of obtaining all the information from the asset, the interviewees explained that in some cases visual inspections and sampling are not possible or are very complicated to perform, either because the structure is buried or the component to be evaluated involves the suspension of service or demolition of part of the structure [EI2], [EI3], [EI4].

Boundaries and challenges

In this category, factors and situations highlighted by participants as constraints in the planning, programming, and execution of infrastructure R&R projects are encompassed:

- There exists limited technical knowledge and experience regarding reengineering, specifically concerning the redesign of existing assets [EI3], [EI4].
- Numerous uncertainties about the future purpose and functionality of assets, related to the adoption of emerging technologies and shifts in user demands. This challenge is compounded by the fact that redesigns are typically planned for periods spanning 80 to 100 years [EI3], [EI4].
- There is a significant shortage of labor and lack of construction materials [EI3], [EI4], [EI6].
- The interests and ambitions associated with infrastructure vary at every level of planning from policy to specific requirements, thus defining the desired improvements and which stakeholder will benefit the most is a challenge [EI6].
- Generally asset owners have an idea of the work to be done but not a deep understanding of the urgency and importance of the tasks to be performed [EI6].
- There is a great variety in the type of assets and owners, in terms of their size, level and complexity, so although the infrastructure R&R challenge is countrywide, it has a decentralized nature that makes cooperation between organizations difficult [EI6].
- Planning processes in small organizations (asset owner) have simple organizational structures and have most decisions made by one person, which becomes a boundary condition (human capital) for performing R&R work [EI2], [EI6]. In addition, it is common in these organizations to have an overall budget that covers both routine maintenance activities and infrastructure R&R, which complicates resource allocation and fundraising [EI2].
- In large organizations (asset owner) with broad organizational structures, there is usually a separate budget for R&R work and multiple roles and people are involved in decision making, increasing the number of interfaces in the process, which in turn increases the complexity of coordinating R&R tasks [EI2], [EI6].
- Political preferences and influence can hinder R&R projects since, on the one hand, politicians are often risk averse and tend to delay investments until the last minute. On the other hand, their academic background is usually oriented to the economic aspect of the projects and not the technical one, so prioritizing technical aspects over economic ones is a challenge [EI2].
- Given that infrastructures are integral parts of larger systems, often interconnected with other networks at the national level, conflicts may arise with concurrent renovation works in other regions and under different ownerships [EI2] [EI5], [EI6].

Intervention decision

From the interviews, various criteria, and rationales for prioritizing infrastructure R&R tasks were identified. Listed below are each of them, without adhering to any particular order:

- Evaluation is conducted to determine if the **asset meets technical and performance requirements** [EI2]. Safety takes precedence in infrastructure assessment, followed by availability. Another criterion included is reliability [EI3], [EI4]. An illustrative example of how these criteria influence decision-making is demonstrated in the case of roads. When there is not sufficient funding for R&R works and there is a safety risk, the agency may opt to limit traffic on the road, restricting the number of vehicles that can pass through, thus sacrificing availability but ensuring safety [EI3], [EI4].
- Based on the information on the remaining lifespan of the assets, an **assessment of the risk of failure** and its impact is carried out to determine which assets should be addressed first. Several categories are considered in the risk/impact assessment, as users and environment [EI5].
- In cases where insufficient information is available about the technical condition of the asset, the risk is considered unacceptable due to the **high uncertainty** associated with it, which leads the owner to prioritize the R&R of these infrastructures. The less is known about the risk of failure, the more urgent is considered [EI2], [EI3], [EI4].

- The prioritization of works takes into account the **importance of the infrastructure**, referring to its influence on societal well-being, economic development, and cultural significance [EI3], [EI4].
- At times, the R&R of certain infrastructures is prioritized based on **political promises** during campaigns to the public [EI2].
- In prioritizing R&R works, the "**corridor thinking**" approach is employed. This involves identifying projects in the area of the asset to be renovated that are planned for the next 10 years, with the aim of scheduling all projects in this area together [EI1], [EI2], [EI3], [EI4]. This approach minimizes inconvenience to citizens and can also yield cost benefits [EI2].
- Taking into account the end of the lifespan of the assets and the **available capacity** in the agency and in the market to carry out R&R projects, priority is given to assets that will reach the end of their lifespan within the peak of works (between 2040 and 2060), which cannot be postponed until the end of the peak, i.e. by the time there is sufficient capacity to carry them out. In this sense, the R&R of these infrastructures is accelerated following the motto "Never late but we can be early", prioritizing the value of the infrastructure over its cost [EI2].
- The completion of relatively simple and standard infrastructure R&R across the country is prioritized to carry out a **collective renovation** with several infrastructure owners, grouping them under a single contract using a portfolio approach [EI2].

It can be observed from the previous points that interviewees mentioned more than one method or approach for task prioritization. This indicates that the programming process takes into account multiple interests and criteria. The order in which these are implemented for decision-making varies among infrastructure owners and even by type of infrastructure. This is the case for assets that are considered unique and of great socioeconomic and cultural importance.

Needs

During the interviews, it became evident that each participant held insights into what is essential for the more effective execution of R&R tasks, with many emphasizing strategic considerations.

- A fundamental change in budgetary thinking is needed, recognizing that the real constraints lie in personnel and time. Therefore, it is not justified to invest a lot of time or trained personnel in solving problems that could be solved with a slightly higher economic investment. In many cases, these additional investments are minimal compared to the overall project cost [EI2].
- Creating an environment conducive to innovation requires flexibility to make changes and tolerate mistakes. Support and assurance from managers and leaders are imperative [EI2].
- A mindset transformation among asset owners is crucial, emphasizing a long-term vision and fostering trust in contractors. This entails tendering projects with long term timelines and substantial volumes, enabling contractors to invest in innovation [EI1].
- Collaboration among asset owners is essential to overcome the constraints of time, personnel, and finances [EI1].
- Create joint theoretical and knowledge bases that allow the adoption of a common language regarding infrastructure R&R, helping to bridge the gap between asset owners and also with other stakeholders [EI6].

3.2.2. Discussion of the Theoretical Framework

In discussing with interviewees the decision-making process for R&R work based on the theoretical framework of the research (Figure 2.4), the following ideas and understandings emerge to complement the framework. Making it representative of the processes that are carried out in practice.

- A distinction should be made between the planning and programming phases. Although planning serves as an input for programming, it does not necessarily guarantee that all planned activities will be translated into R&R programming [EI3], [EI4]. Likewise, planning can be understood at different levels, in this case the strategic level, which refers to the long-term vision and policies, and the tactical level, which refers to the medium term and is related to information and budget management [EI5].

- In boundary conditions, there should be a distinction made between the availability of personnel, whether experts or labor [EI1], [EI2], [EI3], [EI4]. Also, take into account the market capacity [EI3], [EI4].
- Include the phases of the infrastructure management cycle for R&R [EI2], [EI3], [EI4].
- Boundary conditions act as a filter to determine the interventions to be carried out, and these are found in another phase of the process [EI3], [EI4].
- Infrastructure objectives can also include reliability [EI3], [EI4].

Finally, the theoretical framework was modified according to the results of the interviews, the latest version is explained and shown in the Subsection 3.3.2 and Figure 3.3.

3.3. Interview findings

This section is divided into two parts. The first part interprets the results of the thematic area 'Intervention,' as this is the only category where no information was found in the literature, thus it is considered a finding of the research. The second part presents the theoretical framework of the research, which includes all the elements identified in the Literature Review, and shows how each of these elements contributes to the intervention decision based on both theory and the experience of experts currently working on the R&R task.

3.3.1. Intervention: Prioritization Approaches

Both the literature review and the interviews have facilitated a comprehensive understanding of the key preliminary activities for prioritizing infrastructure R&R works. These, as described in Chapter 2, are: Defining infrastructure objectives, determining the technical and functional condition of the asset, and identifying the boundary conditions for project execution. As a result of the evaluation and negotiation among these three aspects, a decision regarding intervention and how the works will be prioritized is made. Considering that each infrastructure owner decides their own methodologies and criteria to prioritize R&R works, five different approaches were identified from the exploratory interviews. These are related to the theoretical basis found in the literature review.

Asset driven approach: Types of infrastructure lifespan

In this case, prioritization of work is done by determining which types of assets require R&R work with greater urgency, either because the asset has reached its technical or functional lifespan, following the definition of lifespan types proposed by Hertogh et al. (2018) and described previously in the literature review. This approach ensures safety, availability and convenience of the infrastructure.

Within this category also falls the case where the infrastructure owner lacks sufficient information to determine the asset's technical condition, and therefore, the associated uncertainty and risk are unacceptable. As a consequence, the R&R of these assets is prioritized.

Importance driven approach: Economic and political relevance

This is the approach that prioritizes unique assets, those that stand out for their importance in the economic development of the nation/region, that have high cultural and/or historical value, which are considered emblematic. Another case is that of assets that have been promised for renewal within political campaigns, so their prioritization is based on fulfilling commitments made to society, thus maintaining credibility and trust in leaders.

Area oriented approach: Corridor thinking

This approach consists of prioritizing all R&R projects located in the same area, thereby minimizing disruptions and disturbances. In practical terms, it usually works as follows:

- Once it has been determined that an infrastructure asset needs to be renewed, the next step is to identify all assets in that area that also require R&R work.
- Owners of these assets are identified along with the year for which the work is scheduled.

- Finally, all assets that require R&R in the next 10 years are grouped and programmed together to minimize disruptions and disturbances for residents.

Capacity driven approach: Flattening the R&R curve

This refers to programming works based on comparing the total required R&R tasks with the owner's capacity for these tasks. In this sense, this prioritization approach uses a long-term vision that aims to ensure the value of the infrastructure and safety.

In practical terms, it works as follows:

- During the planning phase, assets are characterized, and as part of the technical evaluation of the infrastructure, the year or period in which the asset reaches the end of its lifespan is defined. With this information a graph of work over time is created. Providing an overview of what needs to be done. This graph typically shows a peak of work in a specific period. For example, in the case of the Netherlands, the highest volume of R&R activities is from the year 2040 to approximately 2060, as can be seen in Figure 3.2.
- Simultaneously, the owner's budget and personnel resources, as well as the market's capacity to perform R&R tasks, are evaluated. Thus determining the boundary conditions to carry out projects.
- Then, by comparing the tasks with the boundary conditions (in the Figure called "Capacity limit"), the number of tasks that need to be either advanced or postponed is identified (hereafter referred to as delta of works), aiming to have a flat and stable line of works over time instead of a peak. This is achieved by renewing assets before their lifespan is reached, or by applying provisional measures or carrying out partial work to extend the asset's lifespan.

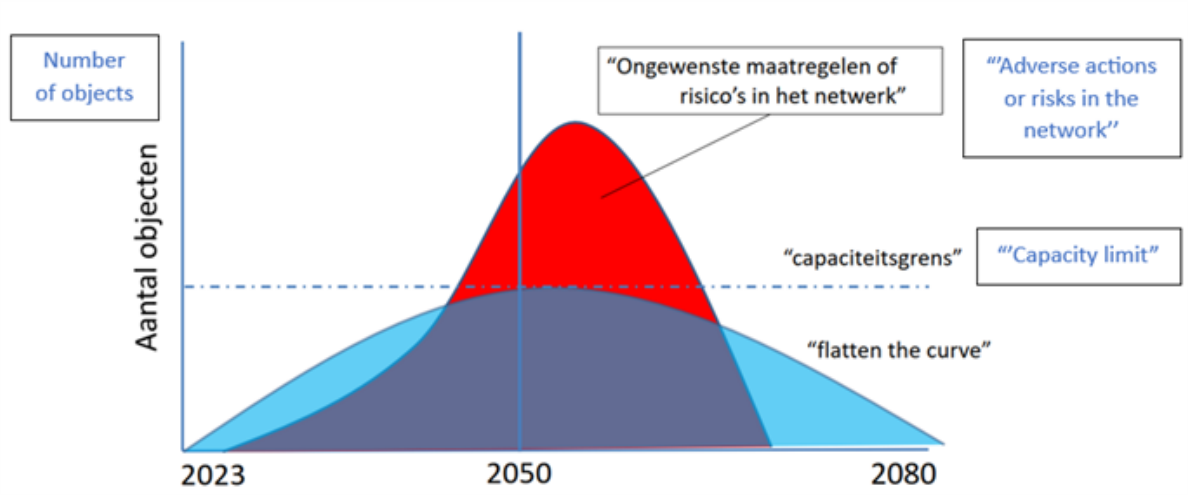

Figure 3.2: R&R works from 2030 to 2080. Retrieved from Province of Zeeland.

Collaboration driven approach: Contractual Portfolio Approach

This approach prioritizes certain types of infrastructure that, while requiring R&R, may not necessarily be urgent but rather should meet the condition that several owners coincide in having considerable amounts of this asset, and that these are very similar to each other in technical terms. In this way, bidding their R&R in a single contract becomes convenient. For this purpose, several asset owners come together and create a portfolio project, in which multiple assets/activities of the same kind are bundled. Achieving greater efficiency in the work, reducing timeframes and costs. Additionally, this approach is particularly appealing to engineering firms and contractors because portfolio contracts are developed over long periods, providing financial security to the company and the opportunity to invest in innovation.

3.3.2. Theoretical Framework: Infrastructure R&R Management Cycle

The theoretical framework in Figure 3.3 is a summary of the findings of the literature review on infrastructure R&R, showing how the various concepts in which this activity is inscribed interact with each other. It also takes into account the practical perspectives of experts working in the field. In other words, the framework is a visual tool that compiles all the study's information and findings on infrastructure prioritization up to this point. It shows the flow of information and the sequence of decisions, without accounting for specific particularities and context variations that might alter the framework.

The Infrastructure Asset Manager understood as the organization in charge, is located at the top of the chart. Three planning phases are distinguished in horizontal gray bands: at the top level is the strategic phase, which has a long-term vision of objectives and goals, defining what is desired for the network/infrastructure. In the middle is the tactical planning phase, which has a medium-term vision, evaluating and determining what is available for the implementation of strategies. This includes both the asset/network and the extent to which it achieves the proposed objectives, as well as the resources available to carry out works. Finally, the bottom band corresponds to programming, where the scope of specific tasks and the order in which they will be carried out are defined.

Focusing on the boxes, those with black borders refer to the three main decisions that must be made as a result of each planning phase, while boxes with orange borders contain the actors/factors specific to that phase, characterized by being defined in relation to their context. For example, in strategic planning, infrastructure objectives are defined/derived from policies and the interests of different stakeholders. Considering that although in most cases all parties named in the chart are part of the analysis, their level of influence and the type of interests vary considerably depending on the type of infrastructure/network being planned and the level at which it primarily operates, which can be national, regional, or local.

Finally, the chart can be fully understood by looking at the relationships and types of interactions that all these components have with each other. Arrows indicate the flow direction of the process. Red arrows indicate connections defined as challenges in the literature, while blue ones characterize those required to achieve effective infrastructure asset management. Gray arrows represent neutral connections.

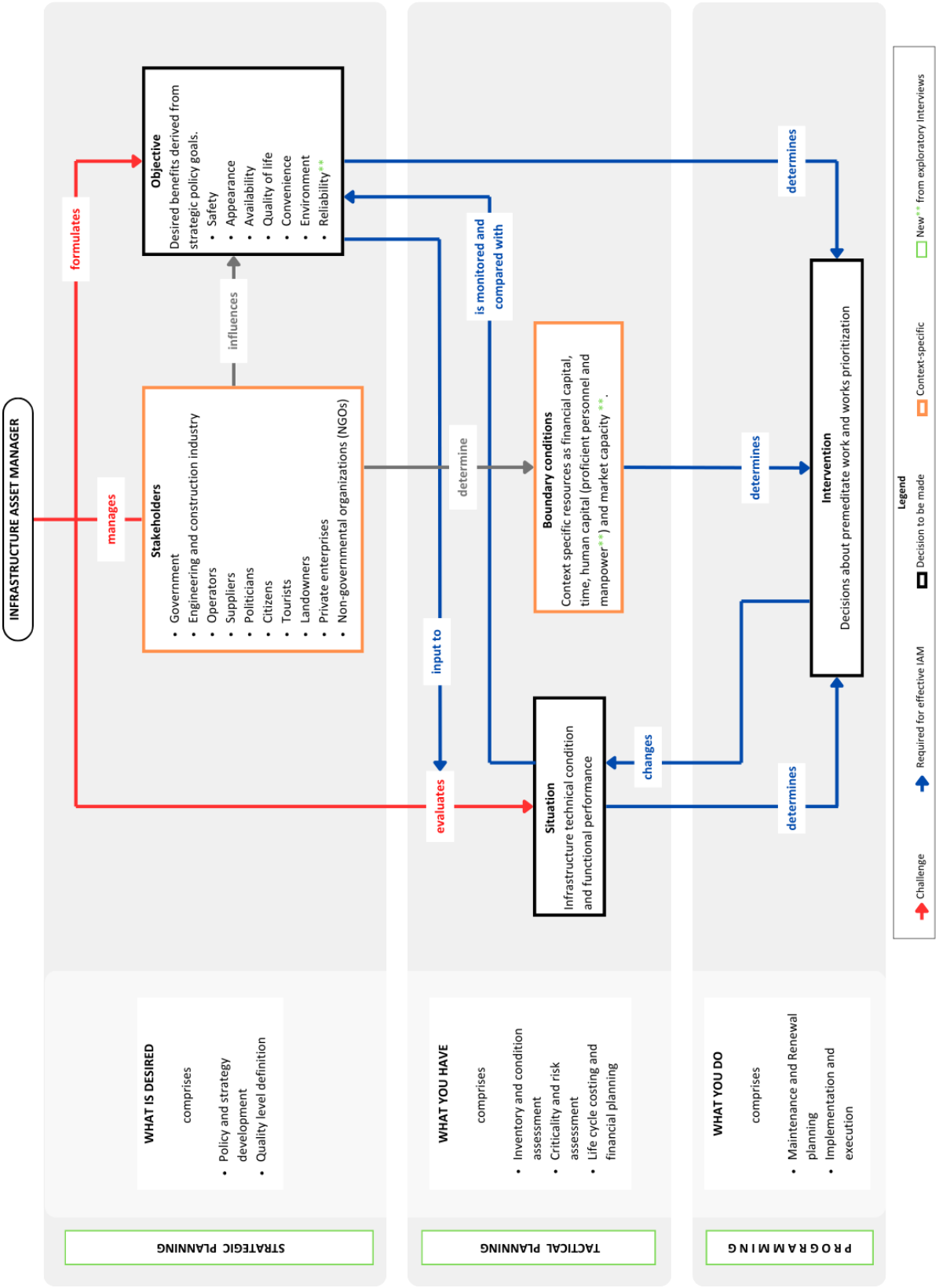

Figure 3.3: Modified Theoretical framework: Infrastructure R&R cycle, decisions and challenges. Based on Neumann and Markow (2004) and Schraven et al. (2011).

4

Discover Phase Analysis

This chapter is included as a closure of the first phase of the research, Discover, and a bridge to the second phase, Define. Closure in the sense that it completes answering the research questions SQ 1: What are the challenges of prioritizing infrastructure renovation and replacement works?, and SQ 2: What are the interests and influence of each infrastructure stakeholder on the prioritization of renovation and replacement works? Specifically analyzing those subjects that in the literature review were not completely defined and about which information was obtained with the exploratory interviews but that require to be contrasted and interpreted to be used in the research. And bridge in that it helps to identify and understand what additional information needs to be gathered with Case Studies to give a complete definition of the infrastructure R&R prioritization problem.

The chapter is divided into three sections. Section 4.1 focuses on characterizing the various infrastructure asset owners in the Netherlands, highlighting the significant variability within this group. Section 4.2 analyzes the stakeholders involved in infrastructure R&R, categorizing them by their interests and levels of influence. Finally, Section 4.3 delves into understanding the prioritization approaches and how they relate to other elements in the R&R management cycle.

4.1. Infrastructure Asset Owner Typology

The literature review on infrastructure R&R tasks in the Netherlands revealed information about different asset owners, highlighting a significant relationship between the level at which they operate and the type of infrastructure they manage. As seen in Table 4.1, national-level assets impact the country's economic and social development, while local-level assets address the needs of specific populations.

Level	**National**	**Regional**	**Local**
Asset owner (quantity)	RWS (1) and ProRail (1)	Provinces (12) and Water authorities (21)	Municipalities (390)
Main infrastructure type	Bridges and viaducts; Tunnels and underpasses	Weirs; Pumping Stations; Sheet piles; Culverts	Sewage; Bridges and viaducts; Roads
Structural complexity	High	Low	High/Low
Budget type	Exclusive	Exclusive/Combine	Exclusive/Combine
Organizational structure	Large	Large/ Medium	Large/ Medium/ Small

Table 4.1: Characterization of R&R works per authority level.

Likewise, from the literature and especially from exploratory interviews, it was found that, generally, the structural complexity associated with national infrastructure is greater than that of local infrastructure. Understanding structural complexity as the number of system components interacting with each other (de Koning & Vanhoucke, 2016). In this case, for example, if an interurban bridge is compared with a

viaduct, it is found that not only is the bridge more complex at a technical level, but it also has many more associated factors that interact with each other and must be considered in its management.

Another important aspect is the financial management of R&R projects. The budget for these activities can be exclusive to R&R or part of the routine maintenance budget, thus considered a combined budget. This also relates to the organizational structure of the asset owner and how tasks are assigned and decisions are made. Large organizations typically have the capacity to hire specialized personnel and fund multiple departments focused on specific tasks, whereas smaller organizations tend to have a simpler subdivision, relying on key individuals who can perform various roles.

Finally, upon examining Table 4.1, it is observed that at the local level, there is only one type of owner, namely the municipalities. However, the existence of 390 municipalities suggests high variability in their conditions, making it difficult to characterize them all under a single description. More importantly, defining the R&R problem is challenging without first understanding how these differences among municipalities influence decision-making. Therefore, it is considered essential to focus on the municipalities as the unit of the case study, taking into account that additionally, they are the owners who bear the majority of R&R work.

Regarding the characterization of the municipalities, it is important to start with a theory that guides and illuminates the aspects to pay special attention to when conducting the case study. While the elements of the infrastructure R&R prioritization process and its integration into IAM are currently known, the organizational aspects and their relationship to this process remain unclear.

To address this, a suitable model that aligns with the research requirements and the type of organization to be characterized is the Capability Maturity Model (CMM). This model evaluates an organization's capacity to achieve its objectives (Paulk et al., 1993; Yavarzadeh et al., 2015). Developed by Carnegie Mellon University to examine software processes, the CMM's applicability has since extended to other industries. Subsequently, Volker et al. (2011) introduced the first version of the Infrastructure Management Maturity Matrix (IM³), which assesses the maturity level of an asset management organization. The IM³ was validated in 2011 and 2012 in Rijkswaterstaat (RWS). It comprises five maturity levels and seven asset management dimensions, which are described below:

Levels of organizational maturity (Paulk et al., 1993; Williams et al., 2003):

- **Initial (Ad hoc):** At this level, the organization has limited experience and is in a stage of learning and development. Processes are often unstructured and rely heavily on individual effort.
- **Repeatable:** At this level, the process is documented sufficiently to allow for the repetition of the same steps. The organization can replicate what it has done before but may not be able to define its processes clearly.
- **Standard:** The process is defined and confirmed as a standard business process. It is decomposed into tactical and operational levels, allowing the organization to articulate what it does and how it goes about it.
- **Managed:** At this level, the process is quantitatively managed by agreed-upon metrics. The organization can control its processes through specified requirements and ensures that these requirements are met through feedback mechanisms.
- **Optimizing:** The organization implements "best practices" learning, and adapts itself over time. It not only corrects problems using experience but also uses experience to fundamentally change and improve its operations.

Dimensions of Asset management (Volker et al., 2011, 2013):

- **Information Management:** This dimension encompasses the availability and utilization of both static and dynamic standardized databases for decision-making. It emphasizes the importance of accurate, complete, and valid data on assets and processes, which are stored in adequate data systems.
- **Internal Coordination:** This dimension focuses on the coordination and problem-solving efforts within different departments of the organization.

- **External Coordination:** This dimension measures the extent of coordination and problem-solving between different project stakeholders, including communication with users.
- **Market Approach:** This dimension addresses the strategy and implementation of integrated and performance-based contracting and innovative procurement methods. It involves leveraging market knowledge and allowing service providers to control parts of the network. Traditional input-based contracts are used on a small scale at the lowest level. At the highest level, contracts are performance-based and encompass entire networks instead of specific asset groups, with market knowledge applied across system planning, design and engineering, operational planning, and work execution.
- **Risk Management:** This dimension refers to the use of risk management methods and life cycle approaches in strategic and operational asset management decisions. Effective risk management requires predefined risk criteria and uniform risk assessment methodologies.
- **Processes and Roles:** This dimension evaluates the clarity, definition, and implementation of job responsibilities and roles within the organization. It measures how well the asset management system is integrated into the quality management system, job descriptions, and human resources management.
- **Culture and Leadership:** This dimension examines the level of knowledge, implementation, and support for asset management-related issues. It refers to the collective mindset programming required for uniform asset management practices.

4.2. Infrastructure Stakeholders Analysis

Regarding infrastructure stakeholders, it is acknowledged that, on one hand, there exists a common group of actors associated with these assets, which has been previously identified by various authors and is documented in the Literature Review (see Chapter 2). On the other hand, this group plays a crucial role in defining the objectives of the infrastructure and the boundary conditions necessary for the execution of works. This indicates that stakeholders determine both the demands for infrastructure and the supply required to construct, maintain, renovate, and replace it. The listing and role of infrastructure stakeholders within the R&R management process, specifically their interactions with other elements in the process, are illustrated in Figure 3.3.

Delving deeper into stakeholder analysis, the level of power and interest of each type of stakeholder in infrastructure R&R is assessed. In this instance, the analysis is undertaken from the perspective of the infrastructure owner, specifically focusing on municipalities, given their predominant responsibility for the assets. A summary of the findings is depicted in Figure 4.1, which categorizes stakeholders into four distinct groups: Crowd, Subjects, Setters, and Players, in accordance with the methodology delineated by Mendelow (1991) and elaborated upon by Eden and Ackermann (2013). This categorization aids the asset manager in comprehensively addressing all stakeholders and managing them effectively for project success. Subsequently, a description of each category and the recommendations provided by the authors regarding their management are presented.

Crowd stakeholders

In the crowd quadrant, characterized by low interest and low power, are NGOs, suppliers, and tourists. The level of interest of NGOs, in particular, depends on the context and whether it aligns with the organization's objectives. For instance, if an NGO's mission is environmental protection and an infrastructure asset is located in a protected environmental area, the NGO's interest in this specific case would increase significantly, potentially shifting it to the Subject quadrant. However, NGOs generally reside in the first quadrant (Crowd) and operate at the national level. These stakeholders have varied objectives and therefore may be concerned with different aspects of infrastructure, ranging from its location to the materials used in its construction.

Tourists and suppliers, despite being related to infrastructure, do not have a direct relationship; rather, they have intermediaries who are other actors. Tourists are directly related to other stakeholders such as private companies including hospitality, restaurants, and recreation centres, among others, which are Subjects. Suppliers are directly related to other types of private companies such as consulting and

engineering firms and contractors, which are Setters. In this sense, both actors (tourists and suppliers) are in the background dealing with other actors who are in the foreground (Hospitality and catering, and engineering and construction industry respectively) in infrastructure R&R. It is important to highlight here that this implies that these relationships can be strategically used to shape and manage the actors in the foreground/background if desired.

Considering what Mendelow (1991) and Eden and Ackermann (2013) say about stakeholder management, the Crowd quadrant should be regularly monitored so that any changes in the level of power/interest of any of the actors are identified on time.

Subjects stakeholders

Subjects are those actors who have a great interest and limited power. In this quadrant, it is found stakeholders who use and give meaning to infrastructure assets, namely citizens, landowners, and private enterprises. All of them, with their different interests, influence the definition of infrastructure objectives, making safety, comfort, and convenience a priority. At the same time, defining whether the performance of the service provided by the infrastructure is sufficient.

Subjects are those who, through the democratic election of local and national authorities, transfer their power over the infrastructure to political parties, so that they manage these assets and look after their interests (Figee et al., 2007). In this sense, depending on the composition of the government, the interests of certain groups of subjects will have more or less power in decision-making regarding infrastructure R&R. In some cases, Subjects may gain power and move to the Player's quadrant when they have significant representation and manage a considerable part of the economy at the level being evaluated.

The subject quadrant is best characterized at the local level, both in its composition and interests. Managing Subjects involves keeping them informed about the state of the infrastructure, and what is planned and executed (Mendelow, 1991). As well as supporting and receiving feedback from them.

Setters stakeholders

The Setters have significant power and low/moderate interest. In this case, these actors are the central government, engineering firms, and construction companies, the last two are seen as a group/industry at the national level. This means that stakeholders found in this quadrant are common to all infrastructure owners, thus shaping the stakeholder landscape in infrastructure R&R in the country.

On the one hand, although the central government can intervene at any time at the local level (high power), its interests concern national issues, thus granting autonomy to local governments to act in any way as long as it aligns with national laws (CoR, n.d.). The central government has various mechanisms to control and shape both the purpose of infrastructure and the technical quality of each asset and the system, which are then translated locally in the form of policies.

On the other hand, since both engineering firms and contractors are found in this quadrant, it can be said that Setters define the market's capacity to carry out R&R works, which constitutes external boundary conditions. They are called external. They do not depend on the infrastructure owner and boundary because they have the power to determine when and how the works are carried out.

Regarding the management of stakeholders falling into this category, it consists of keeping them satisfied so that they act in favour and facilitate the execution of works (Mendelow, 1991; Mints & Kamyshnykova, 2019).

Players stakeholders

Players have considerable influence and interest in infrastructure management. In municipalities, this typically includes the local council and officials, who hold decision-making authority and oversee resource allocation. They play a pivotal role in setting internal boundaries, such as personnel allocation for project planning and financial resources for project execution. According to Mendelow (1991), managing these stakeholders involves close engagement and alignment with the project's vision and objectives to ensure their ongoing support.

Figure 4.1: Infrastructure stakeholder power/interest matrix for municipalities.

In conclusion, understanding and managing the diverse group of stakeholders involved in infrastructure R&R is essential for successful project execution. By categorizing stakeholders, asset managers can tailor their strategies to address the unique interests and power dynamics of each group, ensuring a comprehensive and effective approach to stakeholder management. Specifically, the previous stakeholder analysis and power/interest matrix reveal that:

- All local infrastructure owners have the same stakeholders in the Setters and Crowd categories, as these operate at a national level. Therefore, these two categories establish the given conditions, i.e., the general context of the infrastructure.
- The Setters determine the external boundary conditions (market capacity) and influence the definition of infrastructure objectives (national standards), which by definition are beyond the control of local asset owners when considered individually.
- The Subjects are the users of the infrastructure, thus they have a significant influence on defining infrastructure objectives.
- The Players, being democratically chosen by the Subjects, theoretically represent a sample of the Subjects; their variability in interests and management preferences is captured in the political parties that compose the council, and the number of council members reflects the population size and the extent of its territory (Figee et al., 2007).

All of the above highlights the importance of characterizing local owners, as they are the variable actors in decision-making. To do this, and following the analysis above, it is necessary to delve into the Subjects and Players in different municipalities, so that it is understood to what extent the different conditions and configurations of these categories shape the internal boundary conditions and objectives of the infrastructure.

Additionally, more information is required regarding the municipalities and their potential to collaborate with other owners at the same level and/or at different levels as a strategy to influence the behaviour of the Setters and consequently alter the external boundary conditions. This consideration is based on the interdependence of the actors involved.

4.3. Prioritization Approaches Analysis

Five prioritization approaches were identified in the exploratory interviews, which are described in Chapter 3. However, apart from their description, it is considered important to analyze and identify the criteria that each of them uses to decide which works to prioritize, what type of vision and terminology the organization should employ to utilize them, and as a result, which infrastructure objectives will be benefited, additionally, regarding the boundary conditions, which of them helps to expand or provide better management. A summary of this analysis is found in Figure 4.2 below.

		Assessment		Target		
Term	**Prioritization approach**	**Question**	**Unit**	**Criteria**	**Infrastructure Objective**	**Boundary condition**	**Predecessor**
Short	**Asset driven**	What is urgent?	Individual asset	Technical condition, performance and functionality, maintenance cost, information availability	Safety, Availability	Cost	None
Short	**Importance driven**	What must be done?	Individual asset	Cultural/historical value, political commitment, international mobility	Appearance, Availability	None	None
Mid	**Area oriented**	What is convenient for residents?	Assets in a block/ area	Disturbance and nuisance	Availability, Quality of life, Convenience,	Time, Cost	Asset driven, Importance driven
Long	**Capacity driven**	What tasks cannot be performed in the future?	All local assets	Financial capital, Experts (employees and third parties), manpower, materials	Safety, Availability, Quality of life, Reliability	Time, Cost, Personnel	Asset driven, Importance driven**, Area oriented**
Mid	**Collaboration driven**	What tasks can be carried out in cooperation with other asset owners?	System/network in the regional/ national level	Standard technical features, Construction method in common	Safety, Convenience, Environment	Time, Cost, Personnel, Market capacity	Asset driven**, Capacity driven**

Figure 4.2: Summary of prioritization approaches, their benefits and associated boundary conditions.

II

Define Phase

5

Case study

The second phase of the study aims to understand how variability in the configurations of context-dependent factors within municipalities and the organization in charge influences the decision-making processes in the planning and programming of infrastructure R&R works. For this purpose, it is necessary to have specific and detailed information from different municipalities in order to carry out a comparative analysis to identify the determining factors in the R&R project management process.

This chapter establishes the basis for conducting case studies and comprises three sections as follows. Section 5.1 presents the methodology and criteria for the selection of case studies and provides a description of the chosen cases. Section 5.2 details the data collection methodology employed. Finally, Section 5.3 outlines the methodology for the analysis of results.

5.1. Case Study Preparation

The decision on the number of cases to analyze was made taking into account the purpose of the study and its credibility, following for this the recommendation of Yin (2017), who suggests that, to avoid the risk of deductive theory confirmation and generalizing observations, a minimum of two comparative case studies is preferable.

5.1.1. Case Selection Procedure

Case study selection is a crucial step in qualitative research. It involves determining the selection procedure and its criteria. In this case, to ensure the suitability of the cases, it is decided that the selection criteria are derived from the Literature review and Exploratory interviews (Chapter 3 and 2). The explanation of the selection procedure and justification for each criterion used is presented below.

1. ***The case unit must be a municipality in the Netherlands.***
   In the literature review on infrastructure R&R in the Netherlands, it was found that this task is primarily concentrated in municipalities, which account for 80% of the assets and 55% of the total projected economic investment (Bleijenberg, 2021; Rasker et al., 2023). This means that by focusing the Roadmap specifically on these infrastructure owners, a significant portion of the work is covered, thus reaching a wide radius of influence. Additionally, exploratory interviews revealed that municipalities, compared to other infrastructure owners, face greater barriers and difficulties in planning and carrying out R&R works, which supports the relevance and emphasizes the importance of giving insights to these entities.
2. ***The municipality must already be working on the R&R of infrastructure.***
   From exploratory interviews, it is known that although infrastructure R&R is a current and widely recognized topic among asset owners, for some, especially municipalities, awareness of the urgency of this work is low. This is reflected in delays or postponements of these activities. Taking this into account, it is considered vital that the chosen municipalities have already begun planning and working on infrastructure R&R. This ensures that they have already analyzed both the magnitude of the tasks and the resources they have available, as well as the barriers to carrying out the work.

3. ***The population of each municipality must correspond to a different size.***
   Finally, considering that a roadmap focusing on municipalities is intended, and the Netherlands has 390 municipalities, it is decided that capturing their variability in contextual, organizational, and resource availability conditions is achieved by selecting one municipality per population size. For this, the differentiation made by OECD (2024) is used, who distinguishes metropolitan areas with over 500,000 inhabitants; medium-sized areas between 200,000 and 500,000; and small urban areas from 50,000 to 200,000. This criteria is also based on exploratory interviews in which participants stated that there is a direct relationship between population size, the area of the municipality, and the size of the organization responsible for infrastructure assets.

5.1.2. Case Selection Result

Based on the criteria defined for the selection of case studies, a list of municipalities in the Netherlands was compiled, classified according to their population size as follows:

- Large size: Amsterdam and Rotterdam.
- Medium size: The Hague, Utrecht, and Eindhoven.
- Small size: 's-Hertogenbosch and another 384 municipalities.

This list was consulted and discussed with the company supporting the research, which is knowledgeable about the construction and infrastructure industry in the Netherlands. This was done to first validate which municipalities are currently involved in R&R and secondly to ensure contact with these municipalities for data collection. Finally, the selected municipalities were: Amsterdam, Utrecht and 's-Hertogenbosch.

The following section provides a detailed description of each of the three selected municipalities. This description is based on information available on the official websites of the respective municipalities, supplemented by other publicly accessible sources. The primary objective of introducing each municipality is threefold. First, it aims to elucidate their current political characteristics, preferences, agendas, and objectives. Second, it examines their spatial distribution and use of land, which are indicative of the level of participation by local stakeholders (Subjects). Third, it shows their organizational structure, focusing on the division of tasks and the interdependence between teams and departments in the decision-making process.

This information is systematically considered in the analysis of the case studies (subsequent chapters), to determine whether political characteristics, spatial distribution of land use, and organizational structure of municipalities influence or bias the research findings.

Municipality of Amsterdam

The municipality of Amsterdam is the capital of the Netherlands. It is situated in the province of North Holland, in the western part of the country. Amsterdam is the most populous city in the Netherlands and has a designated UNESCO cultural heritage area. Table 5.1 shows the percentile distribution of land use, of which residential is the majority.

Municipality	**Population (inhab)**	**Total surface area (ha)**	**Land use**			
			Residential	**Hotel and Socio-cultural**	**Private enterprises**	**Agriculture**
Amsterdam	934.927	21.949	21,08%	4,26%	11,50%	12,47%

Table 5.1: Population and use of land in Amsterdam (CBS, 2023).

Formally, the municipality of Amsterdam is governed by a municipal council, which has 45 members that are democratically elected by the city's residents. The council is responsible for making decisions on local policies, legislation, and budgets. The executive authority of the municipality rests with the mayor and a board of aldermen, who are responsible for implementing the decisions of the municipal council and managing the city's daily affairs (Amsterdam, n.d.-a).

Amsterdam is divided into several districts, each with its own district council responsible for local governance within its boundaries. These districts vary in size and population and play a significant role in ensuring that municipal services and resources are effectively distributed throughout the city. The organizational diagram of the municipality can be seen in Figure 5.1.

The current Amsterdam city council's mandate is predominantly left-wing and runs from 2022 to 2026. In their coalition agreement, they propose four main elements, which are: inclusivity, focusing on solidarity and equal opportunities for all residents; commitment to sustainability, aiming to insulate more housing and create green spaces; responsible growth, building housing with a balanced mix of social, middle-income and private units; and public safety, tackling crime (Amsterdam, n.d.-c).

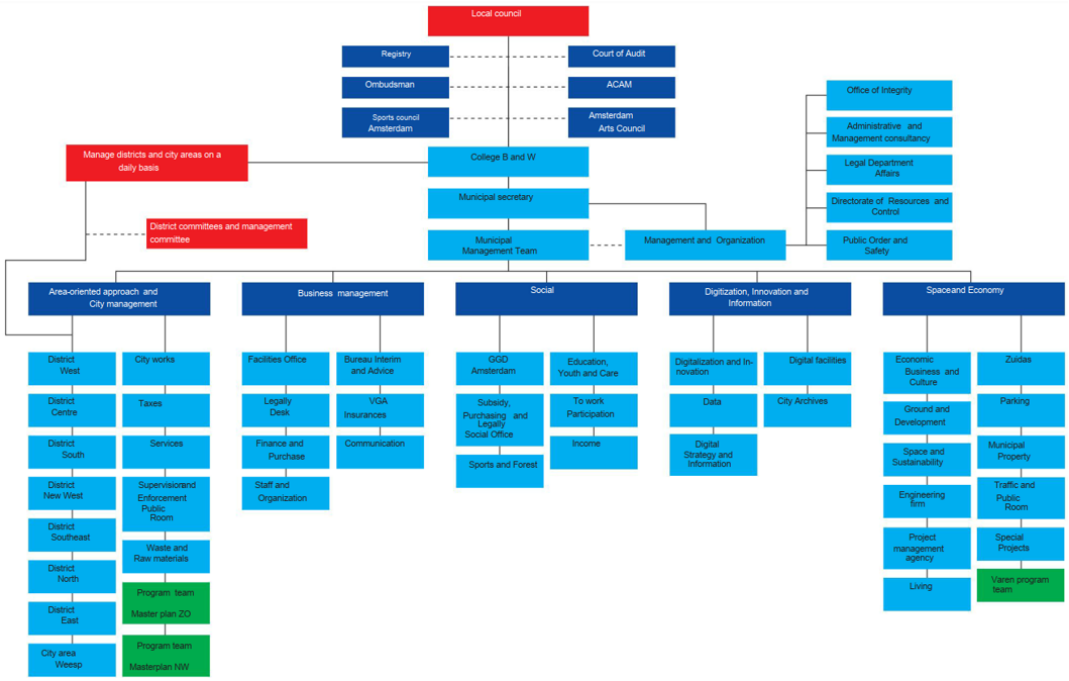

Figure 5.1: Municipality of Amsterdam organization chart. Retrieved from (Amsterdam, n.d.-b).

Municipality of Utrecht

The city of Utrecht is located in the Netherlands and is the capital of the province of Utrecht. It is situated at the center of the country, making it a vital hub for transportation and commerce. Utrecht is known for its rich history, dating back to Roman times, and is characterized by its well-preserved medieval center, which features iconic landmarks such as the Dom Tower, the tallest church tower in the Netherlands (Utrecht, n.d.-c). In Table 5.2, it is found the percentage distribution of land use in the city, where the main uses are residential and agricultural, with just a 2% difference between them (CBS, 2023).

Municipality	Population (inhab)	Total surface area (ha)	Land use			
			Residential	Hotel and Socio-cultural	Private enterprises	Agriculture
Utrecht	374.411	9.921	26,13%	5,53%	9,74%	24,36%

Table 5.2: Population and use of land in Utrecht (CBS, 2023).

The Utrecht city council consists of 45 members (G. Utrecht, n.d.). The organizational structure of the municipality is illustrated in Figure 5.2, revealing its composition of various parts, departments, and teams. This encompasses the Business Strategy and Operations Network (BSN), ensuring the smooth functioning of the internal organization, along with 11 distinct organizational units (Utrecht, n.d.-a).

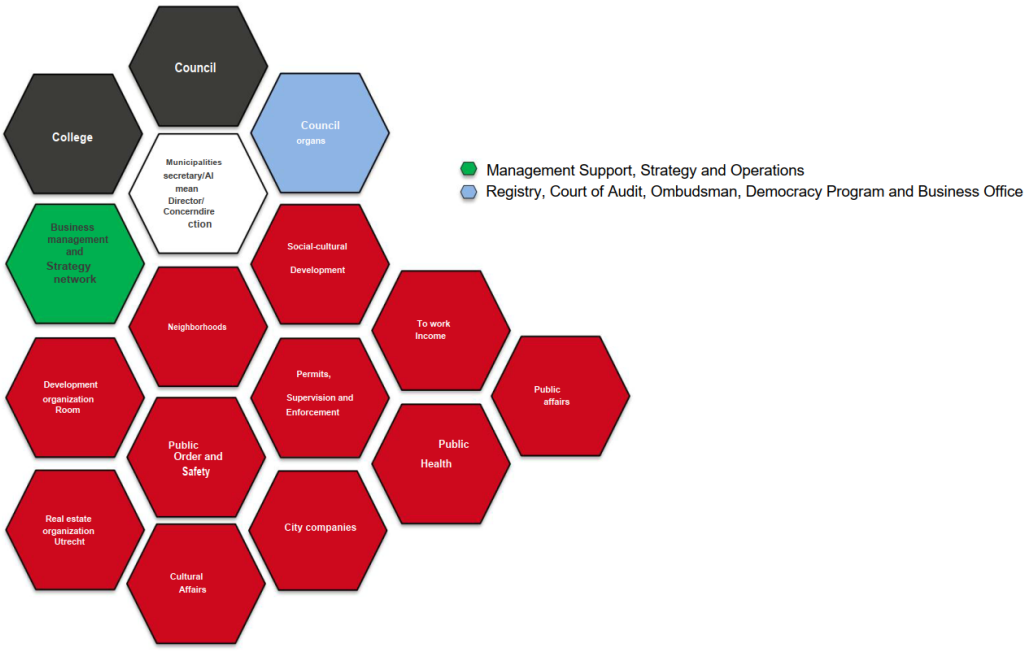

Figure 5.2: Municipality of Utrecht, organization structure. Retrieved from Utrecht (n.d.-b).

As for the city's political agenda, it prioritizes issues such as sustainability, social inclusion, affordable housing, and transportation infrastructure. Utrecht has been at the forefront of implementing innovative urban planning strategies, promoting cycling as the primary mode of transportation, and investing in renewable energy initiatives (G. Utrecht, n.d.).

Municipality of 's-Hertogenbosch

's-Hertogenbosch, commonly abbreviated as Den Bosch, is a city located in the southern part of the Netherlands. It is the capital of the province of North Brabant and holds a rich historical and cultural significance. Table 5.3 shows the percentage distribution of land use in the city, where it is found that the majority use is agriculture, which exceeds twice the percentage of residential land use.

Municipality	Population (inhab)	Total surface area (ha)	Land use			
			Residential	Hotel and Socio-cultural	Private enterprises	Agriculture
Den Bosch	162.165	11.807	16,86%	2,49%	5,50%	46,27%

Table 5.3: Population and use of land in 's-Hertogenbosch (CBS, 2023).

Den Bosch's municipal government is composed of a mayor and council who oversee executive functions such as finance and urban planning. While the municipal council, which has 39 members, establishes policies and approves budgets, advisory bodies provide localized input, and committees delve into specific areas of governance, assisting in detailed examination before decisions are made by the council ('s-Hertogenbosch, n.d.) (See Figure 5.3).

The current municipal administration is primarily led by left-wing representatives. The administrative agenda for the term spanning 2022 to 2026 outlines several key objectives: increasing housing market accessibility, expedited progress towards carbon neutrality, ensuring equal opportunities for all residents, fostering economic development, nurturing a vibrant cultural scene, expanding venues for community gatherings and recreational activities, enhancing transportation infrastructure for seamless, comfortable, safe, and sustainable mobility, implementing intelligent strategies to mitigate the impacts of climate change, prioritizing resident safety, and fostering strong connections with both residents and partners ('s-Hertogenbosch, 2022).

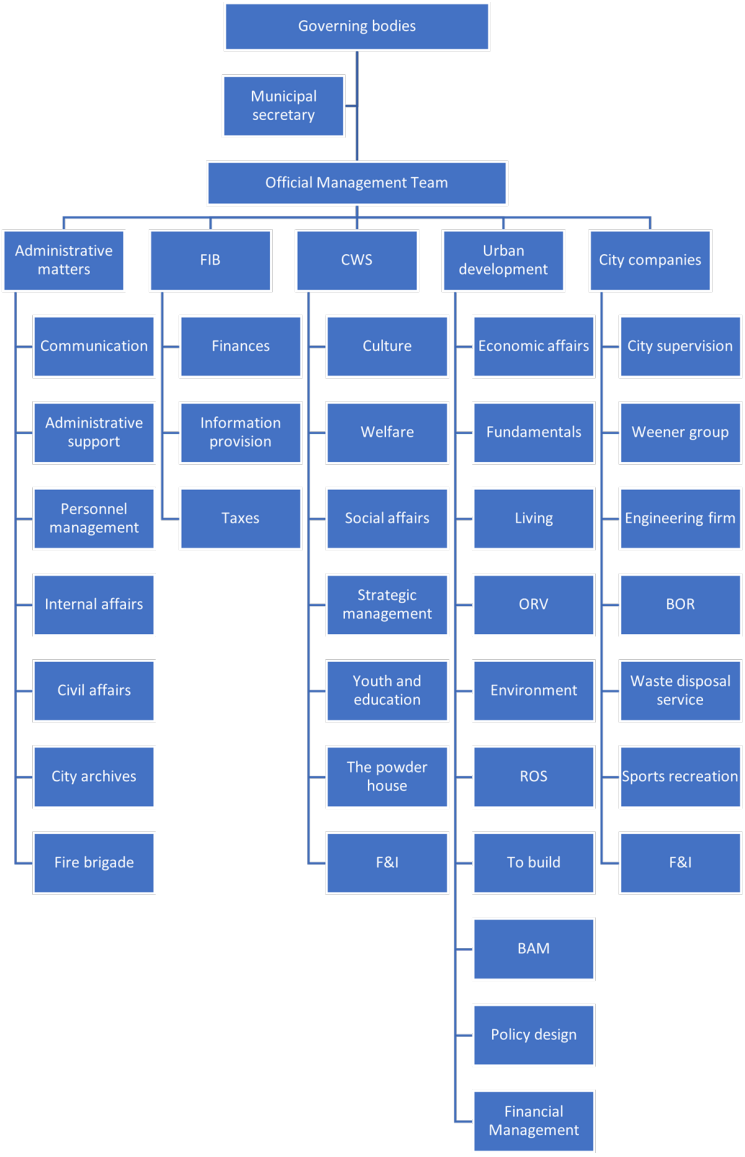

Figure 5.3: Municipality of Den Bosch, organization structure (Tutelaers, 2015).

5.2. Data Collection methodology

This section explains the data collection process for the empirical study in this research. Data is collected through semi-structured interviews for qualitative analysis. The aim is to characterize the organization managing infrastructure, local stakeholders, infrastructure objectives, the current state of infrastructure, and specific boundary conditions of each municipality, as well as their prioritization process. Essentially, these interviews aim to customize the theoretical framework of R&R proposed in the previous chapter with specific information from each municipality. This forms the foundation for comparative analysis and the development of a Roadmap for the prioritization of R&R works adaptable to various scenarios and contextual configurations.

The interviews were set up as semi-structured, for which a protocol with open-ended questions was created to give the interviewer flexibility to delve into more detailed information through follow-up questions. The interview outcome can help fill in gaps in contextual and practical knowledge, validate or discard hypotheses raised from the development of the theoretical framework, and discover factors contributing to the development of a generalizable roadmap. The following outlines the process of selecting interviewees and the interview protocol.

Criteria for Interviewee Selection

Interviewees were primarily selected based on their role as key decision-makers in infrastructure R&R within each municipality. This is a limited and specific group that includes managers of infrastructure R&R teams. Additional, information about the interviewees can be found in Table 5.4.

Code	Municipality	Role	Date of interview
IA1	Amsterdam	Senior Advisor in R&R program	24/04/2024
IA2	Amsterdam	Engineer in R&R program	24/04/2024
IU1	Utrecht	Manager of civil infrastructure	22/05/2024
ID1	s' Hertogenbosch	Technical Advisor	10/05/2024

Table 5.4: Semi-structure Interview sampling

Interview Protocol

In order to conduct an effective interview, an interview protocol was prepared to guide the interviewer. The interview, which lasted 60 minutes, consisted of five parts, each corresponding to a theme. The themes were formed from the Literature Review in Chapter 2. They include questions about the interviewee's background, the infrastructure R&R process, infrastructure decisions, challenges and barriers, and R&R prioritization approaches.

Interviewees were informed about these themes at the beginning of the interview. The interview started with an introduction of the researcher and the interviewee, addressing the purpose of the interview and the research. In this part, the interviewee was informed about confidentiality and the recording of the interview, as outlined in the informed consent form sent before the interview. The protocol and questions can be found in Appendix B.

5.3. Data analysis methodology

The methodology implemented to analyze the results of the semi-structured interviews follows eight steps as described below:

1. Interviewee selection. Before conducting semi-structured interviews, interviewees are identified and selected as previously described.
2. Sending official requests to the interviewees. Interview requests are sent via email. Requests regarding the date and time of the interviews are also made in this step. Once agreed upon, the informed consent form is sent to the interviewees before conducting the interviews.
3. Preparation of the interview protocol to ensure an agile interview process and consistency in the questions (Appendix B).
4. Conducting interviews. The interviews are conducted online through Microsoft Teams. Automatic transcripts are also made during the interviews, after the interviewees' agreement. The interviews are conducted in English.
5. Generating interview transcripts and editing process. Transcriptions of the interviews are made and carefully edited before further data processing.
6. Reading the interview transcripts. The responses are examined and interpreted as a whole. This step helps to gain a thorough understanding of the content and context of the data.
7. Interview analysis. A comprehensive analysis of each of the five themes is conducted, identifying categories and patterns within each. Additionally, the type of relationship between the themes, the level of influence, and interdependence among them are analyzed.
8. Combining the results, the theoretical framework (Figure 3.3) from Chapter 3 is combined with the interviews. The result of the analysis is presented in the report for each case study before making comparisons and generalizations.

The results of the data analysis and interviews from each case study are presented in the following chapter.

6

Case Study Results

This chapter presents the results and findings derived from the case study. The main objective of this chapter is to fill the information gaps previously identified and answer SQ 3: How do infrastructure asset owners currently prioritize their renovation and replacement works?

The chapter is divided into two sections, first in Section 6.1 the results of the case study interviews. Then, Section 6.2 presents the main findings and the final version of the Theoretical framework of the infrastructure R&R management process.

6.1. Case Study Results

The results of the interviews are presented according to the thematic categories established in the interview protocol (Appendix B), which include: the R&R process, decisions on infrastructure, challenges and barriers and prioritization approaches.

The R&R process

According to [IA1], the management of infrastructure assets generally follows what is proposed in Figure 6.1. Where, based on the condition and performance of the asset, it is determined which type of intervention is necessary, whether routine maintenance or renovation, to extend its service life.

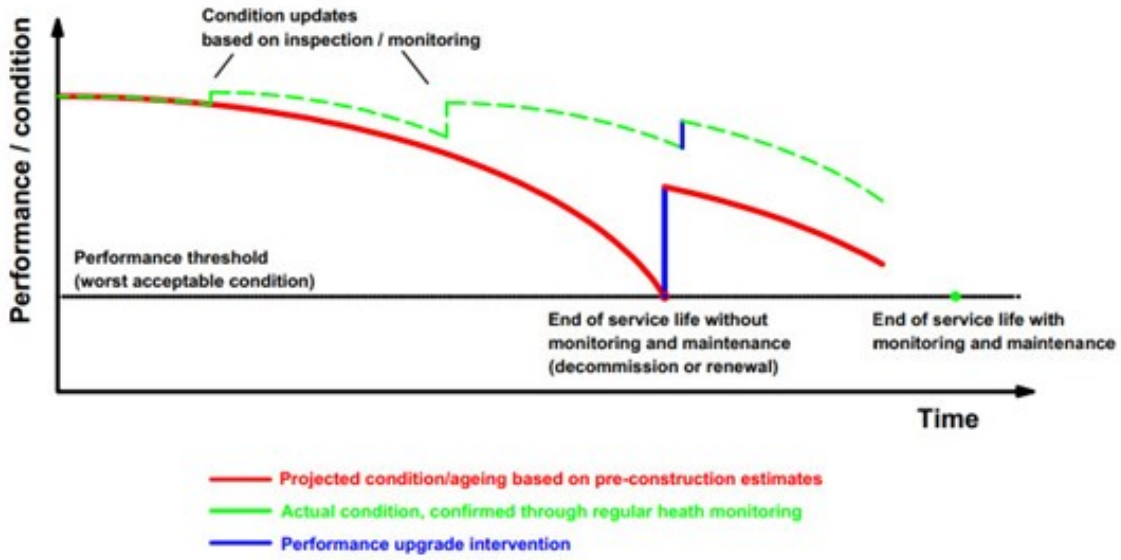

Figure 6.1: Asset deterioration graph (Spyridis, 2016).

The interviewees also said:

- "We got a calculation sheet, that determines the risk of each asset and then gives a ranking from 1 to 1800 in the case of bridges. So the bad one is on the number one and the good one is on number 1800…. It gives the estimation when you have to do the maintenance. So a bad bridge, you have to R&R in 2025, but a bridge with a ranking in the middle the calculation it is going to say you have to do R&R in 2035, for example" [IA1].
- "First is organizing your asset data, keeping it in order. Knowing what type of asset you have, the year it was built, all the drawings, the calculations, **having the data in order; this is one of the most important basic aspects**. But in many older cities, this is sometimes a challenging part because we went from physical drawings to digitalization, and information gets lost. For this reason, inspections are conducted. From there, there are two routes: one more focused on structural safety and the other more on the maintenance side" [IA2].
- "All the assets are regularly inspected and when repairs need to be done, those are planned and carried out… **usually planning is done in a reasonably short term, four or five years**" [ID1].
- "First, the technical state, referring to normal inspections and the second one is compliance...there is also a discussion with other departments responsible for traffic about functionality... sometimes the technical renovation would be a solution for them... we used to look at a broadcast for four years, **it has grown to 10 years**... then we have process meetings to define the projects and to divide the money through the year." [IU1].

Decisions on infrastructure

Infrastructure objectives:

- "Based on our policy of Amsterdam. We have a risk matrix that includes reliability, availability, safety, economics and environment" [IA1].
- "The priority is safety. So, if safety is at risk, you need to act and plan the renewal immediately. Then we have sustainability, which is very important. Next, availability and reliability. And finally, we have the costs" [IA2].
- "Safety is the most important...and we always go for the highest standards for which we have different sets of requirement" [ID1].
- "We have discussions from the maintenance department within our organization because we would like to have a way to determine risks. At this moment, as an employee of these organization, I can't take risks because we do not have a policy that allows it… we have to play more safe than other organizations because we do not have a policy that allows some way of taking risks" [IU1].

Grouping of asset types for project planning:

- "We only use the matrix for the same type of assets. So the calculation sheet is different for each asset type... If you are going to put them all together, it is important to consider that a bridge is much more important than other assets" [IA1].
- "There are many different assets, such as sewage systems, electricity, and waterbeds, each with different asset owners. Each owner has a specific maintenance plan for their asset. All these plans come together in the decision-making process" [IA2].
- "There are different groups for R&R. It is not combined, so we have other people who are more knowledgeable on sewage systems… so different groups but in the same and organization" [ID1].
- "It starts separate. But when we make a plan and you put it on the program then you have to discuss with the other teams to combine the projects. And of course, bridges normally relate to the roads" [IU1].

Challenges and barriers

Market capacity:

- "There is too much work in the Netherlands and too little contractors... we are going to make contracts, but the contractor says well, that is not possible. It is going to be a year later. So I have to move it a year up, and when you move things in your program, everything moves up. That is like a snowball" [IA1].
- "I think the availability of people is more critical... people who have to work everything out that is the issue" [IA1].
- "Manpower is the most difficult, money is always to be found somewhere, and when the bridge is very important to the municipality, money will come... the biggest problem is finding the right personnel to be able to carry out the work. Skilled personnel in the contractor or engineering firm. **People with the right set of knowledge and experience** become rare...I think that is going to be the biggest problem for the coming years" [ID1].
- "There is a capacity shortage not only within us but also within the third parties" [IU1].

Financial capital:

- "We ask for a credit when we need to do the placement of a bridge. It is some kind of loan, and it is project based" [IA1].
- "When the calculations of a bridge show that it is not strong enough for its use, and it is decided to carry out R&R works, the expenses for that project is not budgeted... so the team can take some from the normal budget and put it aside for the bridges in the city... we will make rough calculations of the budget we need, then we just put it to the council and if they think is too much, we have to cut costs. Well, some things we will not be able to carry out, but normally we get funds" [ID1].
- "Then there will be some kind of competition for budget between type of assets, but most of the time when the bridge is important enough and the budget make sense, it is approved" [ID1].
- "When we build a new bridge, when we replace it, we can take a loan, but when we renovate it, we cannot with an allegation so we cannot renovate a lot of bridges, so actually it is financially negative within the current regulations, to renovate bridges" [IU1].

Time:

- "Time to work on the contracts. It takes a minimal of two years to work on the contracts" [IA1].
- "It is another 20-30 years before we really need to do some extra work in bridges" [ID1].

Human capital:

- "We are with 50 people. But we got a separation regarding asset types... there is almost every expert in the team. And if we do not have it, we are going to hire them. So we got the technical, maintenance engineers, managers, coordinators, and team leaders" [IA1].
- "All personnel, of course, is very important and people have to be able to carry out a project. Depending on the urgency and the people available, it could happen that people leave other projects to carry out a renovation or replacement that is urgent.... we are lucky to have about 5-6 employees who are specialized in bridges now" [ID1].
- "The real expertise. Not the project management, but the structural engineers, that kind of the personnel is critical…...at the moment we only have one group for decision making, that is combined for maintenance and R&R, it consist of 15-20 people" [IU1].

Political influence:

- "Sustainability is the thing right now in decision making and bikes… so that is in a decision making point because if a bridge is bad for cars, it may not be bad if only bikes can cross it" [IA1].

- ”In a theoretical case where we cannot find a solution and everyone maintains their positions, unable to reach a solution, then you can bring it to the political system for decision-making. I think it’s a possibility, but I don’t think it’s used much, perhaps once in this entire year”[IA2].
- “There is some political influence but it is mainly for the scope of the projects... when politicians make a decision and they say and establish it, this is very important for us. Those decisions play a role but that is more in in the how we carry out works and not necessarily the decision if we should or should not replace a bridge” [ID1].
- “Political ambitions can be achieved on the long term, but our necessity for R&R is now so sometimes we have to mix it and that is the difficult part” [IU1].

R&R Prioritization approaches

Asset driven:

- “For me it is technical. Sometimes it is also functional. It depends on the project. Normally we only focus on the technical as the most important priority” [IA1].
- ”Technical lifespan is quite easy to determine. We mainly focused on technical lifespan and prolonging the technical lifespan for as long as possible” [ID1].
- “Technical is my priority… we will also have the discussion with the policy teams about the function. How do they want that we replace it and if we can consider something else in the scope. However, that is not our priority” [IU1].

Importance driven:

- “Centrum is priority because it is UNESCO, but that is more about aesthetics” [IA1].
- “Maintaining historical or cultural value are not important in prioritization. We have some bridges that are for example, masonry arch bridges, those date from the 13th and, 14th century. And we like to keep them so we treat them differently than other assets, in that case the most important factor is aesthetics” [ID1].
- “There’s a giant team that is a separate team focus on historical assets, but those will never be replaced because it is historical. So they are only working on strengthening” [IU1].

Area oriented:

- “So we work in all the bridges in one neighborhood and we fixed them and then we go to another neighborhood” [IA1].
- ”We try to make a decision for an area. For example, if all projects are renovation projects and one is rehabilitation, also doing the renovation for that one. This way, you don’t have to come back for another 100 years in a certain area. But the other way around, if all projects are rehabilitation and one should be renovation, you can do another technical inspection to try to make that project also rehabilitation, to reduce sustainable impacts. So in Amsterdam, they started with just the city center area. Then there was an area with an important river for commercial shipping. So they went to that area and then to the canal system” [IA2].
- “When we plan it in two separate projects and if this would create problems for the users twice then we combine it. We can do it at once and the period of closure might be a bit longer, but we just have to close once and not twice in two separate occasions. So we try to combine a project as much as possible and sometimes we delay or speed up projects to carry out them together” [ID1].
- “When we have multiple bridges that need to be renovated or replaced, we try to put them in one contract. But we have to be careful with the planning to not create accumulation points or to lead an area to become inaccessible, so we mostly planned one after the other and not really at the same time” [ID1].

Capacity driven:

- “If you are going to do everything right away, it costs a lot of money. Usually the organization does not get the required capital for that. Also, there is not enough capacity in the

construction industry to do that. Flattening the curve is really difficult, because everything is changing, the demands and policies..." [IA1].

- "At the moment we have a very detailed picture of all our bridges. We know exactly when the bridges have to be renovated. And when we will start publishing the contracts for that... personnel is not really part of the picture, not yet" [ID1].
- "For about 70% of our assets we did not have the construction year. And then it is really difficult to make any expectation of the work coming so we do not have that analysis yet" [IU1].

Collaboration driven:

- "We collaborate to learn from each other and to exchange knowledge… I offered two documents, one is a maintenance package for the different types of bridges. I gave that to other cities so they could use it. And I made a safety guide on how to use a specific norm and I also gave that document to other cities. So they do not have to rethink it" [IA1].
- "There is some collaboration. We had a group of several municipalities, but it stopped. There are some initiatives but nothing concrete. Most of the time, people are left on their own" [ID1].
- "There are several types. There is one that is called the G4, the four largest… but it is on a really high level. The collaboration we have is more based on people knowing each other so that is the personal network. It is not a structured collaboration. We can find each other, and we are willing to help each other, but if no one calls, we will not speak to each other at all" [IU1].

All the results presented above are analyzed in detail and summarized in the following chapter.

With the general information from the municipalities, which was extracted from public and official sources on internet, and the information collected during the interviews, the theoretical framework of the management process for R&R works (Figure 3.3) is modified for each municipality.

Appendix C presents a summary of both the specific contextual conditions of each municipality and the current practices that each one is implementing for R&R works. This information aims to provide a clear and general understanding of how each case study works and the reasons behind the decisions. Thus, enabling to conduct a comparative analysis that highlights the determining factors in prioritizing works for different settings and lays the groundwork for the development of a comprehensive, personalized, and relevant Roadmap.

6.2. Case Study Findings: Double cycle

The interviews revealed that municipalities typically conduct their prioritization process in two cycles. Initially, they focus on specific types of infrastructure before expanding their scope to encompass all assets under their jurisdiction. These stages reflect different organizational perspectives and levels, resulting in different factors being considered during decision making. The first prioritization cycle is carried out for all assets of the same type, depending on the organizational structure of the municipality and whether it considers certain types of infrastructure together or separately. In this sense, each group within the organization responsible for the R&R of a type of asset has the responsibility to decide the scope and programming of these works.

Additionally, it was found that during the first cycle, groups primarily assess the assets' situation based on infrastructure objectives to determine the appropriate intervention. This generally aligns with an asset-driven prioritization approach, occasionally incorporating an importance-driven approach. Consequently, safety and availability are priority objectives, and infrastructure is evaluated on the basis of its technical, functional, and economic lifespan. This implies minimal consideration of boundary conditions during this cycle, with a superficial focus on the availability of internal human resources (experts, advisors, and project managers within the team, referred to as "Players").

During this cycle, a significant disconnect was observed between the groups responsible for different types of infrastructure assets within the organization. Different members lack information or knowledge

about how other groups manage their assets. Furthermore, it is unclear whether the interventions proposed in this stage of the prioritization process conflict with the plans of another department. This is evidenced in the following quotations.

"You really have to actively ask to know the plans of other departments, and sometimes it's a totally different part of the municipality, sometimes it's not even part of the municipality. And then sometimes even invite them into the conversation to get your plans in order so that during the construction phase, we don't have unexpected complications" [IA2].

"When all the maintenance teams make their ten years plan, then from that plan we can look for the combinations. In fact, the decision to compare plans and find combinations is up to us at the moment " [IU1].

"We do not directly compare the R&R plans for different types of assets. This is because they have distinct funding sources and varying lifespans" [ID1].

Then, in the second cycle, the prioritization of the works involves all municipal assets collectively, for which the result of the first cycle is taken as input. This includes assessing all assets programmed for intervention within a specified timeframe, evaluating potential system disruptions, identifying opportunities for project bundling, determining if there are sufficient financial resources to carry out all the works, among others.

This implies that the second cycle underscores a strategic, medium-term / long-term perspective, with greater stakeholder consideration. Consequently, broader infrastructure objectives such as convenience, aesthetics, quality of life, and environmental impact are taken into account. Moreover, both internal and external boundary conditions are taken into account, highlighting a competitive dynamic for resources, where assets of higher importance often receive preferential treatment.

It should be noted that the prioritization of works for the sewage system is managed differently due to its distinct funding source. Consequently, in the second cycle, these assets are solely taken into account to identify potential disruptions and collaborations with other types of infrastructure, rather than for resource allocation.

Therefore, during this second cycle, alternative prioritization approaches become relevant as additional factors are analyzed. These include Area-oriented, Capacity-driven, and Collaboration-driven, which not only align with medium- and long-term objectives but also hold significance due to their resource management benefits (see Table 4.2). All of the aforementioned are visualized in Figure 6.2, where a distinction is made between both cycles, highlighting the key factors in each and the applicable intervention options (prioritization approaches).

Finally, with respect to the transition from the first prioritization cycle to the second, it was found that there exists a challenging gap between short-term and medium-/long-term perspectives. This gap is primarily rooted in the organizational structure of municipalities, where subgroups are solely responsible for the technical aspects of assets and not for their feasibility in terms of resource availability. This implies that experts who understand the condition of the asset and the type of intervention required are not always part of the discussion in the second cycle, where the focus is often more on resource management. In some cases, the second cycle of prioritization even occurs informally within the organization, which means there are no scheduled periodic meetings to discuss various R&R projects and plans, and resource allocation responds to what is considered urgent at the time.

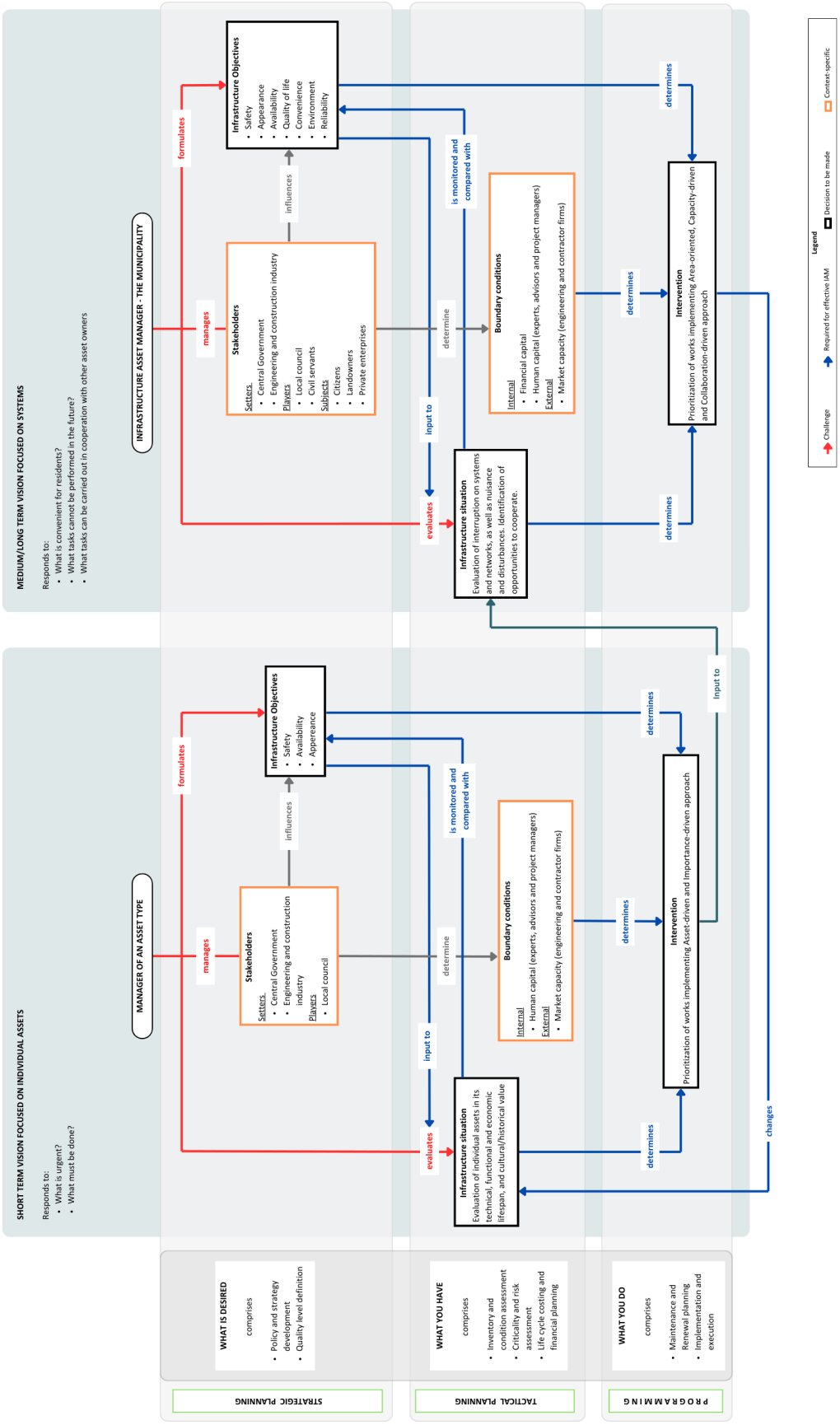

Figure 6.2: Infrastructure R&R prioritization process - Double cycle.

7

Define Phase Analysis

This chapter marks the conclusion of both the second phase of the research, Define, and the first diamond of the research methodology that focuses on the Problem. It analyzes the results of the case studies, identifying similarities, patterns, and differences. It also names new elements identified in the case studies that must be considered in the R&R work prioritization process and concludes with the prioritization problem for asset owners, specifically at the local level.

The chapter is divided into three sections. Section 7.1 presents the comparative analysis of the case studies. Section 7.2 explains the concept of Maturity level that categorised organizations managing infrastructure. Finally, Section 7.3 summarizes and interprets the challenges of prioritizing R&R work, thereby closing the first diamond and transitioning to the second one about solution development.

7.1. Case Study Comparative Analysis

This section introduces a comparative analysis of the case studies undertaken in the research. This analysis provides insights into common approaches, unique strategies, and recurring patterns, facilitating conclusions regarding the significance of diverse elements in the prioritization of R&R works.

The findings of the comparative analysis are presented in three categories corresponding to the planning levels shown in Figure 3.3, beginning with strategic planning and reviewing its components, which include stakeholders and infrastructure objectives. This is followed by tactical planning, encompassing infrastructure situation and boundary conditions. Finally, programming focuses on the decision-making regarding the type of intervention to be carried out.

7.1.1. Strategic Planning

- Regarding stakeholders, according to the description of municipalities in Chapter 5, it is notable that small municipalities tend to have predominantly agricultural land use, with marginal commercial use. This is relevant for understanding the municipality's political preferences and how they are reflected in the political parties leading the local council. However, the results did not find a direct relationship between land use, stakeholders "Subjects", and infrastructure objectives. As previously mentioned, stakeholders "Players" serve as intermediaries between "Subjects" and infrastructure objectives.
- A pattern identified in infrastructure objectives is their close alignment with governing policies and political agendas. These have the power to shape how risks related to infrastructure are evaluated, as seen in Utrecht, and the ranking of infrastructure objectives, as observed in Amsterdam.
- All municipalities prioritize Safety as the primary infrastructure objective. However, unlike other municipalities, Amsterdam places Availability in third place instead of second, giving priority to Sustainability in this case. This reflects the municipality's flexibility in organizational resources including not only environmental considerations in the list of objectives but also prioritising them. This implies that the organization has the capacity to carry out a more extensive and comprehensive decision-making process.

- Municipalities with areas recognized as UNESCO World Heritage Sites, such as Amsterdam, are compelled to consider additional factors, including aesthetic aspects, giving these areas separate and special treatment. This aligns with the Importance-driven approach.

7.1.2. Tactical Planning

- Each municipality has different timelines for infrastructure project planning. In the case of Amsterdam, it has a long-term vision that includes the R&R of all assets over periods exceeding 15 years. Utrecht adopts a medium-term vision with plans for 10-year periods, while Den Bosch has a short-term vision with projects spanning approximately 5 years.
- All municipalities assess the technical and functional situation of infrastructure separately for each asset type. Evaluations are based on a combination of standards, deciding based on the strictest criteria to ensure compliance with all applicable regulations.
- Sewerage has an exclusive funding source generated through taxes, thus this asset does not ”compete” for economic resources, unlike other infrastructure assets.
- In large municipalities, specialized teams focus exclusively on R&R works, whereas in small municipalities, these teams often overlap with routine maintenance personnel. Additionally, large municipalities with extensive infrastructure face higher personnel demands and have the flexibility to hire additional staff. Conversely, small municipalities, dealing with sporadic demands, find it less economical to hire staff for short-term requirements, often opting for subcontracting.
- Market capacity emerges as a critical boundary condition for both large and small municipalities. In all cases, interviewees justified that while economic financing may not be straightforward, it is always achievable. However, engineering and construction firms often face a shortage of personnel with the necessary knowledge and experience for the jobs.
- Since personnel responsible for infrastructure R&R are divided by asset types, implementing the area-oriented approach described in Chapter 3 is not feasible. Nevertheless, it was found that in many cases, municipalities group assets of the same type located in the same neighbourhood, which can be considered an alternative way to apply this prioritization approach.

7.1.3. Programming

- All municipalities adopt the Asset-driven and Importance-driven approaches as standard methods to prioritize R&R works. As a result, these approaches can be considered the default approach in responding to minimum required considerations.
- No municipality adopts the Area-oriented approach by grouping projects of different types of infrastructure within a given space, since communication between teams responsible for different types of infrastructure is minimal. However, within each team, projects of the same asset type have been grouped within a given space.
- Despite municipalities being aware of the concept of ”Flattening the curve of works” related to the Capacity-driven approach, its implementation is limited and aligned with the type of vision for project planning. It was not found to be comprehensive for all asset types and their entire lifecycle period.
- There is a significant dependence between the Capacity-driven approach and the availability of information about each infrastructure asset. Municipalities with limited information find it cumbersome and time-consuming, requiring additional financial and human resources to gather all necessary input to implement this approach.
- Regarding the Collaboration-driven approach, a pattern observed in municipalities is that while there are existing alliances to share R&R infrastructure learnings, none of them collaborate on jointly contracting works, such as portfolio contracts.

7.2. Organizational Maturity Level

Chapter 4 analyzed the different types of infrastructure managers in the Netherlands, highlighting the need for a detailed description and categorization of organizations operating at the local level due to their extensive variability in contextual conditions. This led to the introduction of the concept of organizational maturity. Additionally, the stakeholder analysis identified that the groups termed ”Players” (Local Council and Civil Servants) and ”Subjects” (Citizens, Landowners, and Private Enterprises) vary across different municipalities. Therefore, case studies should focus on these actors to identify their influence and relationship with the prioritization of R&R works.

The semi-structured interviews conducted within the case study, which included three municipalities of varying population sizes, revealed that the size and extent of a municipality are closely related to the size of the organization responsible for infrastructure and the internal boundary conditions for project implementation (financial capital and human resources). This is explained in the descriptions of Chapter 5 and illustrated in the organizational diagrams of the municipalities in Figures 5.1, 5.2, 5.3 and in the modified theoretical frameworks with information from each municipality in Appendix C. However, the size of the organization does not always reflect its capacity to decide and carry out infrastructure R&R tasks.

A clear example of this is the municipality of Utrecht, with a medium population size and the same number of municipal council members as Amsterdam, reflecting its national importance. Due to a lack of information about its infrastructure assets, this municipality has been delayed in its R&R tasks, forcing it to act reactively while the information gap is closed and it gains the capacity to plan projects strategically and proactively.

On the other hand, although Utrecht is still in the stage of assessing the infrastructure situation and determining the year in which the technical and functional lifespan of each asset ends, its plans are made for 10-year periods, implementing a medium-term vision for project planning. In contrast, Den Bosch, a smaller municipality with better records and availability of information about the state of its assets—thus being in a more advanced stage of the R&R process—currently plans its projects for 5-year periods, implying a short-term vision for its infrastructure tasks.

These findings suggest the need to differentiate between organizational size, project planning term, and the stage of the prioritization process the infrastructure manager is in. While the size of the municipality is important and indicates the availability of economic and human resources, other aspects such as information availability, planning terms, coordination level, and role definition also play a crucial role in how the municipality responds to infrastructure R&R demands. Implying that the characterization and classification of local organizations must respond to a comprehensive assessment of their capabilities. This leads the research back to the concept of organizational maturity, specifically the IM³, which focuses on infrastructure asset managers.

As previously described, IM³ includes seven asset management dimensions (information management, internal coordination, external coordination, market approach, risk management, processes and roles, and culture and leadership) that predominantly reside at the tactical planning level of the organization, aligning with its activities and scope (inventory and condition assessment, criticality and risk assessment, and life cycle costing and financial planning). As well as with the aspects identified by the case study as determinants of the organization’s capacity to carry out R&R tasks.

These dimensions are evaluated on a five-level maturity scale (ad hoc, repeatable, standard, managed, optimized) (Volker et al., 2013). This assessment provides a diagnosis of the organization’s capacity, enabling the classification of the municipality into specific maturity levels and identification of dimensions needing improvement.

Finally, it is concluded that interpreting the results of the case study with a focus on the infrastructure manager reveals that the prioritization options for R&R depend closely on the maturity level of the organization. Achieving higher maturity levels requires sufficient financial and human resources, as well as the freedom, flexibility and support to propose changes, aim for ambitious goals, and even experience failures in the process.

7.3. R&R Prioritization Challenges

Analyzing the results of the case study identifies the following three challenges for local infrastructure asset owners concerning infrastructure R&R.

First, **information management**, there is a significant dependence on the amount of information available about the asset and the municipality's flexibility to plan, decide, and prioritize. This dependence becomes a challenge when the municipality has a large volume of assets with missing as-built information or data lost during digitization processes, as well as insufficient records of past interventions and routine maintenance work. Another aspect of information management identified as a challenge is handling information as a single set. Given the extensive list of assets and the numerous variable factors to consider for each, managing and contrasting this information becomes exceedingly complex for municipalities. Consequently, in some cases, the municipality is divided into areas for management purposes.

Second, **internal coordination**, while all municipalities evaluate the infrastructure's situation (technical, functional, and economic) separately for each type of asset, this practice facilitates a deep understanding of each intervention case but naturally creates a disconnection between teams. This hampers the comprehensive analysis of R&R tasks and fosters ideological conflicts regarding desired infrastructure outcomes and practical conflicts in implementing plans. Thus, this division acts as a barrier to internal coordination within the organization.

Similarly, the execution of the R&R prioritization process in two cycles, with the first cycle focusing primarily on the technical and functional aspects of the asset and the second cycle considering economic and feasibility aspects at a higher organizational level, creates a knowledge and vision gap between the teams associated with each level of the organization/prioritization cycle. This gap not only hinders internal coordination but also complicates collaboration, project grouping, and optimal resource allocation. Figure 7.1 illustrates the challenge of internal coordination based on the Theoretical Framework of infrastructure R&R works.

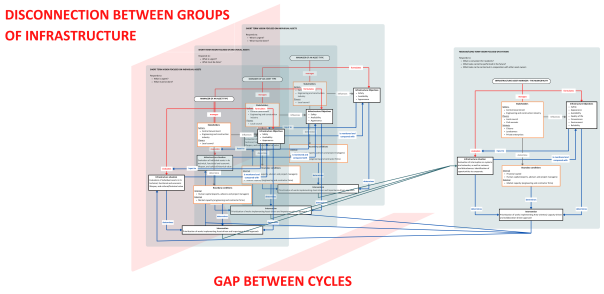

Figure 7.1: Internal coordination challenge.

Third, **uncertainty**, implementing prioritization approaches aligned with medium- and long-term visions, such as Area-oriented, Collaboration-driven, and Capacity-driven strategies, implies a challenge for the organization. This is not only because it requires shifting from an immediate, reactive culture to a strategic, proactive one, but also due to the uncertainty associated with future stakeholder interests. This uncertainty is reflected in concrete facts such as:

- Periodic changes in governance and political parties. The fact that users can elect council members implies that the focus and management preferences for local infrastructure are dynamic and can change radically every four years if users decide so. Consequently, although public officials, who typically remain consistent despite changes in leadership, can analyze stakeholder interests, predicting future preferences is as challenging as forecasting which political parties will dominate the municipality's governance in the next 20 years.
- Changes in standards and technological development. In the short and medium term, technical requirements appear relatively stable as they are defined by regulations that may remain valid for over 10 years. However, in the long term, technical requirements and technological transitions affecting infrastructure cannot be guaranteed and are difficult to predict.

III

Develop Phase

8

Roadmap Development

This chapter initiates the second diamond of the research methodology, focusing on the Solution and specifically addressing the Development stage. The primary objective is to answer SQ 4: How can municipalities decide between different prioritization approaches for infrastructure renovation and replacement works? To achieve this, divergent thinking is employed, facilitating the exploration of various ideas and different ways to propose solutions.

The chapter is structured into three sections through which the Roadmap is constructed. Section 8.1 outlines the objectives and target audience of the Roadmap. Section 8.2 details the elements and factors included in the Roadmap, as well as the levels and stages into which the information is divided and classified. Finally, Section 8.3 elucidates the resulting Roadmap and its interpretation.

8.1. Roadmap Purpose

The purpose of the roadmap, as derived from the research, is to provide comprehensive insight and knowledge about the process of prioritizing infrastructure R&R works, intending to assist municipalities in making informed decisions tailored to their specific contexts and settings. This roadmap details the identification of all the elements and factors involved in the prioritization process and delineates how these components interrelate. Additionally, it clarifies the role of the organization responsible for infrastructure management, distinguishing between the various stages, levels, and actors within the process. The primary target audience for this roadmap consists of local organizations managing infrastructure assets, specifically asset owners tasked with the prioritization of R&R works. Furthermore, the roadmap offers recommendations to enhance the municipality's capacity to plan and execute these R&R projects effectively.

8.2. Roadmap Design

The following describes the design process of the Roadmap, explaining the reasoning behind the choices made for the solution. This involves distinguishing between the elements and factors that comprise the R&R process and the stages and levels in which the process unfolds.

8.2.1. Elements and Factors

To develop the central point of the Roadmap, which will be further elaborated on in subsequent sections, the initial step is to distinguish between the elements that fundamentally constitute the R&R process and the factors that shape these elements. The characterization of these factors is context-dependent and therefore variable.

Figure 8.1 maps all the elements and factors of the R&R process derived from the literature review, without any particular order, and illustrates the connections between them. These connections are based on insights from both the literature and exploratory interviews. Additionally, the figure incorporates the five prioritization approaches identified during the exploratory interviews.

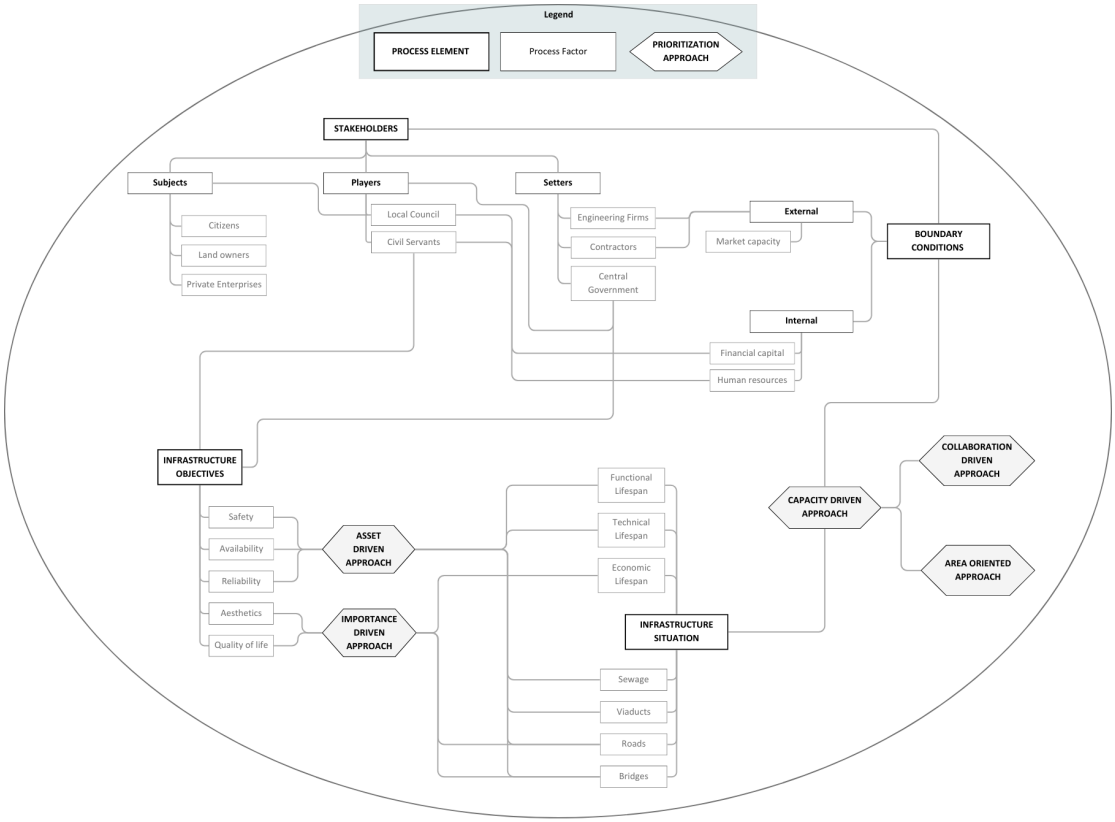

Figure 8.1: Elements and factors of the infrastructure R&R prioritization process.

This diagram serves as a comprehensive visualization of the entire R&R process, encompassing all relevant information. It facilitates the exploration of different ways to organize, classify, and present the process.

8.2.2. Levels and Stages

To effectively differentiate between the levels and stages in which the R&R process develops, it is essential to distinguish between two domains: the process itself and the municipality as the organization responsible for infrastructure.

First, the domain of the R&R process concerns the elements and their respective levels of authority, whether national or local. The stakeholder analysis presented in Chapter 4 is particularly useful for this purpose. It identifies that the stakeholders referred to as Setters operate at the national level, along with the corresponding External Boundary Conditions. Moreover, the analysis of prioritization approaches, as shown in Table 4.2, indicates that the collaboration-driven approach uses regional and national systems and networks as the implementation unit. Therefore, when presenting the process, it is crucial to distinguish between the national level—which includes Setters, External Boundary Conditions, and the Collaboration-driven Approach—and the local level, which encompasses the remaining elements and factors.

Second, the organizational domain pertains to the infrastructure asset owner. Literature suggests that IAM involves nine stages, which can be categorized into three planning levels. These levels vary in term and scope, ranging from long-term and organization-wide at the strategic level, to medium-term and specific functional units at the tactical level, and finally, to short-term and task-focused at the operational level, where activities are scheduled. The inclusion of this domain emerged from exploratory interviews where experts highlighted the importance of distinguishing which elements of the process belong to each stage (see Chapter 3). Consequently, the second version of the theoretical framework (Figure 3.3) includes the organizational domain, illustrating the relationship between elements and planning levels.

Furthermore, case studies validated the applicability and relevance of the maturity level concept as an indicator of the organization's capacity to handle the R&R task, primarily situated at the tactical level, as explained in Chapter 7. Specifically, maturity levels, ranging from Initial to Optimized, are connected to different prioritization approaches, indicating which approaches can be implemented by the organization at each maturity level. At the highest maturity level, all approaches are applicable, enabling the organization to achieve the maximum benefits.

In Figure 8.2, the domains and their corresponding division into levels and stages can be seen.

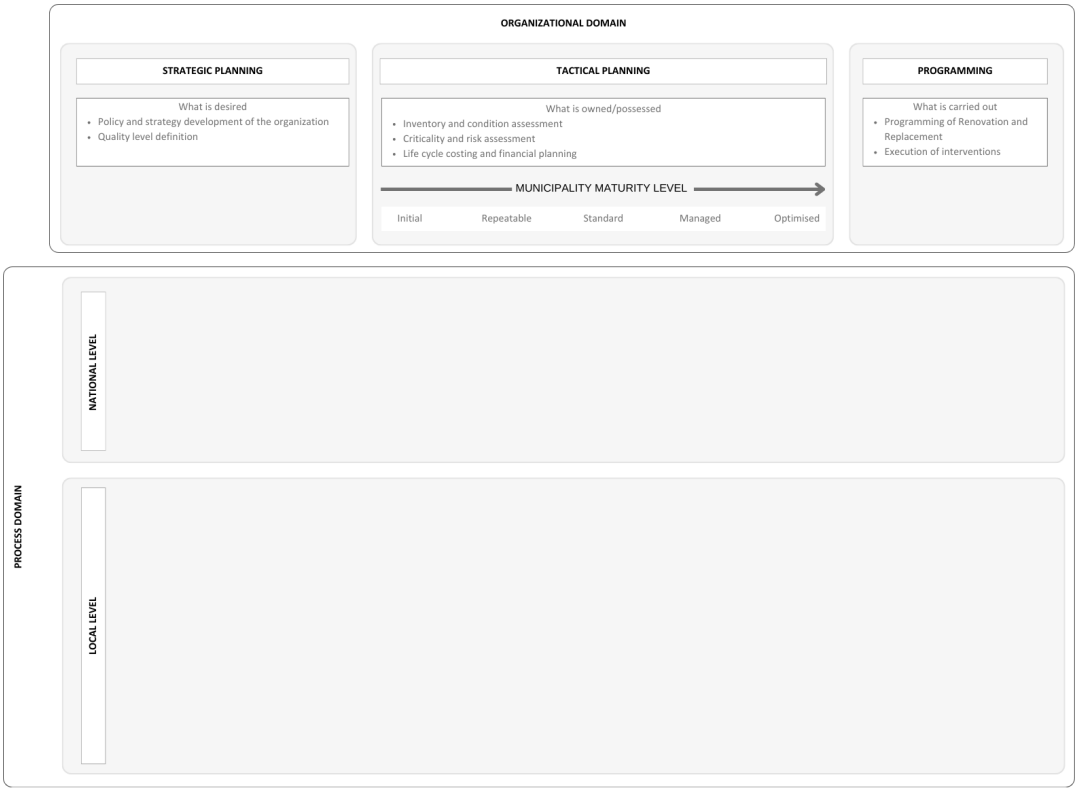

Figure 8.2: Domains, levels and stages of the infrastructure R&R prioritization process.

8.3. Roadmap Explanation

An analogy is chosen as the starting point to elucidate the roadmap. Imagine you are in the Netherlands and you want to travel to Tromsø, Norway, to see the Northern Lights. You have decided to make this journey by car. Naturally, you begin to plan the trip and make a list of everything you need to consider.

First, you evaluate the car: it's model and condition, whether it is suitable for a 3,000 km journey, and the speed and duration it can handle safely. Another crucial aspect is what keeps the car running—electricity and water need to be supplied periodically. You also consider their costs and where you can obtain them along the route.

Second, you consider the driver's condition: how many hours they can drive continuously, their sleep requirements, and their road experience.

Third, you think about the route: the countries and cities you will pass through, road conditions, speed limits, potential traffic when entering cities, and planned stops. You decide to first stop at Copenhagen, Denmark, and then at Ume, Sweden.

By combining all this information, you determine that, depending on the type and model of the car and the available budget, you may or may not reach Tromsø. Alternatively, you could reach Copenhagen and hope for one of those rare instances when the Northern Lights are visible there, or you could make it to Umeå, which increases your chances of seeing the lights.

You also realize that the travel time depends on both the road conditions and the car's and driver's capabilities. Driving a race car wouldn't save any time if the speed limit is 80 km/h, nor would it be beneficial if the driver or the car cannot maintain the maximum allowed speed.

Finally, taking all these factors into account, you decide to invest wisely in the best combination of car, driver, and route to ensure you reach Tromsø as quickly, safely, and affordably as possible.

This simple analogy helps in understanding the challenge of infrastructure R&R. In the context of this study, the car symbolizes the infrastructure asset owner (municipalities), with its model and type corresponding to the organizational structure, political agendas, and maturity level. The driver represents the team within the organization specifically responsible for R&R, thereby also indicating the organization's maturity level. The electricity and water required for the car to operate refer to the internal boundary conditions, namely the financial and human resources necessary for project execution. The road represents the external boundary conditions, which is the market's capacity to undertake R&R projects. Finally, the stops or alternative destinations represent the different prioritization approaches.

First Milestone: Asset-Driven and Importance-Driven Approaches

- Destination: Copenhagen

In the scenario where the journey to Tromsø shifts to Copenhagen, the prioritization of R&R infrastructure projects follows an Asset-driven and Importance-driven approach. This is due to the organization's low maturity level, preventing any forward-looking planning beyond these immediate concerns.

This process is illustrated in detail in Figure 8.3. Initially, in the organizational domain, a strategic plan is formulated, encompassing the development of policies and the definition of quality levels, essentially determining the desired outcomes. In the R&R process domain, the key element from which everything else derives is identified: the stakeholders. Here, Players, driven by Central Government regulatory demands, set the infrastructure objectives, the second process element, aiming to benefit the Subjects.

Once the criteria for evaluating the infrastructure are defined, planning proceeds to the tactical level. At this stage, available resources and infrastructure are assessed. On one hand, the infrastructure situation, the third process element, is determined through inventory and condition evaluation of the assets (technical, functional, and economic). For municipalities, this primarily involves four types of infrastructure: sewer systems, viaducts, roads, and bridges. On the other hand, boundary conditions for project execution, the fourth element of the R&R process, are identified. These include external boundaries from engineering firms and contractors (market capacity) and internal boundaries from the Local Council and Civil Servants (financial and human resources).

Despite having identified all the elements of the R&R process at this point, the organization's maturity level shows that, due to the lack of standardized processes, a comprehensive analysis of these elements is not possible. Consequently, transitioning to the next stage of organizational domain task programming is done based on minimum requirements for individual asset units. Task prioritization is thus driven by asset risk assessment, employing an Asset-driven approach that focuses on addressing urgent needs.

Additionally, at this point, there is a variant: the Importance-driven approach, applicable only to roads and bridges of significant cultural, historical, or economic importance to the country. In these cases, prioritization is based not on urgency but on the necessity to preserve the asset's value.

All the aforementioned considerations imply that expecting to fully and timely address R&R infrastructure tasks through a prioritization approach that evaluates assets individually and independently of resource availability, as well as the internal capabilities of the organization and the market, is highly improbable. This is comparable to travelling to Copenhagen with the expectation of seeing the Northern Lights.

The most reliable way to achieve the goal of witnessing the Northern Lights is to reach Tromsø, with Copenhagen serving merely as an intermediary stop rather than the final destination. Similarly, to effectively address the R&R challenge, it is essential to consider the condition and importance of the assets. However, this should not be the sole basis for project programming. Instead, this information should be utilized as input for the subsequent stages of the process.

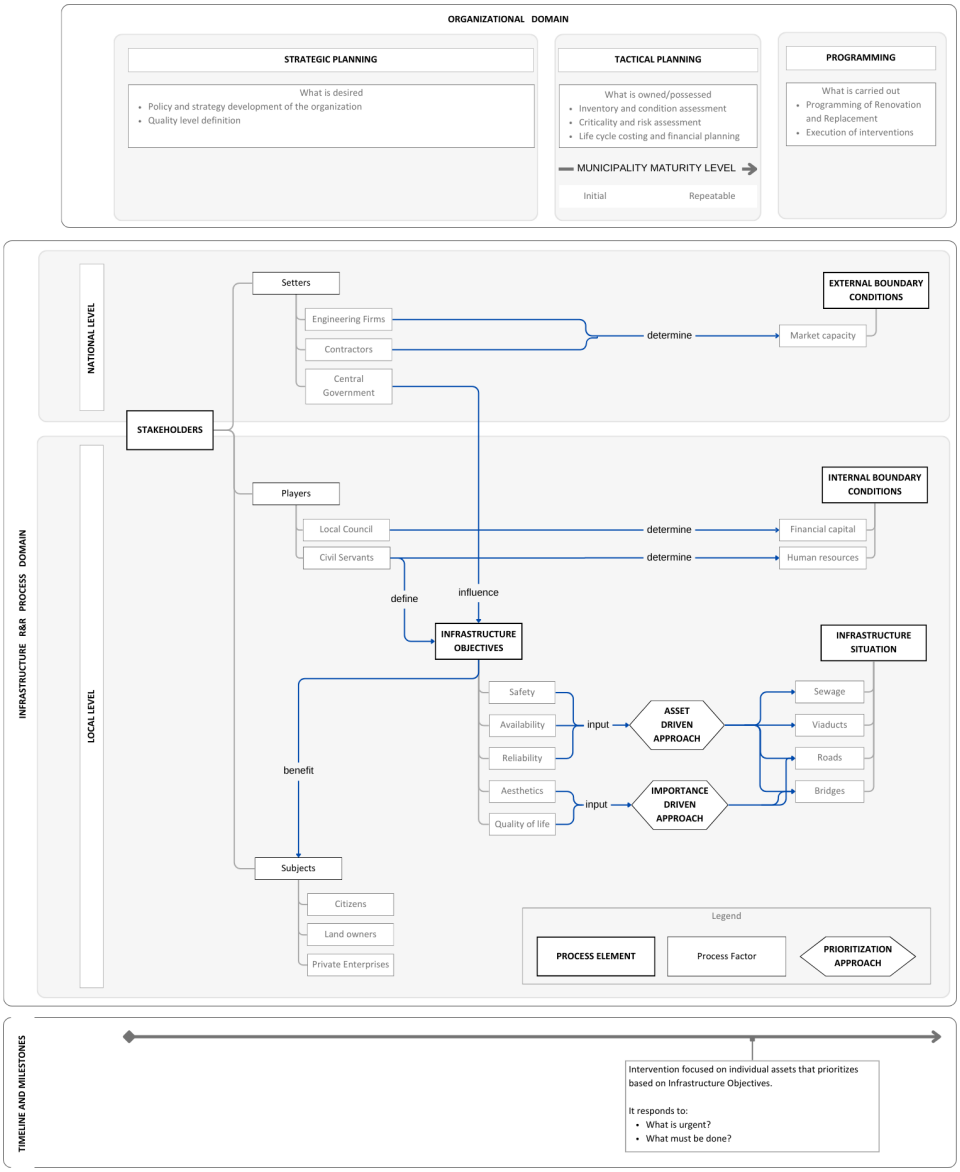

Figure 8.3: Roadmap: first milestone (Copenhagen).

Second Milestone: Capacity-Driven Approach

- Destination: Ume

In the scenario where the final destination is Ume, the prioritization of R&R infrastructure projects follows a Capacity-driven approach. This approach leverages a high level of organizational maturity. However, the organization has limited flexibility to implement structural changes and incorporate new methodologies to optimize processes.

This process is illustrated in detail in Figure 8.4. In the organizational domain, specifically at the tactical planning level, an extension is presented. The existing activities remain intact, but two new maturity levels—standard and managed—are now included. This growth in organizational capabilities allows the R&R teams to perform comprehensive and integrated analyses.

In the R&R process domain, on the one hand, it is shown that by contrasting internal boundary conditions with external ones, the capacity limit is determined. On the other hand, by consolidating all information regarding the infrastructure's situation—namely the totality of tasks with their respective intervention dates—the timeframe and scope of activities comprising the R&R challenge in the municipality are determined. Subsequently, this information is compared and analyzed to identify tasks that

cannot be completed in the future due to exceeding capacity limits and the periods when demand for work surpasses what the organization and the market can carry out.

At this point, the process moves to the programming stage, where R&R tasks are prioritized based on a comprehensive view of the workload over time. The goal is to ensure that all tasks are executed, either by scheduling interventions in advance (before the end of their lifespan) or by delaying them (extending their lifespan) to periods when capacity exceeds demand. This approach spreads the work evenly over time, avoiding peaks in workload.

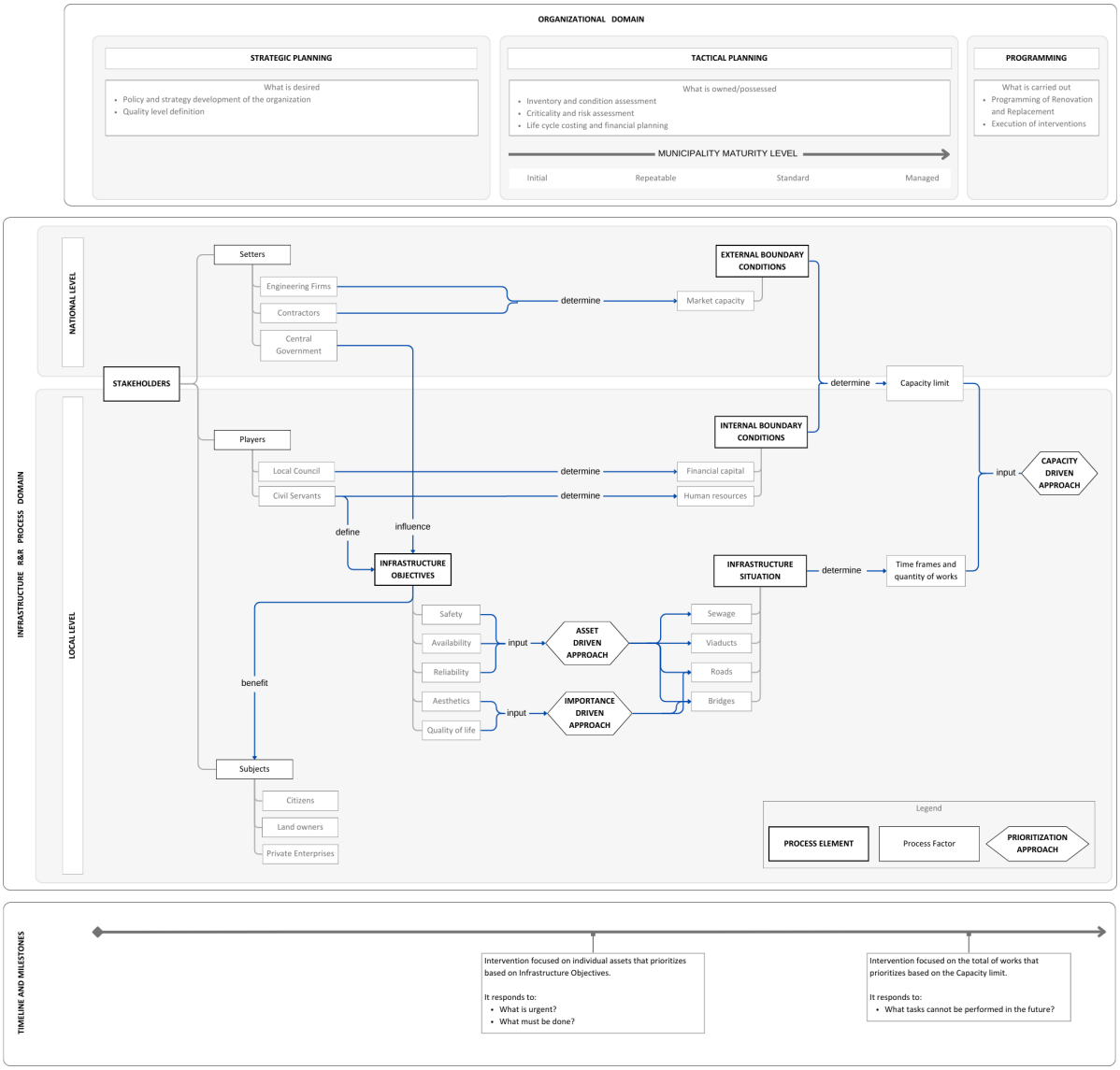

Figure 8.4: Roadmap: second milestone (Umeå).

From the above, it can be concluded that while the prioritization of tasks using the asset-driven, Importance driven, and Capacity-driven approaches, in that respective order, provides the municipality with a significantly favourable advantage to address the R&R challenge—comparable to seeing the Northern Lights from Ume—this approach is strictly limited to compliance. It does not consider options for resource optimization or adding value for stakeholders, which would be equivalent to reaching Tromsø, where the chances of successfully seeing the Northern Lights are very high.

Prioritization of the infrastructure R&R task: Collaboration-Driven and Area oriented approaches

- Destination: Tromsø

In the best-case scenario where the final destination is Tromsø, the prioritization of R&R infrastructure projects employs a Collaboration-driven and Area-oriented approach. This scenario involves an organization at the highest maturity level, which proactively seeks to improve its practices, goes beyond basic requirements, and has the capacity to implement structural changes to maintain high levels of effectiveness and performance.

As shown in Figure 8.5, after defining which tasks need to be advanced or delayed, the team responsible for infrastructure R&R analyzes the capacity limit to identify the leading boundary condition—whether it is market capacity, financial resources, or human resources—that leads the delta or difference between the number of required tasks and the number of tasks that can be completed.

With this understanding, it becomes possible to program tasks and use the prioritization approach that best addresses the leading boundary condition, thereby expanding capacity. Returning to the analogy, this is comparable to investing in a car that can reach the maximum allowed speed on the highway, rather than a race car that will never be used to its full potential. Alternatively, it could mean choosing a car and selecting the highest-speed roads, even if it means paying higher tolls, to ensure timely arrival during the Northern Lights season.

In other words, it is about considering all elements and how they affect each other. Task prioritization must account for asset situation, importance, total number of tasks, and internal and external capacities. Then, it must go a step further by programming projects in a way that groups assets and collaborates with other asset owners in contracting these projects.

Collaborating with other infrastructure managers (at the same or different levels of authority, whether local, regional, or national) who also need to perform R&R tasks through long-term portfolio contracts creates a learning curve that benefits both the market and public organizations. The Collaboration-driven approach reduces time, errors and risk in the performance of works and even promotes investment in innovation by ensuring a constant cash flow. However, it is recognized that portfolio contracting may not always be feasible due to the varying nature of assets or projects.

Another approach to go beyond basic requirements, which should be equally implemented, involves grouping assets within the same area into a single project. This again involves collaboration, but internally within the organization, among teams responsible for the R&R of different types of infrastructure assets. The Area-oriented approach reduces costs, interruptions, and disturbances to residents, thus improving their quality of life and convenience.

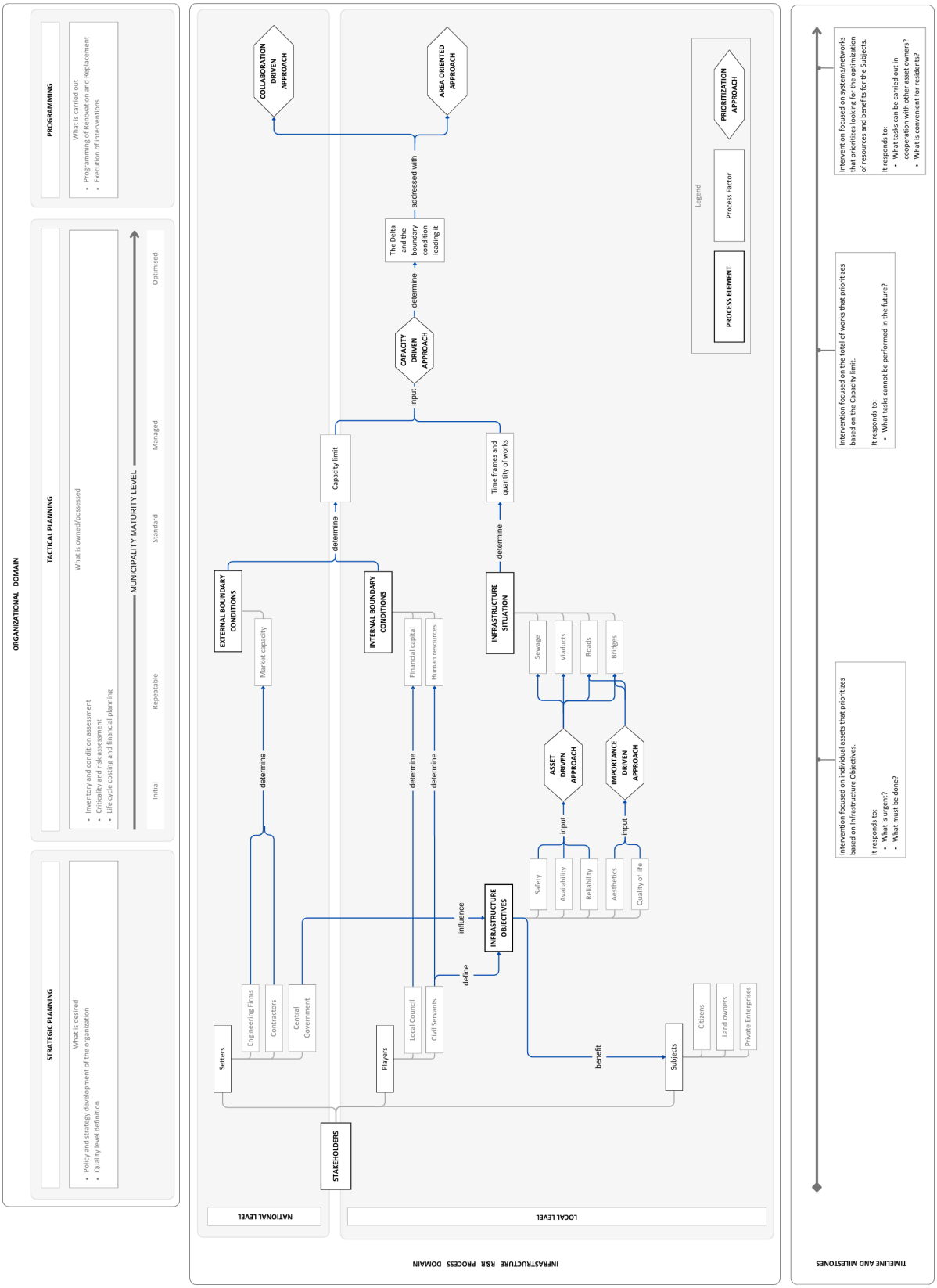

Figure 8.5: Roadmap for the prioritization of R&R works.

SUPPORT SHEET - CONCEPTS AND DEFINITIONS

Prioritization approaches

Prioritization approach	Definition	Vision term	Predecessor	Assessment		
				Question	Unit	Criteria
Asset driven	Prioritizes based on asset lifespan, ensuring safety and, availability. It includes cases where insufficient information on asset condition leads to prioritization due to uncertainty about risk.	Short	None	What is urgent?	Individual asset	Technical condition, performance and functionality, maintenance cost, information availability
Importance driven	Prioritizes unique assets vital for economic development, cultural value, or political commitments, maintaining credibility and trust in leaders and the organization in charge.	Short	None	What must be done?	Individual asset	Cultural/historical value, political commitment
Capacity driven	Prioritizes R&R tasks based on owner capacity, aiming for a steady workload over time. Uses long-term planning to manage peaks by advancing or postponing tasks, ensuring infrastructure value and safety.	Long	Asset driven and Importance driven	What tasks cannot be performed in the future?	All local assets	Financial capital, Human capital (technical experts, managers and manpower) and, materials
Area oriented	Prioritizes the grouping of R&R projects in the same area to minimize disruptions. Identifies all assets in need of R&R within a timeframe and schedules them together. It implies internal collaboration.	Mid	Asset driven, Importance driven and, capacity driven	What is convenient for residents?	Assets in a block/ area	Disturbance and nuisance
Collaboration driven	Prioritizes R&R for similar assets owned by multiple entities, bundling them into a single contract for efficiency. This reduces timeframes and costs, appealing to contractors and encouraging innovation through long-term financial security.	Mid	Asset driven, Importance driven and, capacity driven	What tasks can be carried out in cooperation with other asset owners?	System/network in the regional/ national level	Standard technical features and, common construction method of assets

Organizational maturity

Level	Description
Ad hoc	The organisation has limited experience and is at a learning and development stage.
Repeatable	The organisation can repeat what it has done before, but not necessarily define what it does.
Standard	The organization can say what it does and how it goes about it.
Managed	The organization can control what it does in the way of processes. It specifies requirements and ensures that these are met through feedback.
Optimised	The organization is "best practice," capable of learning and adapting itself. It not only uses experience to correct any problems but also uses experience to change the way it operates.

(Williams et al., 2003)

Asset Management Dimension	Description
Information management	The availability and use of (standardized) static and dynamic databases for decision making.
Internal coordination	Coordination and problem solving between the different departments of the organization.
External coordination	Coordination and problem solving between the different stakeholders of a project, including communication with users.
Market approach	Strategy about and implementation of integrated and performance based contracting and innovative procurement methods.
Risk management	The use of risk management methods and Life Cycle approaches in decisions on strategic and operational asset management level.
Processes and roles	Clarity, definition and implementation of job responsibilities and roles within the organization.
Culture and leadership	Level of knowledge, implementation and support of asset management related issues.

(Volker et al., 2011)

Figure 8.6: Roadmap support sheet.

Additional considerations

- Alternative scenarios

Both the collaboration-driven and area-oriented approaches are, by definition, relatively simple, and the asset owner might consider their early implementation, that is, after the asset-driven approach, which will always be the first to implement. However, the asset owner who decides to take this shortcut will encounter additional challenges and will not achieve the benefits these approaches promise.

To schedule joint projects involving different types of infrastructure (Area-oriented) or different asset owners (Collaboration-driven), at a minimum, information about local assets and time (flexibility) to schedule the project/portfolio with other teams/organizations is required. An owner implementing only the Asset-driven approach does not have this information, as they only possess details on assets needing urgent intervention (a reactive view of R&R tasks). This means they lack comprehensive information on local assets and the time and flexibility to plan and schedule projects, adapting to the agendas and needs of the collaborating parties.

Moreover, even if the asset owner occasionally manages to program projects using either of these collaborative approaches (internal or external), the benefits and advantages they offer will be minimally achieved. Projects will be scheduled without a strategic and long-term vision for R&R tasks. For instance, if the collaboration-driven approach is implemented, it will always benefit from a steep learning curve and will encourage market investment in innovation. However, it will be challenging to intentionally address specific market shortages and efficiently invest resources without a broad vision and options to compare and evaluate.

Successful implementation of both external and internal collaboration requires changes in the organizational structure of municipalities. Currently, these entities are not designed to facilitate team collaboration, as teams are often unaware of what other teams are planning and the criteria they use (see 7.1). Additionally, there is no common information and reporting platform for infrastructure owners, further complicating the collaboration for resource and personnel allocation.

Another important consideration is the scenario where the asset owner does not start from the strategic level, analyzing stakeholders and defining objectives, but instead goes directly to the tactical planning of R&R tasks. In this scenario, objectives related to the technical and functional condition of the assets will be considered by default, as they are stipulated in regulations for the design or redesign of infrastructure. However, other objectives, such as quality of life, will remain ignored. Additionally, resources will be included in the analysis, but traceability will be complicated, increasing the risk of inefficient use of resources and unmanaged involvement of stakeholders, as they are barely identified.

Taking into account these alternative scenarios and recognizing that they represent the majority of municipalities in the Netherlands, which exhibit low to medium levels of organizational maturity, the study proposes a set of practical recommendations (Chapter 10) aimed at providing guidance and concrete actions to help overcome current challenges and improve organizational capacity.

IV

Deliver Phase

9

Discussion

This chapter marks the initiation of the final phase of the research methodology. During the delivery phase, convergent thinking is employed to critically reflect on the study's results and findings and their implications for the current body of knowledge and industry.

The chapter is structured into five sections. Section 9.1 provides a summary of the study's purpose and research questions. Section 9.2 offers a general reflection on the research, serving as an introduction to the detailed discussion of findings in Section 9.3, which explains the implications of the findings in the context of the research questions and literature. Section 9.4 analyzes the applicability of the results and the proposed Roadmap. Finally, Section 9.5 discusses the limitations related to the study's design and methodology.

9.1. Purpose of the Study

This study aims to improve the understanding of the elements, factors, and conditions that are part of the planning and prioritization process for infrastructure R&R works. By investigating these determinants, the study aims to develop a comprehensive Roadmap that provides insights into the process and guides municipalities in effectively choosing prioritization approaches for R&R tasks, thereby responding to stakeholder demands and optimizing resource allocation.

To achieve this objective, the study addresses the primary research question: How can municipalities in the Netherlands effectively prioritize infrastructure renovation and replacement works to meet stakeholders' demands and optimize resources? To provide a comprehensive answer to this question, the research also examines the challenges of prioritizing infrastructure R&R works, the interests and influences of various stakeholders on this prioritization, the current practices of infrastructure asset owners in prioritizing their R&R tasks, and the decision-making processes municipalities use to choose between different prioritization approaches.

9.2. General Reflection

The study is grounded in the urgent need to unravel the challenge of prioritization of infrastructure R&R works, understanding its components, and providing theoretical guidelines for decision-making. This was achieved through research comprising four phases, relying on both theories related to the main topic and empirical investigation. The findings of the research indicate that, although the theory does not explicitly describe the prioritization process or the various prioritization options, it does include the elements that constitute each of them and even theories such as the concept of organizational maturity that connects the various findings of the research. In this regard, the present study is considered to have validated, connected, and reinterpreted previous studies, as well as contributed to the development of certain theories. The following section discusses in greater detail the theories and proposals that this research complements and supports.

9.3. Discussion of Research Findings

To discuss the findings of this study, the discussion begins with the quote that introduced the problem of prioritizing R&R works at the beginning of this document. Schraven et al. (2011) stated that the main challenge facing infrastructure managers in their efforts to improve the effectiveness of decision-making is the alignment between three decision areas: objective, situation, and intervention. This study concludes that if this challenge is redefined from practical terms focused on specific actions to more general terms that consider actions within an organizational context, the main challenge to increasing the effectiveness of task prioritization is the lack of organizational maturity.

- Challenges of infrastructure R&R

The study identifies that although Volker et al. (2011) seven dimensions of asset management, described in the concept of organizational maturity, are certainly challenging for local asset owners, two dimensions are particularly critical: information management and internal coordination.

Firstly, regarding information management, the study reiterates and confirms what previous research has emphasized: decision-making about interventions and asset condition assessment depends on the availability of reliable and up-to-date data, aligning with the findings of Di Sivo and Ladiana (2011) and Schraven et al. (2011).

Secondly, concerning internal coordination, it is important to note that this challenge was omitted from the literature review because it appeared in only one article, making it seem less significant compared to other challenges. Had this challenge been considered from the outset, the study could have focused more extensively on the organizational aspect. Nonetheless, the research revealed that internal coordination plays a critical role in enabling local organizations to effectively prioritize R&R tasks. This finding supports the concept of silo mentality as proposed by Parlikad and Jafari (2016), which suggests that organizations often operate in isolated silos based on traditional disciplines. This structure complicates the prioritization of interdisciplinary assets, as each department competes for limited funds.

Furthermore, it is found that Vanier (2001) study, which emphasizes the need for seamless data integration and information exchange, as and Parlikad and Jafari (2016) study, which states that effective asset management requires good communication, interdepartmental information exchange, and a clear understanding of network value, both coincide in combining information management with internal coordination. This suggests that while information management can be assessed and evaluated individually within each department, internal coordination must be evaluated in terms of information management and decision-making processes. Therefore, achieving effective internal coordination requires strong foundations in information management.

This research also identified other challenges that, although not dimensions of asset management, add complexity to these processes: uncertainty and bureaucracy. Uncertainty in this study is associated with changing political agendas, technical regulations, and stakeholder interests. This challenge particularly affects and adds complexity to dimensions such market orientation, risk management, and external coordination. This relates with the findings of Rasker et al. (2023), who also acknowledges uncertainty as a factor contributing to the complexity of the R&R task. However, in this study, uncertainty is specifically tied to the breadth of tasks and the frequent lack of awareness among infrastructure owners regarding the condition of their assets.

Bureaucracy, on the other hand, involves all the logistics of decision-making, especially resource allocation, where there can be a discrepancy between the priorities of those allocating resources and those responsible for guaranteeing asset integrity. This aligns with Volker et al. (2013) assertion that politics play a significant role in public organizations in the allocation of budgets for asset management. Furthermore, operating in a historical context with substantial stakeholder responsibility, these organizations are entangled in bureaucratic structures that can delay the further implementation of asset management processes.

-Moving from the challenges of prioritizing R&R tasks to specific prioritization approaches, it is known from the literature review that the current state of the art lacks concrete and explicit definitions characterizing various prioritization approaches. This study addresses this gap by providing valuable insights into prioritization processes within local infrastructure management organizations. Distinguishing be-

tween different approaches, their elements, associated factors, and the organizational prerequisites for their successful implementation.-

- Infrastructure R&R prioritization approaches

Among the five prioritization approaches proposed (Asset-driven, Importance-driven, Area-oriented, Capacity-driven, and Collaboration-driven), only the Asset-driven approach has comprehensive support in existing literature, although not under this specific terminology, as coined in this research. There exists substantial information on activities associated with this approach, such as evaluating asset technical and functional conditions and interpreting inspection outcomes. Consequently, the Asset-driven approach stands out as the most standardized and widely adopted in the industry.

Additionally, this study asserts that while the Asset-driven approach is essential, it should complement rather than singularly dictate decision-making. It should be integrated with other approaches that consider diverse aspects, enabling comprehensive and strategic task prioritization. This perspective aligns with E. G. Too (2012) findings, emphasizing that current practices predominantly focus on operational levels and individual assets, reliant on databases, asset inventories, technical models, and analytical tools. This author also underscores asset management's need to adopt a proactive stance, combining engineering principles with robust business practices, information management, economic theory, and traditional maintenance concerns.

- Recommendations for effective infrastructure R&R

It can be argued that this study responds to E. G. Too (2012) suggestion, who proposed that improving asset management performance requires addressing three issues: adopting a strategic approach, developing a process framework to guide decision-making, and identifying and developing core capabilities necessary to effectively execute strategic processes. In this regard, this research takes a proactive stance in asset management by developing a Roadmap for decision-making and identifying the necessary organizational capabilities. These capabilities encompass management dimensions embedded within the concept of organizational maturity. This not only underscores the relevance of the current study but also highlights the added value it contributes to the state of the art and, to the industry in overcoming the three issues identified by E. G. Too (2012).

Finally, this research emphasizes the importance of both internal and external collaboration to address the urgent challenge of R&R in infrastructure. Di Sivo and Ladiana (2011) suggest that internal system integration should be the first challenge to improve efficacy and that Public Administrations and Authorities developing territorial management tools must share their experiences and best practices with other managers. Similarly, the forecast from Rasker et al. (2023) recommends promoting collaboration among managers and across administrative levels, utilizing clear communication and flexible strategies. This research aligns with Di Sivo and Ladiana (2011) and Rasker et al. (2023) perspective and goes a step further by proposing that these integrations and collaborations should extend to the contractual level. Projects should be tendered jointly, either by combining projects located in the same area and addressing different disciplines within the organization (Area-oriented approach) or in collaboration with other asset owners who need to renew assets with similar characteristics, making the tendering of a portfolio contract convenient (Collaboration-driven approach).

9.4. Applicability of the Research

The applicability of the developed Roadmap for prioritizing R&R works in infrastructure management is grounded in its dual foundation: a thorough literature review and insights from experts actively working in organizations managing infrastructure in the Netherlands. This ensures the Roadmap is both theoretically rigorous and practically applicable.

Specifically tailored to meet the needs and conditions of local asset owners in the Netherlands, the Roadmap integrates practices and lessons learned from the field to address the unique challenges and requirements faced by infrastructure managers in this region. It ensures that its recommendations are immediately applicable and practical for asset owners in the Netherlands by focusing on contextual relevance. Additionally, while designed with local conditions in mind, the Roadmap's principles and methodologies are adaptable for use in various contexts and levels of authority, emphasizing scalability

and flexibility. Moreover, the Roadmap promotes continuous improvement through ongoing evaluation and refinement based on feedback from its application. It allows asset owners to continuously adapt the guidelines to evolving conditions and emerging challenges, thereby ensuring sustained relevance and utility.

9.5. Limitations of the Research

The study presents the following limitations associated with its methodological aspects:

- **Literature Review:** Regarding the availability of information on prioritization approaches for infrastructure R&R projects, it was found that since the challenge of prioritization is relatively new and has gained attention, especially in the last five years, it is in a relatively early stage. Consequently, there is still no comprehensive record of the practices of infrastructure owners or advanced research on this topic, with existing literature focusing more on the problem rather than possible solutions. This led the present study to propose and provide recommendations based primarily on the empirical part of the research. This implies that the findings are somewhat susceptible to personal judgment bias.
- **Case Study:** The research is based on three case studies, which, while capturing the variability of contextual conditions in which the prioritization of infrastructure projects is conducted, acknowledge that many different scenarios should be considered. Therefore, the findings of the present study should be critically evaluated before implementation.
- **Number of Interviewees in Case Studies:** A limited number of interviewees was selected, focusing solely on roles responsible for decision-making in the prioritization of infrastructure projects. However, due to the fact that municipalities have dedicated teams for specific types of infrastructure, the interviews were conducted primarily with managers in charge of bridges, only partially incorporating the perspectives of those responsible for other types of infrastructure. While this limitation is justified and allows for the collection of sufficient and pertinent information, it also implies a bias towards the information and perceptions of those overseeing processes for a specific type.
- **Validation:** Considering that the theoretical framework information was contrasted with exploratory interviews and the hypotheses from the discovery part of the research were confronted with the case studies, all information included in the Roadmap had been evaluated by experts beforehand. Therefore, an additional validation was not deemed necessary. This means that the Roadmap has only been tested in its theoretical aspect and not applied in practice, mainly due to time constraints, and thus its effectiveness in concrete scenarios remains unproven.

10

Conclusion

This chapter marks the conclusion of the second diamond in the research methodology, signifying the completion of the study and the Delivery phase. It consists of three sections. Section 10.1 addresses the research sub-questions as well as the main question. Section 10.2 presents the author's recommendations to the industry, and finally, Section 10.3 suggests additional research avenues that were not covered in this study or that could further develop its findings.

10.1. Answering Research Questions

Below are the answers to the research questions posed at the beginning of the study.

SQ 1: What are the challenges of prioritizing infrastructure renovation and replacement works?

The prioritization of infrastructure R&R projects presents significant challenges due to the complexity of managing multiple factors, stakeholders, and dynamic conditions. These challenges were identified through a literature review (Chapter 2), and validated with exploratory interviews (Chapter 3), and case studies (Chapter 7). The key challenges are:

- **Defining Objectives:** Interpreting policies, norms, and strategic goals to define quantifiable objectives for the infrastructure (Dekker, 1996; Schraven et al., 2011; E. G. Too, 2012).
- **Managing Multiple Stakeholders:** Balancing the interests and expectations of various stakeholders in infrastructure assets and incorporating them into the decision-making process (Dekker, 1996; Schraven et al., 2011).
- **Infrastructure Assessment:** Evaluating the technical and functional performance of infrastructure is hindered by inadequate monitoring systems and poor information management (Foundation, 1996; Pathirana et al., 2021; Vanier, 2001).
- **Aligning Decision Areas:** Aligning decisions regarding infrastructure objectives, situations, and interventions while anticipating changes in each area and avoiding premature convergence on solutions that exclude other viable options (Schraven et al., 2011; E. G. Too, 2010).
- **Information Management:** Ensuring complete and accurate documentation of asset information, including construction details and past interventions (Di Sivo & Ladiana, 2011).
- **Internal Coordination:** Integrating and collaborating across departments and disciplines within the organization to comprehensively analyze asset prioritization (Parlikad & Jafari, 2016).
- **Managing Uncertainty:** Predicting changes in political agendas, technical regulations for infrastructure, and technological developments (Hertogh et al., 2018; Schraven et al., 2011). This also involves having organizational flexibility and adaptability to respond to the dynamic nature of the factors involved in the R&R prioritization process.
- **Managing Political Influence:** Making timely and even anticipatory decisions and resource allocations for infrastructure R&R, ensuring that politicians and public servants responsible for approving investments understand the urgency and risk related to assets' R&R (Volker et al., 2013).

SQ 2: What are the interests and influence of each infrastructure stakeholder on the prioritization of renovation and replacement works?

Stakeholders in the infrastructure sector exhibit varying degrees of interest and influence, these can be categorized into Crowds, Subjects, Setters, and Players according to Mendelow (1991) and Eden and Ackermann (2013). The complete stakeholders analysis can be found in Chapter 4 and Figure 4.1.

- **Crowd Stakeholders:** NGOs, suppliers, and tourists typically have low interest and power concerning infrastructure R&R. NGOs' interest may increase based on specific contexts. However, their overall influence remains limited, primarily operating at the national level. Suppliers and tourists indirectly impact infrastructure through intermediary actors, such as hospitality and construction firms, respectively.
- **Subjects Stakeholders:** Citizens, landowners, and private enterprises fall into this category with high interest but limited power. They heavily influence infrastructure objectives, prioritizing safety, comfort, and convenience. Through democratic processes, they transfer power to elected politicians who manage infrastructure assets based on public interests and local needs.
- **Setters Stakeholders:** Central government, engineering firms, and construction companies possess significant power but moderate interest. They set national standards and market capacities for infrastructure R&R works. Central governments enforce policies and technical regulations, while engineering and construction firms define the market's capacity to undertake projects.
- **Players Stakeholders:** Local councils and officials hold considerable influence and interest in infrastructure management. They play a crucial role in internal decision-making, allocating resources and setting local objectives for R&R projects.

SQ 3: How do infrastructure asset owners currently prioritize their renovation and replacement works?

Based on exploratory interviews and case studies, the process that asset owners in the Netherlands use to prioritize infrastructure R&R work is identified. This process includes various elements and factors detailed in the Literature Review (Chapter 2). As shown in Figure 6.2, the R&R process implemented by local asset owners is structured as two prioritization cycles.

The first cycle occurs within each department dedicated to a specific type of infrastructure or field of expertise. Each group evaluates the condition of their respective assets based on the infrastructure's objectives—typically safety, availability, and appearance—assessing the technical, functional, and economic lifespan of each asset individually. After evaluating the infrastructure's condition, each subgroup applies two prioritization approaches: asset-driven and importance-driven. The asset-driven approach prioritizes assets that are urgent due to associated risks, while the importance-driven approach focuses on assets that must be addressed due to their social, cultural, historical, or political value. Additionally, the organization's internal capacity, including the availability of personnel to manage and supervise projects, is marginally considered in this first cycle.

Once each infrastructure type group has its prioritized list of assets, these lists enter the second prioritization cycle collectively. In this cycle, additional factors are considered to provide a broader view of the R&R tasks and the organization's capacity to execute them. At this stage, potential conflicts among projects from different departments are checked, and resource allocation is carried out. Some municipalities conduct more comprehensive analyses than others, considering factors such as convenience for residents, future workloads, capacity for execution, and potential opportunities for contractual collaboration with other asset owners.

However, in most cases, the second cycle focuses mainly on the financial and practical feasibility of projects prioritized for reasons of urgency or social/cultural obligations. Each prioritization cycle involves different professionals within the organization, each bringing a unique perspective on the R&R tasks. It is important to note that, in most cases, the second prioritization cycle is not well-defined within the organization and tends to be more reactive than proactive. This allows civil servants the freedom to make decisions as simple or comprehensive as they deem necessary.

Likewise, it must be distinguished that the sewage system is managed differently from other local assets, as it has a separate funding source. Residents pay a tax that is exclusively allocated to this system. This means that these assets do not compete for resources; therefore, in the second prioritization cycle, they are considered only to evaluate whether there are interruptions or opportunities for collaboration with other projects.

SQ 4: How can municipalities decide between different prioritization approaches for infrastructure renovation and replacement works?

Municipalities can choose different approaches for prioritizing infrastructure R&R work based on their level of organizational maturity. The concept of organizational maturity, proposed by Volker et al. (2011), classifies organizations into five maturity levels (initial, repeatable, standard, managed and, optimized) based on their capacity to achieve objectives. These levels account for the state of the organization in seven dimensions of asset management: information management, internal coordination, external coordination, market approach, risk management, processes and roles, and culture and leadership (detailed in Chapter 4).

Once an organization understands its maturity level, it can determine which prioritization approaches are feasible and can be implemented sustainably and successfully over time. This study concludes, after interpreting the case study results and reviewing the literature, that the choice of prioritization approaches depends more on the organization's maturity level than solely on the availability of financial and human resources. While resource availability facilitates achieving higher maturity levels by providing the flexibility to make changes, investments, pursue ambitious goals, and tolerate failures, it does not guarantee the effective use of this flexibility.

In conclusion, at lower maturity levels (initial and repeatable), organizations typically implement asset-driven and importance-driven approaches for prioritizing R&R work. As organizations reach higher maturity levels (standard and managed), they can adopt additional approaches, such as capacity-driven. At the highest maturity level (optimized), organizations can access all approaches, including collaboration-driven and area-oriented methods.

RQ: How can municipalities in the Netherlands effectively prioritize infrastructure renovation and replacement works to meet stakeholders' demands and optimize resources?

After an extensive literature review, exploratory interviews with experts, and the analysis of case studies, the author proposes a specific Roadmap for prioritizing infrastructure R&R work. This Roadmap aims to meet stakeholders' demands and optimize the use of available resources. It is described in detail in Chapter 8 and presented in Figure 8.5.

The Roadmap for infrastructure R&R prioritization in Figure 8.5 illustrates that the prioritization process begins at the strategic planning level of the municipality. Here, civil servants interpret government policies regarding infrastructure and define infrastructure objectives to meet the demands and interests of stakeholders, including citizens, landowners, and private enterprises.

The organization then moves to the tactical planning level, where the municipality evaluates the technical, functional, and economic condition of the infrastructure to determine which assets require urgent intervention. In addition, assets with cultural, historical, or political value are identified for priority intervention. This stage implements the Asset-driven and Importance-driven approaches, which form the basic prioritization methods.

At this point, the tactical planning level extends as far as the organization's maturity allows. Assuming that the organization has an optimal level of maturity, the next step is a comprehensive evaluation of the limiting conditions for the execution of the project. This includes external boundary conditions, such as market capacity, which engineering firms and contractors can achieve, and internal boundary conditions, referring to the human and financial resources available within the organization for R&R projects.

The municipality must then compare the workload over time with the capacity limit (both external and internal boundary conditions) to determine which projects should be advanced or delayed to ensure that intervention demands remain below the capacity limit, implementing the capacity-driven approach.

As a result of this approach, the municipality identifies the boundary condition that leads to the gap between organizational capacity and workload. This is crucial for the final planning level, the operational level.

At the operational planning level, the municipality programs R&R interventions, considering what is most beneficial for stakeholders and resource optimization. By implementing the Collaboration-Driven Approach, projects of the same nature are grouped into a portfolio contract and jointly tendered with other asset owners. This approach leverages market capacity, reduces time and costs. Likewise, the programming of R&R interventions is done by implementing the Area-Oriented approach, which minimizes disruptions for residents and reduces costs.

In conclusion, municipalities can effectively address R&R tasks by implementing prioritization approaches in the following order:

1. **Asset-driven approach** to ensure the safety and functionality of the assets.
2. **Importance-driven** approach to maintaining the historical, cultural, and political value of exceptional assets.
3. **Capacity-driven approach** to ensure the municipality can fully respond to R&R tasks over time.
4. **Area-oriented approach** to benefit residents with fewer interventions and optimal resource use.
5. **Collaboration-driven approach** to maximize market capacity and promote investment in innovative and optimal construction methodologies.

The order reflects the organization's ranking of priorities, with the primary focus always being on ensuring the well-being of the population. Additional approaches are incorporated as the municipality reaches the organizational maturity necessary to implement other layers of prioritization, which involve long-term visions, proactive attitudes, and a willingness to collaborate.

10.2. Recommendations

At this stage of the study, it is clear that effective prioritization of R&R works requires high organizational maturity. Thus, the primary recommendation is for asset owners to enhance their capacity across the seven asset management dimensions and implement the appropriate prioritization approaches as they mature. Specific recommendations for particular scenarios and challenges are presented below.

10.2.1. Municipalities with Initial-Repeatable Maturity Level

For infrastructure owners who currently prioritize their R&R projects solely based on the socio-cultural value and the technical and functional condition of the asset, and who, despite wanting to implement other criteria and prioritization approaches, find that their organizational capacity is insufficient to maintain a proactive methodology, the following actions are recommended.

Creation of Dedicated Teams for Urgent R&R Projects (Asset-driven approach)

- To municipalities

To address the issue of short-term vision, where urgent R&R interventions consume the entire capacity of the organization, municipalities are advised to create dedicated teams to manage urgent projects within each group responsible for a specific type of infrastructure. This approach will free up capacity within these groups, allowing them to focus on long-term projects and improve asset management dimensions. In this way, R&R obligations are met while organizational maturity increases. Figure 10.1 illustrates how these dedicated teams assist in transitioning the organization towards a proactive methodology by gradually incorporating long-term analysis into R&R tasks.

Separate Funding Source for R&R Works (Importance-driven and Capacity-driven approaches)

- To the central government

In cases where the Importance-driven approach is used to fulfill individual political agendas, resulting in the misuse of resource allocation power for the convenience of a limited group, a recommendation is directed at the central government. It suggests modifying the funding source for R&R works to

make them independent of local government control, as depicted in Figure 10.1 with a cross. Instead, a methodology similar to that of sewer systems could be implemented using an independent tax. This action offers three major benefits: first, it ensures the transparent and effective use of financial resources; second, it addresses the uncertainty associated with periodic changes in mandates and political agendas; and third, it eliminates the need to change the mindset of politicians, who often view R&R works as ”unattractive” due to their high economic cost and low perceived social added value, as well as the inconveniences they entail. This enables timely or even anticipatory R&R works, thus facilitating the implementation of the Capacity-driven approach.

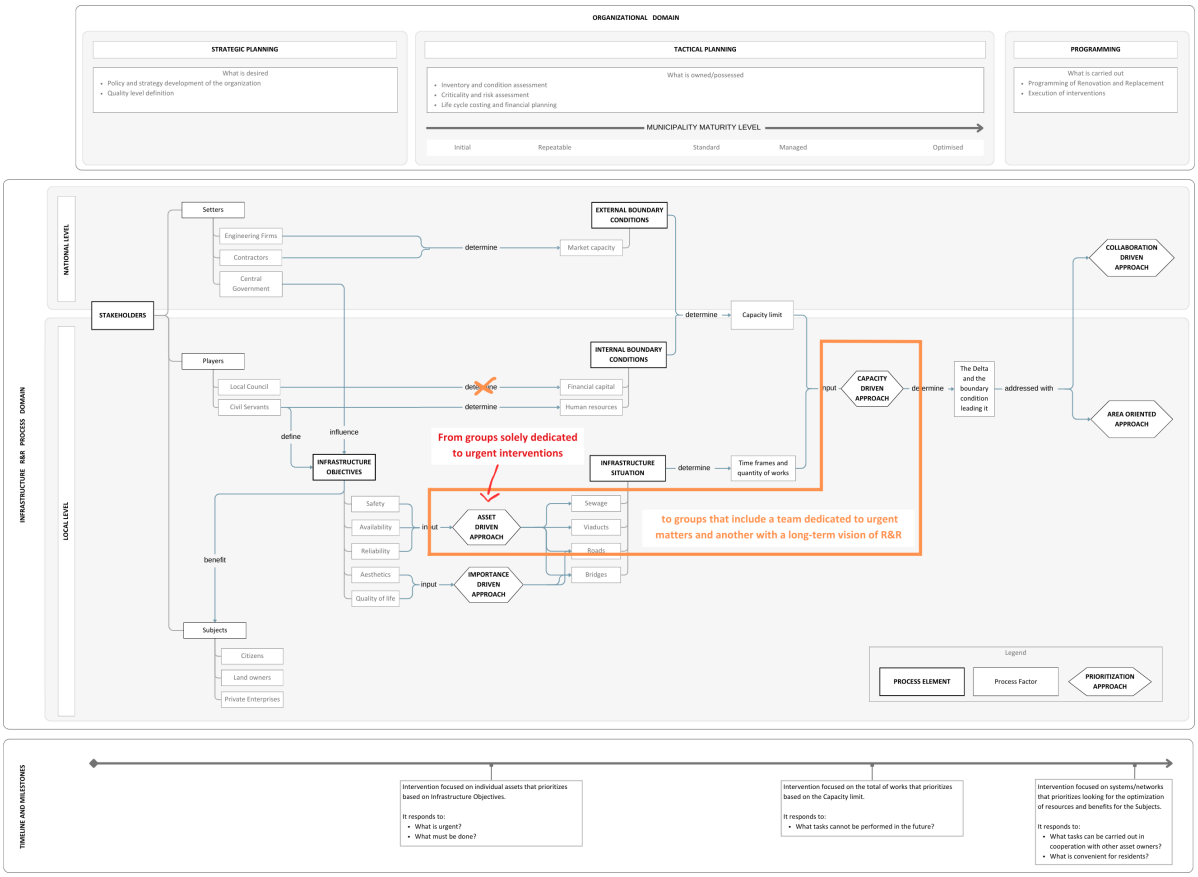

Figure 10.1: Dedicated teams and separate funding source for R&R - Roadmap.

10.2.2. Municipalities with Standard-Managed Maturity Level

For infrastructure owners who already have a long-term vision for R&R projects but do so independently within each group by infrastructure type, and who want to implement integrated prioritization approaches that benefit the organization and residents, the following actions are recommended.

Formalization of the Second Prioritization Cycle (Area-oriented approach)

- To municipalities

Given that the organization lacks standardized and formalized communication lines between teams responsible for different types of infrastructures or even between disciplines, leading to information gaps and disconnection between processes (Figure 7.1), and hindering internal collaboration, it is recommended that asset owners formalize the ”second prioritization cycle.” This involves mandatory and frequent meetings with all those involved in R&R to present reports and discuss projects and prioritization decisions made by each infrastructure team with other teams. The goal of these meetings is to identify collaboration opportunities between groups. Figure 10.2 illustrates how the formalization of the second prioritization cycle enables the implementation of the Capacity-driven approach across all local

assets, ensuring not only a long-term vision but also a comprehensive scope, thus facilitating internal collaboration for project execution (Area-oriented approach).

Establishment of a Central Public Information Platform for R&R (Collaboration-driven approach)

- To the central government

To address the communication and information gap between different asset owners regarding ongoing and planned R&R projects, it is recommended that the central government create a centralized virtual information platform. All asset managers (local, regional, and national) should report their infrastructure assets (availability of information), projects, and intervention plans (dates and scope) on this platform. This platform should facilitate the sharing of best practices, with the experience of advanced R&R owners serving as examples for those just beginning, and identify collaboration opportunities for creating portfolio-type contracts. This will make it clear which owners are sufficiently mature to implement the Collaboration-driven approach (having the required basic information and financial and human resources for projects). Figure 10.2 represents this information platform within the Roadmap with a cloud icon.

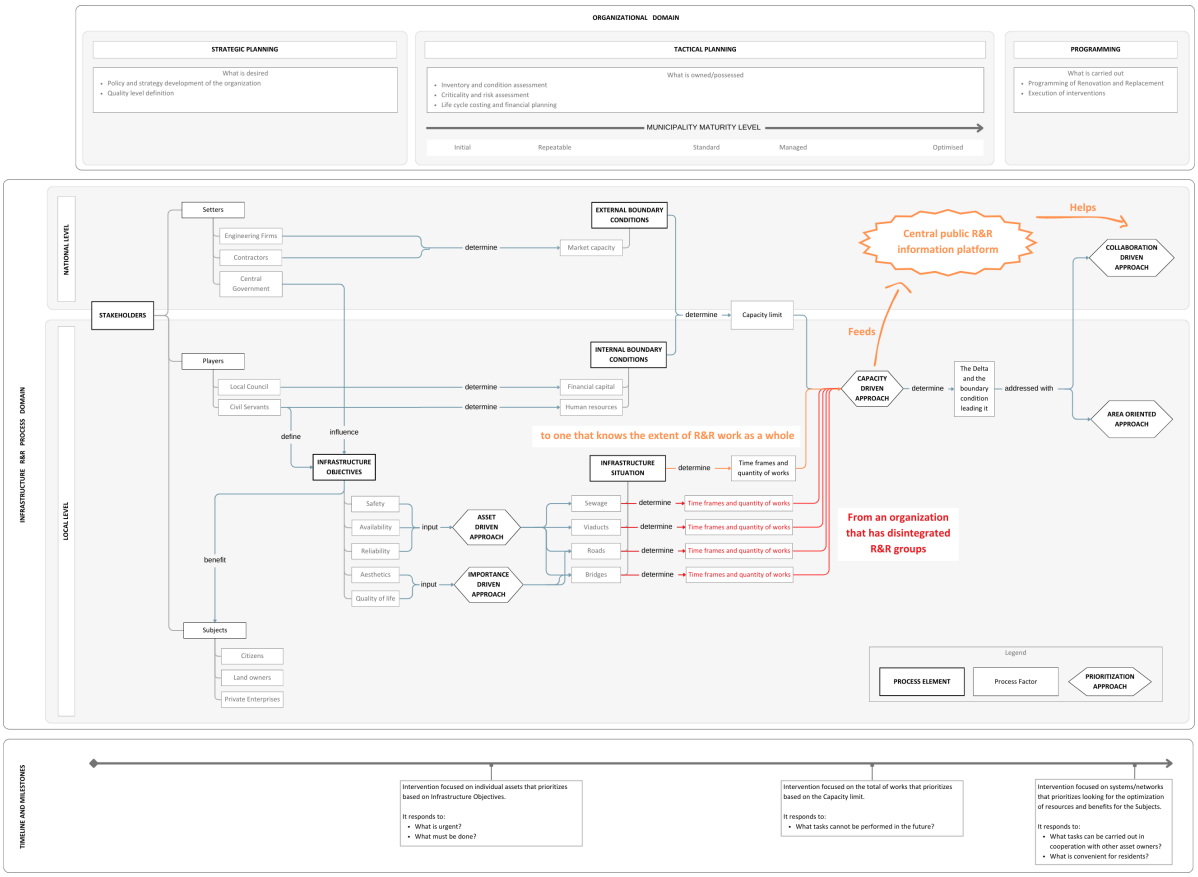

Figure 10.2: Formalization of the second prioritization cycle and central public information platform of R&R works - Roadmap.

10.2.3. All Asset Owners

A crucial recommendation applicable to all asset owners, regardless of their organizational maturity level, is the **Adoption of Alternative Procurement Criteria**. This recommendation advocates for the use of criteria beyond traditional economic metrics (MEAT) in project procurement. Instead, it proposes strategic criteria that, when collectively applied by all infrastructure asset owners, can shape the market's capacity to execute R&R projects. For instance, these criteria can prioritize factors such as fostering innovation and improving construction performance.

10.3. Future Research

Considering the findings and limitations of the research, the following aspects are suggested for future research:

- The present study identified a wide variety of local asset owners who cannot be characterized under a single description. Therefore, it is worthwhile to dedicate a study specifically to characterizing these managers, focusing on small municipalities. This should involve an in-depth study of the influence that stakeholders, referred to as Subjects, have on decision-making, and also explore whether spatial distribution and land use types have any relation to the definition of objectives or the preference for the type of prioritization approach to implement.
- This study found that organizational maturity is a determining factor in the choice of prioritization approaches. Therefore, it is considered important to continue the research by evaluating different local organizations responsible for infrastructure assets, implementing the Infrastructure Management Maturity Matrix (IM3) proposed by Volker et al. (2011). This would allow the research to diagnose the level of maturity of local asset owners and suggest modifications to adapt this matrix specifically to municipalities for inclusion in periodic evaluation and feedback processes of the organization.
- This research has examined the perspective of asset owners; however, it would be interesting to investigate the point of view of local council members, specifically those who have significant influence over the allocation of resources for the execution of R&R infrastructure projects. This aims to understand how these actors can be better involved in the process and achieve benefits to address this challenge.
- Although this research recommends the use of portfolio-type contracts and identifies them as key to successfully addressing the task of R&R infrastructure, the scope of this study did not include the procurement aspect of R&R works. For this reason, it is suggested that future studies investigate the portfolio contract, determining the conditions that asset owners collaborating with each other should meet. Additionally, the scope could be expanded to study which types of contracts are most suitable for each type of prioritization approach.

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A

Literature Review

This section delineates the methodology employed for conducting the literature review, drawing on the frameworks proposed by Creswell and Poth (2016) and Verschuren et al. (2010). The process is systematically divided into steps as outlined below:

1. **Development of a Search Strategy:** A search plan is formulated by identifying key variables and selecting pertinent keywords. The deployment of a well-defined keyword strategy is crucial for the efficient retrieval of relevant literature from academic databases. The selected keywords for this study are organized and detailed in the subsequent table.

Group 1	Group 2	Group 3	Group 4
Infrastructure, Stakeholders, Lifespan	Infrastructure, Asset Management, Lifecycle	Infrastructure, Renovation, Replacement, Renewal, The Netherlands	Infrastructure, Land use, Stakeholders

Table A.1: List of key words related to Infrastructure R&R.

2. **Execution of Database Searches:** For the purposes of this research, an array of scholarly databases, including Google Scholar, Scopus, Science Direct, ResearchGate, Elsevier, and Web of Science, are utilized to locate both research papers and conference proceedings. Additionally, the TU Delft Repository is searched to find master theses that are pertinent to the topic of study.
3. **Employment of Boolean Logic in Searches:** The search within these databases is refined through the use of Boolean operators ”AND” and ”OR”. This involves crafting various combinations of the previously identified keywords or altering their sequence to enhance search results.
4. **Initial Screening of Search Results:** The outcomes of the database searches are initially evaluated by examining the titles and abstracts of the search results. This preliminary scan aims to ascertain the relevance of the articles to the research topic.
5. **Selection Criteria Based on Citation Metrics:** A priority is given to articles with higher citation counts, as these are typically of higher impact. Conversely, articles with fewer citations are generally excluded from detailed review at this stage.
6. **Incorporation of Snowball Sampling:** Following a thorough examination of selected articles, the snowball sampling technique is employed. This entails reviewing the bibliographies of key articles to uncover additional relevant literature or to identify new keywords that can inform subsequent searches (Verschuren et al., 2010).
7. **Iterative Searching:** The search strategy, including the combination of keywords and search history, is documented to facilitate iterative searches. Should the initial search results prove unsatisfactory, the process is repeated to identify additional literature. This iterative approach may be conducted in multiple rounds as necessary.
8. **Focused Review of Selected Literature:** Finally, the research focuses on a curated collection of articles that meet the established criteria. These sources are then utilized to address the sub-research questions, providing a comprehensive understanding of the topic under investigation.

B

Semi-structure Interviews

B.1. Interview Protocol

Introduction

- The interview is semi-structured and includes predetermined and not planned questions to initiate the discussion.
- The interviews are part of different case studies, each of them corresponding to a municipality in the Netherlands.
- The purpose of these interviews is to gain in-depth understanding of the decision making process for the programming of infrastructure Renovation and Replacement (R&R) tasks in Dutch municipalities. Identifying key factors in the decision making process, as well as barriers and challenges in the prioritization of R&R works.
- The interview is expected to take approximately 60 minutes.
- The interview starts with background questions of the interviewee followed by open-ended questions related to the purpose of this interview.
- The interview is confidential, answers will not be traced back to the interviewee. Data derived from the interviews will be processed anonymously.
- By providing a signed informed consent form before the start of the interview, the interviewee is providing consent to the processing of the information provided during the interview.
- The interview transcript can be sent back to the interviewee after the interview.

Interview Questions

Welcome and thank you for agreeing to participate in this study. My name is Laura Loaiza, I am a master student at TU Delft and I am doing my graduation internship at Witteveen+Bos. My thesis focuses on the Renovation and Replacement of infrastructure in the Netherlands, in which I am working in collaboration with my supervisor Xaief Ezechiëls.

The purpose of these interviews is to gain in-depth understanding of the decision making process for the programming of infrastructure renovation and replacement tasks in Dutch municipalities. Our goal is to identify key factors in the decision making process, as well as barriers and challenges in the prioritization of R&R works.

The information you provide will help us achieve these goals. Please be assured that your responses will be treated with the utmost confidentiality. Your experience and insights are crucial to this initiative, and I look forward to a productive and informative discussion.

Thank you once again for your time and participation.

Background Questions

1. What is your role in the company? Responsibilities within the company.
2. Could you describe what is your role regarding the R&R of infrastructure?

The R&R process

3. Describe briefly what an asset management process looks like.
   (a) Is it different for R&R?
4. What leads to a decision to carry out R&R works?

Decisions on infrastructure

5. How do you determine infrastructure objectives?
   (a) Is there a ranking of objectives?
   (b) Is the distribution of land use important for determining objectives?
6. Is there any given grouping of infrastructure types when planning R&R projects? For example, sewer with roads.

Challenges and barriers

7. What difficulties do you encounter in prioritizing R&R projects?
8. When you are evaluating the capacity of the municipality to carry out R&R projects, what are the factors you take into account?
9. Among the following resources: financial capital, expert personnel and manpower, which do you think is more scarce or critical for the municipality?
10. What information is available to plan R&R works?
11. Is there a group within the municipality specifically in charge of R&R or is it the same group in charge of maintenance?
    (a) How many people does the group have?
12. Where is the R&R/maintenance group located in the organizational structure/chart?
13. What professionals/ experts are available to plan R&R works within the organization?
14. Does the municipality have employees in charge of carrying out the inspection and evaluation of the infrastructure condition?
    (a) Designs?
15. Do you have a combine budget for routinary maintenance and R&R works?
    (a) Is financing different by type of infrastructure?
16. Is there any political influence in decision-making about R&R works?

R&R prioritization approaches

17. How do you prioritize R&R works?
18. Among the three types of lifespan: technical, functional and economic, is there a priority ranking? *Asset driven.*
19. Is cultural or historical value an important factor in the prioritization of R&R work? *Importance driven.*
20. When you decide to carry out R&R works, do you try to prioritize other R&R activities located in the same area in order to do them all at the same time? *Area oriented.*
21. Do you carry out R&R works before the asset reaches its lifespan? *Capacity driven.*
22. Is there any type of collaboration between municipalities and/or with other asset owners (provinces, water authorities, RWS and ProRail) regarding R&R works? *Collaboration driven.*

B.2. Interview email

Dear *[name of the interviewee]*,

My name is Laura Isabel Loaiza Osorio, I'm a master's student in Construction Management and Engineering (CME) from the TU Delft. Currently, I'm doing my research graduation project within Witteveen+Bos under the supervision of Xaief Ezechiëls (first company supervisor) and Rob Rijnen (second company supervisor), committee member Dr.Ir. A (Ad) Straub (chairman), Dr. E. J. (Erik-Jan) Houwing (first supervisor), and Ir. L.P.I.M. (Leon) Hombergen (second supervisor) . I'm contacting you because I have selected the "*[name of the municipality]*" as a case study for my research study. I believe that your experience and knowledge can contribute significantly to my research study.

This research aims to improve the understanding of the factors and conditions that play a determining role in the choice of a prioritization approach to infrastructure Renovation and Replacement (R&R) works. In doing so, it seeks to develop a decision framework to guide municipalities on how to program R&R activities to respond to stakeholder demands. To achieve this, I would like to conduct a 60-minute interview with you, during which I will ask open-ended questions to gather your knowledge and perspectives on the topic. The interview will be recorded to facilitate transcription, and every effort will be made to ensure the confidentiality of your responses, with personal data anonymized.

If you would like to participate in this research, I would be happy to schedule an interview with you. Participation in this research is entirely voluntary, and you may choose not to answer any questions during the interview if you wish. Please feel free to contact me if you require further information about this research.

Looking forward to hearing from you.

Best regards,

Laura

C

Case Study

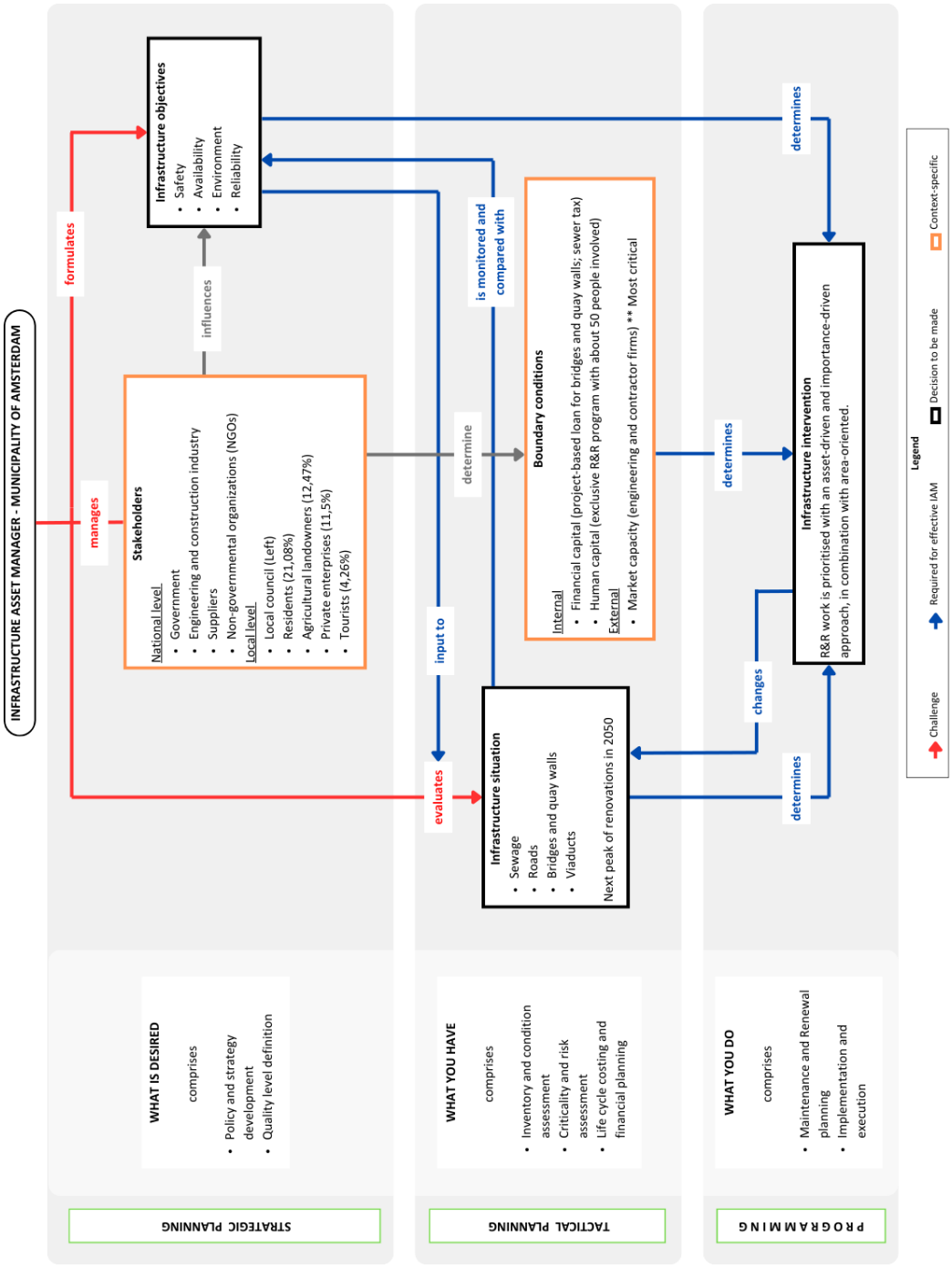

Figure C.1: R&R management process: municipality of Amsterdam

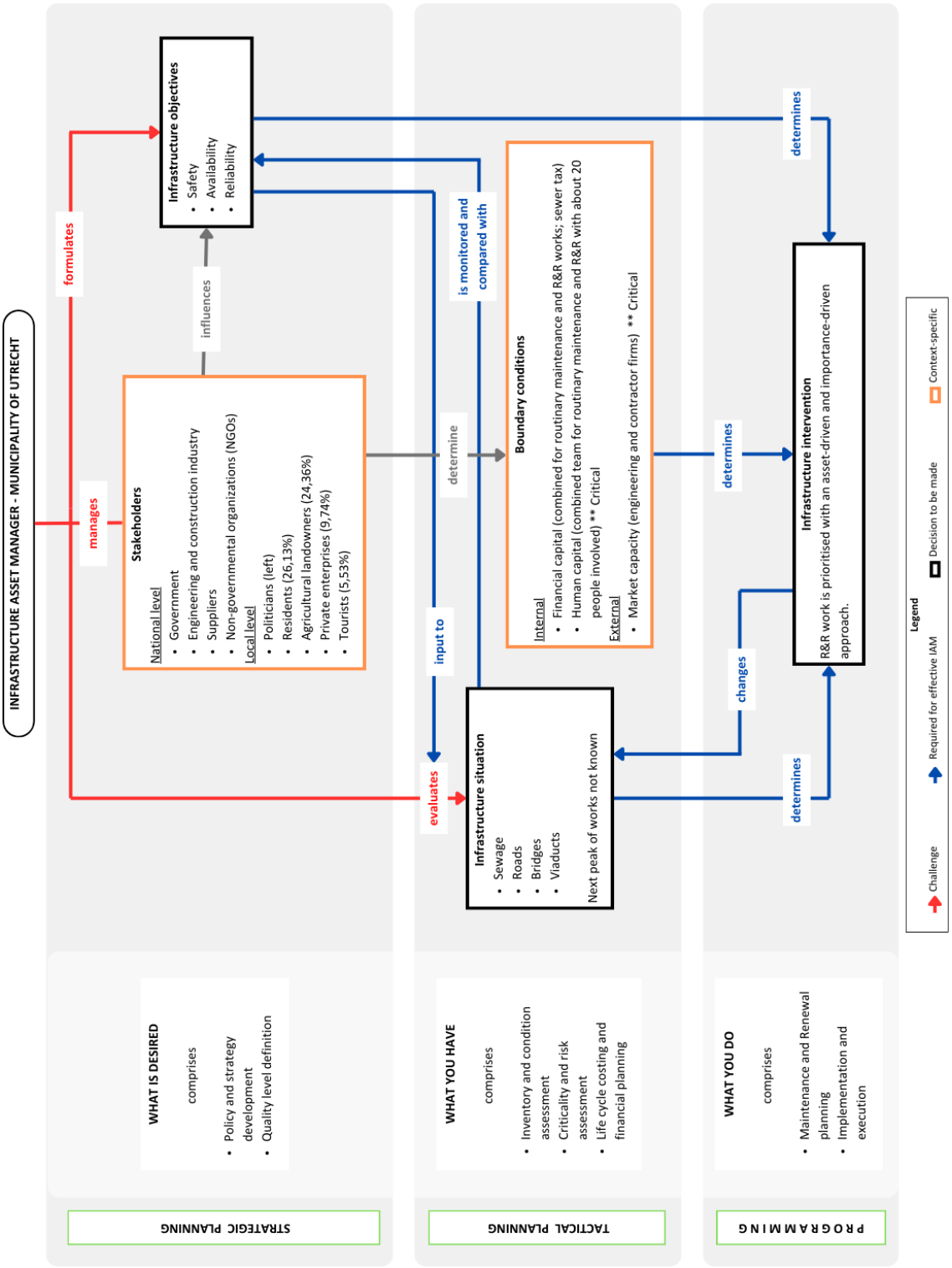

Figure C.2: R&R management process: municipality of Utrecht

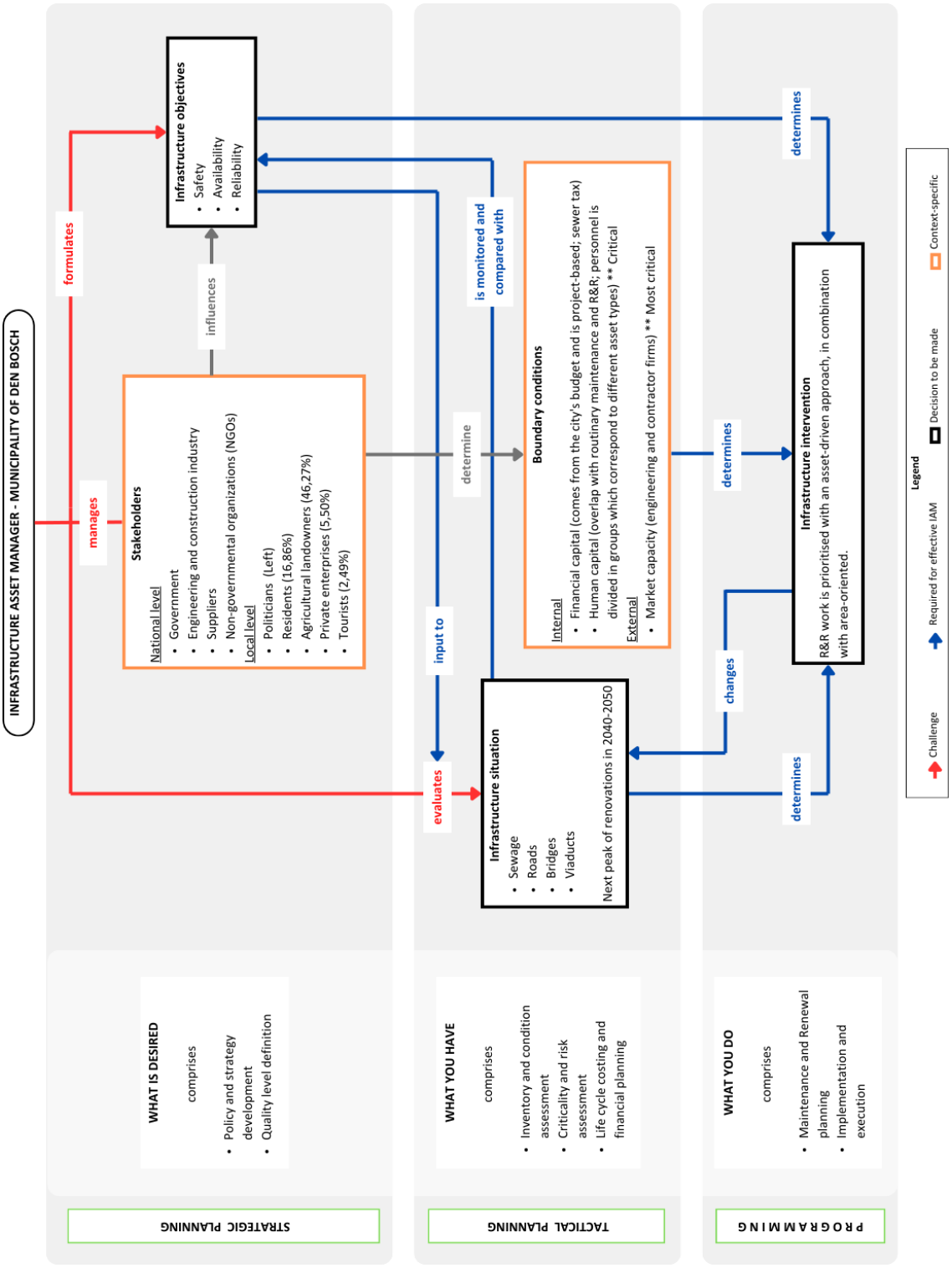

Figure C.3: R&R management process: municipality of Den Bosch