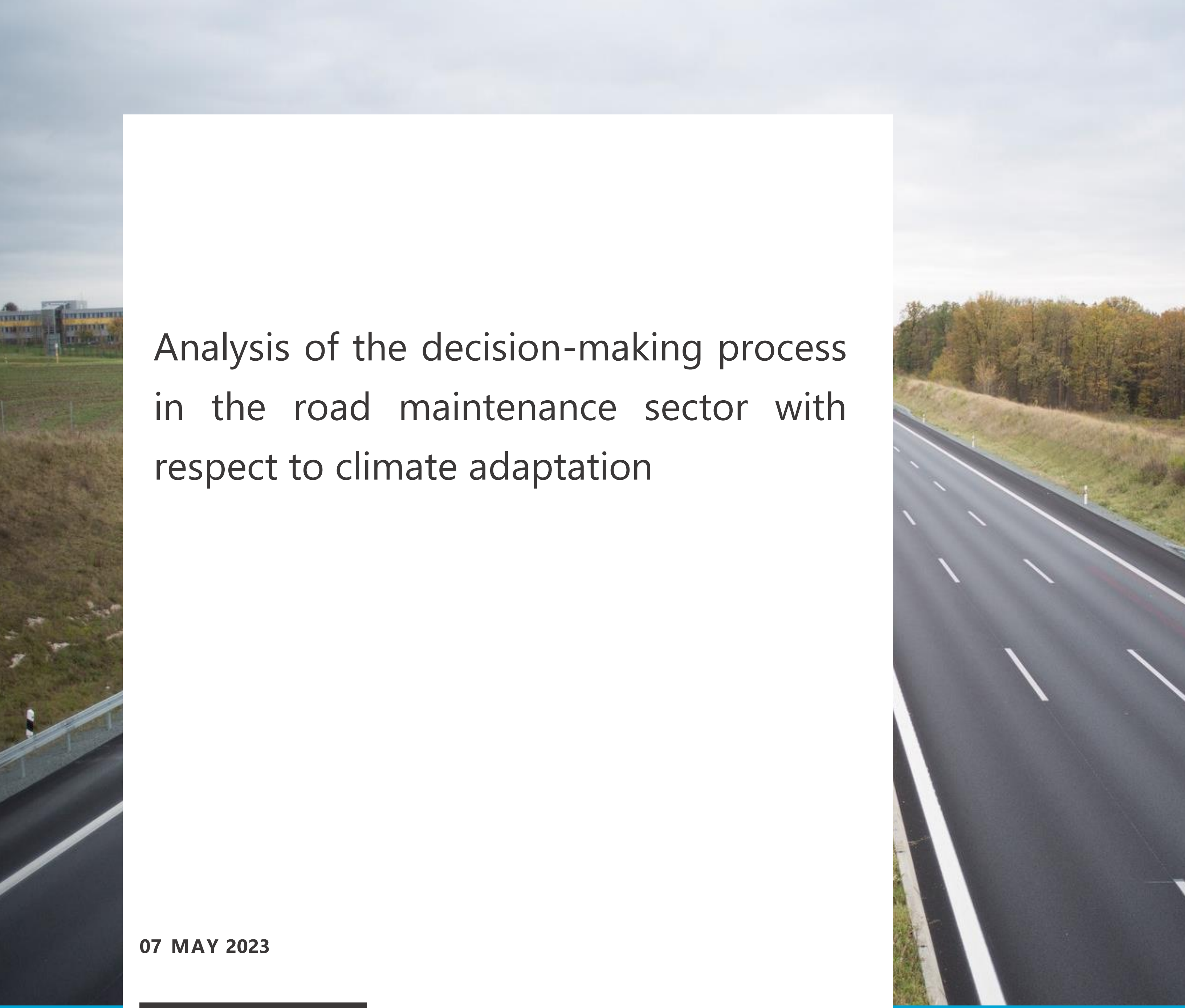

Analysis of the decision-making process in the road maintenance sector with respect to climate adaptation

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Analysis of the decision-making process in the road maintenance sector with respect to climate adaptation

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Preface

Another great journey ends here. I would like to use this opportunity to express my gratitude to my supervisors, Prof. Lisa Scholten and Prof. Wijnand Veeneman, for their unwavering support throughout my research endeavor. They have been a constant source of guidance, encouraging me to push my boundaries and strive for excellence.

I am deeply grateful to the participants of this study who generously shared their time and knowledge. Without their willingness to be a part of this research, completing this thesis would not have been possible.

I would like to acknowledge and thank my parents, Elpida and Anestis for their endless encouragement and support even from afar, as well as my younger brothers, Nikos and Aimilianos for being there to constantly have fun with me for studying too hard but never stopped believing in me.

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Executive summary

Road networks are crucial for economic and sustainable growth, but their stability can be compromised by various factors. In the Netherlands, where the road network is dense and extensive, challenges such as traffic loads, drainage, and secondary road works impact infrastructure integrity. Poor road conditions contribute to accidents and cost billions of Euros annually. On the other hand, climate change poses additional risks, including structural damage and vulnerability to extreme weather. These issues have captured the attention of the Dutch government which in turn pushes the road maintenance authorities to take initiatives and become more climate-conscious with the decisions they take. Although the asset managers are responsible for these decisions and play a crucial role in maintaining roads, they face numerous difficulties in transitioning to a climate-adaptive road maintenance policy due to the aging and fast deteriorating infrastructure, increasing traffic, and limited resources.

There are various factors that accelerate the deterioration of the road infrastructure. Factors such as increased traffic loads and sublayer conditions affect pavement deterioration, while poor drainage systems also play a significant role in making the road infrastructure overflow with water after a heavy rainfall. Additionally, the presence of other systems like sewage pipelines can cause structural problems in the road infrastructure. Thus, effective asset management is essential to optimize asset utilization, enhance quality, minimize costs, adapt to climate change, and increase asset lifespan.

The study aimed to examine the decision-making process of asset managers in road maintenance and their efforts to enhance climate adaptability. The focus was on identifying stakeholders involved in decision-making and the criteria influencing their decisions. Several hypotheses were developed to explore these aspects, which were tested through interviews with experts in road maintenance and climate adaptation. The hypotheses highlighted challenges such as budget constraints, limited knowledge of climate adaptation within organizations, data availability for informed decision-making, staffing issues, and the influence of internal policies on driving climate adaptation efforts within road maintenance authorities.

The results derived from the interviews provide valuable insights into the complex nature of road maintenance scheduling, highlighting the involvement of multiple stakeholders with diverse objectives. The process comprises inspections by internal and external visual inspectors, as well as input from maintenance crews and public participation through complaint filing. Asset managers consult with external advisors and contractors to determine appropriate maintenance measures and develop long-term plans. Collaboration among asset managers and coordination with upper management, emergency services, and the traffic department are essential. However, qualitative-driven inspections and limited budgets pose challenges, particularly with the approaching end of lifecycle for many roads in the Netherlands. Budget constraints affect climate adaptation efforts, while iterative planning, coordination, and budgetary considerations further complicate decision-making. Integrating nature near roads is currently the preferred option, as it enhances the aesthetics in the city and is also a great way to mitigate heavier rainfalls, increasing temperatures and drought by acting as a drainage system and creating shade respectively. However, the lack of standardized processes, guidelines and budget make the overall transition to climate adaptation in the road infrastructure very slow. More time and budget have to be invested in understanding how the goals that Netherlands has set for climate adaptation can be reached, in order to create robust policies for a future-proof road infrastructure.

Introduction

Road networks represent the backbone of our society. They are a highly complex piece of infrastructure, but yet, a fundamental part of our daily lives. Just like the ant nests that are designed in an intelligent way so that they provide a safe and an efficient passage for the colony to grow, as described by Professor Yang (Yang et al., 2022), a road network has the same significance for our own economic and sustainable growth (Ng et al., 2019).

However, any flaw that comes to surface can compromise the stability of the whole network, incurring a number of consequences that the asset managers responsible for the road infrastructure have to tackle. The intensity of such challenges is even stronger in the Netherlands, where the Dutch road network spans around 150,000 km, while due to the country's flat topography, it is one of the densest networks in the world (5 km/km^2) (Visser, 2010). Due to a large number of stressors, that include continuous traffic loads, drainage, natural soil conditions (Ali & Khan, 2017), the road infrastructure deteriorates over time, while efficient inspection and maintenance strategies are vital to upkeep the network in a healthy and operational state. These stressors, however, depict just one side of the cause of the problem. The integrity of the road infrastructure is also heavily affected by secondary road works, such as for the maintenance of wastewater systems, natural gas pipelines, powerlines and fiber wiring systems. A malfunction on each of these systems can cause a domino effect on the "lifetime" of the other systems, and thus, the road infrastructure (Santos et al., 2021).

To understand the gravity of the outcomes of this problem, at a European level, according to the International Transport Forum, more than 5% of road accidents occur due to poor road conditions. This tragic statistic, apart from its heavy human life toll, cost roughly 3.5 billion Euros to the Netherlands at an annual level (ITF, 2021), signifying the importance of maintenance of the road infrastructure for the Dutch government. At the same time, vehicle ownership in the country steadily increases, while it is estimated that by 2023 the waiting times due to congestion on the Dutch roads will increase by 35% compared to 2018 (Tinga, 2018). On the other hand, environmental considerations arise, making climate change an increasingly important factor each year. The average surface temperature in the Netherlands has been increased at least 2.3℃ in the past 100 years, while in the same time frame there was also 21% increase in the precipitation (*KNMI Klimaatsignaal '21 - Hoe Het Klimaat in Nederland Snel Verandert*, n.d.). This climate change poses a risk for the road infrastructure, rendering its structural integrity and drainage systems vulnerable to damages due to the high temperatures and heavier rainy weather (Groot et al., 2006). Thus, efficiency in the road infrastructure is critical to preserve the right quality and increase the infrastructure's climate resilience. It has also been found that extending the life of pavement through maintenance can reduce greenhouse gases by up to 2% and drivers can save up to 5%

in energy consumption, tire wear, vehicle repair and general vehicle maintenance costs, because of smoother road surfaces (Islam & Buttlar, 2013; Lee & Madanat, 2017).

Observing this climate change, the Dutch government has identified the potential issues that the road infrastructure can have and has taken several initiatives in order to become climate adaptive, as analyzed in the Road Maintenance Policy Plan 2020-2024 (Overheid, 2020). Since there is a higher chance of precipitation as mentioned above, the government has taken initiatives to set up water drainage effectively so that the water is adequately drained before roadways. Therefore, in order to avoid unevenness and maintain coherence with the sewage system, the first meter of the verges is kept lower than the paved surface. On the other hand, high heat can cause expansion at the transitions from roadways to bridges as well as potential damage to asphalt. In addition, the milder winters will lessen the annoyance and harm that thawing, and frost may bring. The settling of the peat bundle has a significant negative impact on the municipality. Pavements and verges subside as a result of this settling. Moreover, trees along the road absorb a lot of water, which results in additional settling. A typical solution for this matter that is followed in the Netherlands, according to the road maintenance policy plan includes extending the space between trees and the road, building stronger foundations, and boosting the water level in ditches along the edge of the road.

As the gatekeepers of the road infrastructure, asset managers play a crucial role in ensuring that the roads are safe and reliable. However, with the increasing challenges of road maintenance based on the aforementioned factors, asset managers are facing tough decisions that will impact the future of the transportation network.

The aging road infrastructure, increasing traffic volume, and weather-related damages are putting pressure on asset managers to allocate limited resources effectively and efficiently. With funding and manpower becoming an important factor, asset managers must make informed decisions that prioritize the most critical maintenance needs while balancing long-term planning with short-term demands. Not only do they have to coordinate all these different criteria that drive their decisions, they also have to consider how they can become climate adaptive when drafting up a road maintenance plan for the whole road network they oversee. Thus, it is essential to portray and analyze the process that the asset managers when scheduling a road maintenance towards a climate adaptive asset management strategy and identify gaps where this process can be improved.

Research Objective

The importance of high-quality road infrastructure in our daily lives may not always be apparent to us. If we took a moment to imagine a world without roads, we may think of a variety of daily activities that we currently carry out on a daily basis but would not be realized without them. On a parallel level, climate change has a more severe impact on the road infrastructure by the year, pushing the asset managers to find out ways to adapt on these changes. The research objective of this thesis is to analyze the decision-making process of asset managers in the road maintenance sector and investigate if and how they take initiatives towards climate adaptation when creating their road maintenance plans. The study aims to identify the factors that influence the decision-making process of asset managers and how they integrate climate adaptation measures in their road maintenance planning. The thesis seeks to provide insights into the challenges faced by asset managers in the road maintenance sector in responding to climate change and identify best practices for effective climate adaptation. The ultimate goal of this research is to contribute to the development of sustainable road infrastructure management that can withstand the impacts of climate change.

Research Questions

Based on the above research objective, the following research and sub-research questions are formulated.

- To what extent do road maintenance authorities take initiatives to become climate adaptive in road inspection and maintenance, when and why (not)?
    - Which entities participate in the decision-making process of the asset inspection and maintenance planning, what is the formal relationship among them, and which are their respective responsibilities?
    - Which are the criteria that the asset managers and other individuals involved in the policy making include in their decision-making process?
    - What are the current initiatives when it comes to climate adaptation planning in the field of road maintenance and what are the challenges in implementing them?

Literature review

The road infrastructure is a crucial component of modern society and is exposed to a plethora of factors that are found in the literature which can lead to the road surface becoming worn out. This deterioration can have a negative societal impact, as it makes the pavement less safe for the drivers, increasing the risk of accidents. At the same time, the management of the road infrastructure is a complex task that requires the coordination of multiple stakeholders and balancing a variety of objectives. Asset managers are faced with the challenge of coming up with a road maintenance plan that meets all these objectives. To address these challenges, multiple solutions have been presented in the literature, having a variety of authors introducing different frameworks that can be adopted to increase the efficiency of the asset managers in meeting their goals. Integrated asset management approaches are also proposed for road maintenance, while many publications suggest asset management methods, that leverage technology, and utilizing best practices in decision making processes.

Pavement deterioration factors

There are numerous factors that affect the condition of the pavement and affect the structural integrity of the road network, resulting in the need of proper maintenance. Ali analyzes these different factors on his paper on "Investigation of the factors affecting the deterioration of local road" and thus this article will be the foundation of this research finding (Ali & Khan, 2017).

Traffic loads

First of all, increased frequency of vehicles passing through a road segment, as well as the forces that the road receives from traffic loads can be a key factor for pavement deterioration. However, Pais contends in his own paper that the road segment's degradation is caused by both the traffic load and the poorly chosen asphalt layer thickness in relation to the projected traffic load. (Pais et al., 2013). Although the first thought might be that the poor selection of the thickness level points to a design flaw, many municipalities might opt for less asphalt thickness in order to cut down costs. This assumption however is being disapproved by Knott, who supports that higher layer thickness may result in higher investment in the short-term but significant cost-effectiveness in the long run (Knott et al., 2019). Apart from the traffic loads, during the design process of the road infrastructure, the engineers shall also investigate the natural soil before construction (Dawson & Gomes Correia, 1996). If the sublayer of the pavement is not in the right condition to support the forecasted traffic loads, it can have a destructive effect on the pavement itself by the increased sublayer pressure as defined by Dawson.

Drainage

Ali has also highlighted that insufficient drainage systems may result in early degradation of the road infrastructure. Specifically, a drainage system is the use of an artificial method of removing excess water from the road infrastructure (Kebede Warati, 2015). Kebede also notes that not only rainwater can cause significant problems to the pavements through erosion, but also groundwater can also rise up to the surface and damage the infrastructure. A recent and major problem that was caused by poor drainage systems is the Princes Margriettunnel on the Dutch highway A7 that happened in mid-December 2022 (Rijkswaterstraat, 2022), as described by the relevant asset management authority, Rijkswaterstraat. This problem was caused by the groundwater that rose up to the surface and caused major issues on the highway. The authorities placed sandbags as a counterweight to prevent further damage, however, the damage was so significant that the highway will remain closed for the coming months, affecting millions of people that rely on this road on a daily basis.

Pavement deterioration factors caused by other systems

Apart from the main pavement degradation factors mentioned above, there are other isolated factors that most of the literature, including Ali, neglects to notice. The road network is not just the asphalt itself. It is a whole ecosystem of different infrastructures tied to one. Specifically, apart from the pavement itself, underneath the asphalt, it is not uncommon to find gas pipelines, the sewage system, powerlines and other similar systems (Santos et al., 2021). Thus, if one of these systems is damaged, it can also cause a major structural problem on the pavement itself as well. On the premises of this literature review, we will analyze only the effect of the sewage systems in more detail.

Sewage systems

Kuliczkowska on her article makes an excellent connection between the sewage system and the road infrastructure (Kuliczkowska, 2016b). She highlights that the road infrastructure may deteriorate if one of the wastewater pipelines gets damaged. When thin and plastic pipe layers are used, the risk probability for severe damage to occur increases as well. Proper and frequent inspections, as well as maintenance actions are also mandatory to minimize this risk. On another paper from the same author, it is described that the opposite effect can also happen, where a collapsed road segment or increased traffic load may likewise damage the sewage pipes and generate a ripple effect, thereby increasing the magnitude of the damage (Kuliczkowska, 2016). Kwak also agrees with Kuliczkowska and argues that the sinkholes that occur on the roads can cause major problems on the sewage systems (Kwak et al., 2020). That verifies the observation that we have seen from Santos above. Although these systems are isolated and are managed by different authorities, we should handle them as interconnected systems that an effect on one causes another effect on the others.

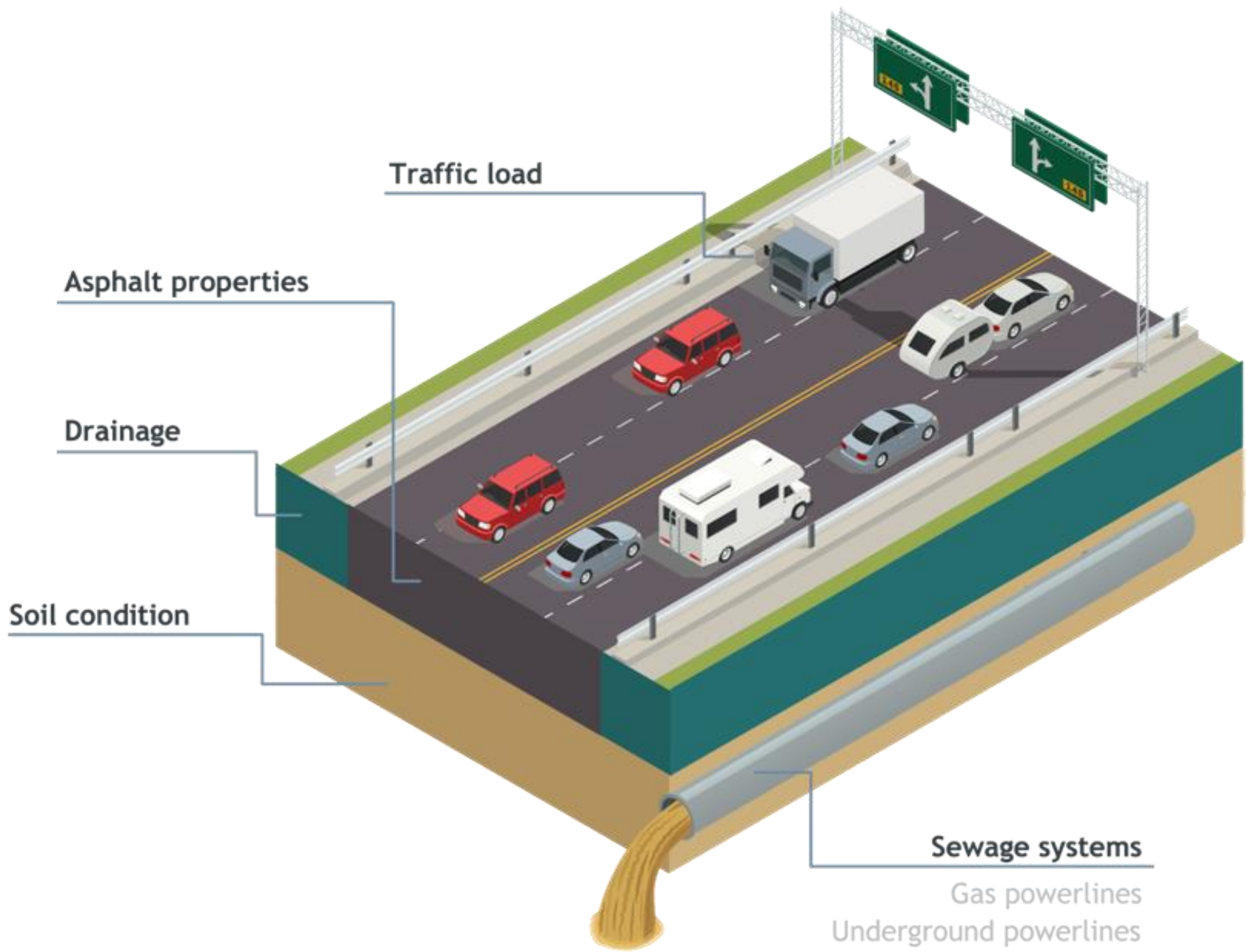


Figure 1: Pavement deterioration factors

The role of asset management

Before we analyze how the pavement deterioration is handled by the respective authorities, first we need to understand why the proper asset management is of major importance. The role of asset management is to ensure that assets are utilized efficiently, cost-effectively, and sustainably, while meeting service standards. Effective asset management practices enable organizations to optimize asset performance, reduce downtime, and minimize the risk of asset failure. According to a study from World Economic Forum, in Figure 2, the goals of asset management are segmented into 3 main categories, Increasing quality, Increasing Asset's Life-time and Decreasing the total cost (World Economic Forum, 2014).

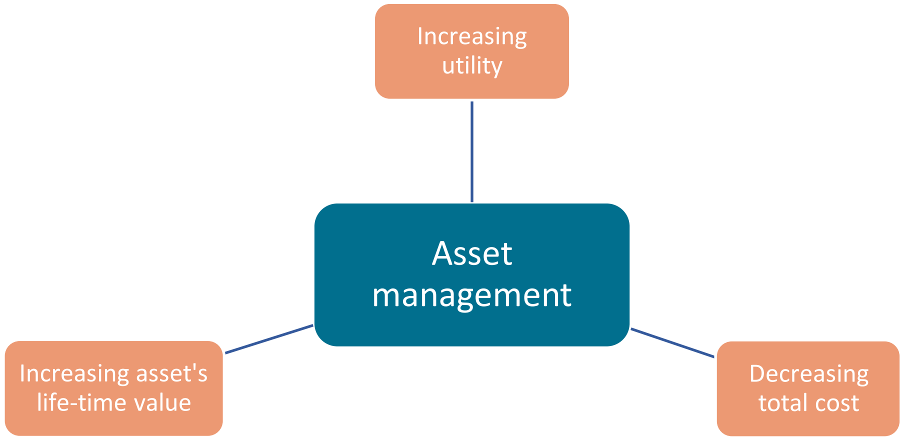


Figure 2: Goals of asset management

Maximization of asset utilization

The contributors of the article suggest that the governments should make the most of their current resources to raise peak throughput by encouraging customers to use the entire system capacity, freeing backup capacity, and making targeted capacity enhancements at bottlenecks.

Enhancement of asset quality

In order to raise service standards and produce a satisfying user experience from beginning to end, operators should embrace a customer-centric operating model. In order to deliver smooth and integrated services, they should also collaborate with infrastructure users, nearby assets, or government organizations. They should also use smart technology to improve user performance and save costs.

Cost minimization

Due to restrictions on public spending, active cost management is becoming more and more crucial. Lean concepts, systematic application of new technology, and outsourcing maintenance or IT services are all ways that operators might cut waste. Performance-based outsourcing agreements have lowered service provider costs by 10% to 40%. Operators with legacy organizations can optimize the degree of centralization, introduce shared services, and delayer in order to manage overheads and organizational structures.

Climate adaptive

The "Reduce, Recycle, Replace" mantra should serve as the foundation for a comprehensive program of sustainability initiatives developed by infrastructure operators. Companies should involve all employees in sustainability efforts, make it a top-management priority, and measure and enhance sustainability just like any other company operation. In order to have a bigger positive influence, they should also adopt a multistakeholder engagement strategy that involves open dialogue with communities and teamwork with other operators and users.

Increased asset lifespan

The two most crucial facts are that better asset deterioration modeling and remote condition monitoring are increasingly helping preventative and predictive maintenance, and that climate change is making natural disasters more frequent and deadly. Governments must identify and evaluate risks, create cross-sector master plans, and add additional resilience to existing assets in order to handle these dangers. Non-structural actions should also be taken to establish natural buffer zones and adopt more resilient design standards for upcoming upgrades and reconstructions.

A new life-cycle view

All feasible project choices should be identified, and governments should look into more affordable options such throughput optimization, loss reduction, demand-side measures, system-wide capacity balancing, and targeted expenditures to unclog existing sites. A thorough cost-benefit analysis that considers the project's whole life cycle should be used to make the decision. The majority of life cycle costs are still subject to intelligent design and engineering choices, thus the life cycle cost analysis should be carried out early on and in the context of the particular asset. The prospective quality of the service and level of risk to the government budget should be taken into consideration while selecting the most effective delivery method.

Road maintenance and Climate adaptation

The Dutch Road infrastructure spans around 150,000 km. Most of the road infrastructure is controlled by the municipalities that control around 130,000 km of municipal roads, while the provinces control around 8,000 km of provincial roads and Rijkswaterstraat controls the national roads with 5,500 km of total length (StatLine, 2022). As of 1st of January 2023, there are 342 municipalities and 12 provinces, summing up to 355 different authorities (including Rijkswaterstraat) that control the road infrastructure (Rijksoverheid, 2023). The Netherlands, as indicated in the introduction, not only has one of the densest road networks in the world, but it also has a sizable number of various road asset managing authorities. The management of this type of infrastructure is a very difficult task for asset managers to tackle, who also have to meet different goals set by the asset owners, one of which is becoming more climate adaptive as a road maintenance planning authority. To analyze this challenge that the asset managers face and identify ways to tackle it, this section is going to be segmented into two pillars: decision-making processes for asset management, as well as frameworks and tools in asset management. The decision-making process involves evaluating the condition of road assets, prioritizing repairs and maintenance, and determining long-term investment strategies. On the other hand, frameworks used as tools in asset management include risk-based asset management frameworks, pavement management frameworks, and bridge management frameworks. These frameworks help organizations to effectively manage and maintain their assets by providing a structured approach to asset management that is based on data and evidence. Effective road infrastructure management is crucial not only for ensuring safe and efficient transportation systems, but also pave the way for a climate adaptive strategy.

As described before, climate change is a major challenge for cities, while at the same time they must modify their urban systems to account for anticipated hazards in order to become sustainable. Municipalities are crucial in helping to set up actor networks, facilitate adaptation strategies, and adapt urban systems to the dangers of climate change (Uittenbroek, 2015). Various ways for addressing climate adaptation in urban policy are evident in practice, with some municipalities giving it high priority on the political agenda, setting up climate departments with funding, and developing specialized adaption plans. Nevertheless, not all cities can or are willing to use a focused approach due to overloaded political agendas and inadequate investment capacity (Bulkeley et al., 2009).

Several municipalities have made the decision to immediately include climate adaptation into already-existing policy areas and associated organizational processes in order to continue addressing the issue. Although the mainstreaming strategy is thought to result in more effective and efficient policy-making, there are obstacles preventing its present implementation in practice. Identification of patterns of actor interaction and coordination of viewpoints, interpretation, and knowledge is important in order to overcome organizational structures as a barrier to mainstreaming climate adaptation. Routines are repetitive actions that display an organization's norms and culture and are interconnected with the respective outputs of the organizational process (Sydow et al., 2017), as observed in Figure 3.

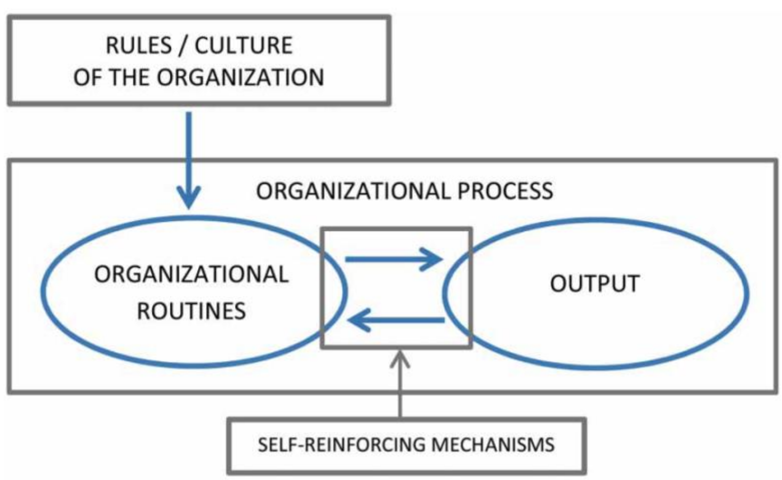


Figure 3: Self-reinforcing mechanisms in public organizational processes

To comprehend the dynamics of these organizational routines, Sydow et al. defined four self-reinforcing mechanisms: complementary effects, coordination effects, learning effects, and adaptive expectation effects. Whereas the coordinating effects are founded on the idea of economies of scale, the complementary effects are generated by integrating similar resources and behaviors. When resources and behaviors are linked together in a way that makes one form of synergy predominate and makes it challenging for actors to evaluate other potential synergies, these impacts can result in a potential barrier. Only if the people involved in the organizational process believe that the synergy between climate adaptation and the other objectives is superior can climate adaptation be mainstreamed. As more actors adopt and adhere to the same routine, coordination effects develop, making it feasible to anticipate other players' behavior. However, this can result in too many or too strict laws being produced. As a result, actors may be constrained in the process because they must follow the rules and are unable or unwilling to act outside of them. In order to compete with the predominate synergy, exploratory learning is required to investigate procedures that mainstream climate adaptation in the output and may also be regarded successful and efficient. The concept behind adaptive expectation effects is that actors' preferences change in response to other players' expectations. Actors frequently change their preferences to justify their actions, but doing so can be detrimental to the planning process since they might do so without verifying whether or not their assumptions are accurate. It is crucial to have consensus on how to approach climate adaptation if we are to mainstream it. In addition to helping us understand how actors make the most of their routines, self-reinforcing processes can also be used to explain how organizational routines might operate as a barrier to change.

Preliminary phase

In order to better understand the literature and create more accurate hypotheses, a series of preliminary discussions were initiated with asset managers from the province of Overijssel, North Holland and North Brabant. The main outcome of those discussions is summarized below.

Asset managers in the field of road maintenance encounter a range of key takeaways and challenges that shape their decision-making and workflow. One of the primary concerns they face is the limitation of their budget, which restricts their ability to carry out necessary road maintenance actions. However, when safety risks arise, they are obligated to allocate funds beyond the initial budget to minimize the potential for accidents and ensure the safety of road users (personal communication, January 2023). Despite this, when it comes to climate adaptation and sustainability measures, there is some budget available, but it is often insufficient to drive transformative changes in their overall approach.

Data availability also poses a significant challenge for asset managers. In the road sector, there is a scarcity of comprehensive and up-to-date data. Most of the information they rely on comes from qualitative visual inspections, which involve subjective notes and assessments of road quality (personal communication, December 2022). This lack of robust data hinders their ability to make data-driven decisions and implement evidence-based strategies for road maintenance. Furthermore, the process of road maintenance planning is not a straightforward process but rather involves the collaboration of numerous stakeholders. Asset managers must navigate complex coordination efforts to achieve integrated asset management. This requires effective communication and coordination among different asset managers to align schedules, share resources, and obtain necessary approvals. The involvement of multiple parties adds layers of complexity to the planning process and necessitates careful consideration of diverse perspectives and objectives.

The adoption of new technologies is an area of concern for asset managers. While there is a recognition of the potential benefits that emerging technologies can bring to road maintenance, the implementation process presents challenges. Solution providers often present options that are either prohibitively expensive, not addressing the specific needs of the asset managers, or require substantial changes to their existing workflow (personal communication, January 2023). Time constraints further complicate the situation, as asset managers often lack the luxury of extended periods for experimentation and uncertain results. As a result, careful evaluation and consideration are required to determine the suitability and feasibility of technology solutions that align with the specific needs and constraints of the road maintenance authorities.

In conclusion, asset managers in road maintenance face various obstacles in their efforts to ensure safe and sustainable road infrastructure. Limited budgets, data availability constraints, the complexity of coordination, and the challenges surrounding the adoption of new technologies all contribute to the intricate landscape they navigate. Overcoming these challenges requires strategic decision-making, effective resource allocation, and a willingness to explore innovative solutions that address their unique needs and contribute to the long-term success of road maintenance endeavors.

Research Method

To answer the research questions mentioned in the "Research Questions" chapter, an **interview survey design** is selected. A survey interview, as described in the "Data Collection, Primary vs. Secondary" chapter in the "Encyclopedia of Social Measurement" book, is a research approach for primary data collection (Hox & Boeije, 2005). In this survey design, a significant and representative sample of a targeted population is interviewed. The social sciences, psychology, and business are just a few of the disciplines that can benefit from this methodology (Bryman et al., 2021). This approach allows to generate insights based on the answers provided by semi-standardized questions. The purpose of this methodology is to gain as much information possible in order to create an objective view on the topic that is the basis of the research conducted. Using the results derived from the interview analysis, researchers can compare and contrast many cases to uncover similarities and differences. These cases can be picked based on a specific research topic or phenomena of interest, and comparisons can be performed between cases that are comparable in some ways but distinct in others. These different phenomena of interests will occur based on formulated Hypotheses that will help in answering the Research Questions. In other words, the objective of this method is to get a deeper comprehension of the phenomena under investigation and to generate more strong ideas to explain it. Another reason why the survey interview design was selected as the research method is that it enables a more in-depth examination of complicated processes which can't be easily evaluated quantitatively, through a questionnaire for example. The method enables researchers to investigate how different factors influence the results of the compared cases and how those aspects may be connected to the research issue at hand (Kaarbo & Beasley, 1999), which in this thesis is the transition to climate adaptation in the area of road maintenance.

The research will be implemented according to an adaptation of the research process followed by Seawnght & Gerring and is presented in Figure 14 (Seawnght & Gerring, 2008). A synopsis of this process includes a literature review, which has already been implemented and then the generation of hypotheses derived both from the literature and personal communication with asset manager as a preliminary phase and generation of a list for potential respondents. As soon as the potential respondents are selected, the interviews were planned with the people that have approved the interview invitations. The Human Research Ethics Committee (HREC) of TU Delft has approved the planned method that the interviews have been implemented. The interviews are conducted following an interview guide seen in Appendix E - Interview guide, transcribed and analyzed with a list of codes that has been generated through the survey selection criteria. A consent from the interviewees was granted via an Informed Consent Form that can be seen in Appendix B - Informed Consent Form. Furthermore, the themes are being documented based on the identification of patterns and connections retrieved from the data. For this process, the data analysis workflow is analyzed in Appendix F - Data analysis methodology. Finally, a decision-making model is used to analyze the process of road maintenance scheduling based on the themes created.

Decision-Making Model selection

After analyzing these four decision-making models independently, as seen in Appendix A - Decision-making models, it is clear that all of them have positive and useful elements, as well as some disadvantages, that render them more suitable and applicable to some areas more than others. Thus, each case / sector should be examined individually when selecting the right model for decision-making. Climate adaptation has received a lot of controversy over the years raising a number of challenges when it comes to asset management. It becomes difficult for asset managers to decide between mitigation versus adaptation strategies. Specifically, mitigation refers to efforts that try to decrease carbon emissions and limit global warming, whereas adaptation refers to policies that assist individuals and governments in coping with the repercussions of climate change currently occurring or cannot be avoided (Baron & Petersen, 2015). Others contend that an excessive emphasis on adaptation might distract resources and attention away from mitigation, which they argue is more urgent and beneficial in the long run. On the other hand, others argue that adaptation is required and complementary to mitigation since it may minimize the social and financial costs of climate change and boost resilience. Thus, we can understand that transforming road maintenance scheduling in becoming more climate adaptive is neither a simple, nor a linear process since many stakeholders will be involved.

Having already analyzed the **garbage can model**, we can understand that this model might be a bit idealistic and simplistic for such complex challenges that the road maintenance sector has. It may disregard the influence of the organizational system that the road maintenance authorities are currently structured making it very difficult to be adopted by the said authorities (Buijs et al., 2009). Some of the pitfalls of the **Arenas & Rounds model** include oversimplifying decision-making factors, neglecting external influences, overlooking long-term sustainability considerations, lacking flexibility in an iterative process, and limited focus on collaborative decision-making (Geert & Teisman, 2000). These limitations can hinder a comprehensive analysis of the decision-making process and its relationship with climate adaptation in road maintenance. Moreover, the **advocacy coalition framework** can also be referred to as a highly rigid and restrictive model, not leaving a lot of room for flexibility in the decision-making, making it a less favorable option for this sector. Combining all the different characteristics of these decision-making models and understanding the challenges of the road maintenance sector through the literature review, the model that seems to be more applicable to this area would be the **Multiple Streams Model**. The Multiple Streams Model is a good option for examining how climate adaptive programs affect asset managers' decision-making in relation to road maintenance. This model has a number of benefits for researching this procedure. It emphasizes issue-driven analysis, allowing researchers to comprehend how particular concerns related to climate change and infrastructure resilience are identified and articulated within decision-making. According to Kingdon, the idea of policy windows in the Multiple Streams Model enables examination of ideal times when problems, the political environment, and viable remedies coincide, illuminating the timing and forces behind climate adaptive measures. The Multiple Streams Model also addresses interactions between politicians, specialists, interest groups, and asset managers, illuminating the roles and dynamics of many stakeholders by recognizing multiple streams and players. Additionally, the Multiple Streams Model's focus on processes fits very well with the iterative and dynamic nature of plans for climate adaptation. Finally, this model's capacity for complex problem analysis offers a framework for comprehending how long-term sustainability, stakeholder participation, engineering considerations, financial restrictions, and climate science are integrated into decision-making. In conclusion, the Multiple Streams Model is the selected model for the analysis part of this thesis as it provides a thorough framework to evaluate the impact of climate adaptive programs on asset managers' decision-making in road maintenance.

Survey selection criteria and potential respondents

First, it's important to define a number of hypotheses that have been derived based on the research questions mentioned in page 11. As soon as these hypotheses are formulated, then more specific criteria for the selection of respondents will be derived. Once these are decided, the potential road maintenance authorities shall be identified. This can be done using existing databases of relevant organizations, or consulting with experts in the field. The initial list of potential respondents will be considered as "leads" with a comprehensive list of relevant organizations (municipalities, provinces or other authorities) which meet the selection criteria. It's important to ensure that the selected sample of respondents is representative of the broader population of people involved in road maintenance scheduling or/and climate adaptation in the road infrastructure. In other words, it was essential to identify people that are capable of validating or invalidating the below-mentioned hypotheses.

Hypotheses

The following hypotheses have been derived based on the Research Questions mentioned in section Research Objective. After each hypothesis, an explanation is provided to provide more information on how these hypotheses were originated.

Hypothesis 1

Different policies regarding climate change push asset managers to become more climate adaptive regarding their plan for road maintenance.

Responding to climate change does not arise within the operational level but rather at a political / strategic level (Overheid, 2020). Thus, asset managers who primarily work in the operational level in response to the request of their regional policies regarding climate adaptation.

Hypothesis 2

Budget limitations discourage road maintenance authorities in becoming more climate adaptive.

Road maintenance authorities are already working with strict budgets (Bulkeley et al., 2009), meaning that they already have to prioritize which road segments should be maintained on the respective fiscal year. To make the transition on climate adaptation in road maintenance is translated to the asset managers as an extra expense that requires a budget that they do not have at hand (personal communication, January 2023).

Hypothesis 3

Larger road maintenance authorities in terms of number of employees have more capabilities in becoming climate adaptive compared to smaller ones.

Having more personnel and departments that actively work on making other processes more sustainable and climate adaptive means that less effort is required from the asset managers, since they won't have to build a large amount of new knowledge or reinvent the wheel for the road network that they are in charge of (Alm et al., 2021).

Hypothesis 4

Adapting to climate change is a very slow process, as it necessitates coordination with several departments, contractors, and other stakeholders, where the exchange of information is challenging.

Whenever a road maintenance for specific road segments needs to be scheduled, it requires coordination of stakeholders that are not easy to reach out (Uittenbroek, 2015). Thus, involving more stakeholders into play that will help in making the transition to climate adaptation will make the process even slower.

Hypothesis 5

There is little to no documentation or use of data-driven approaches within the road maintenance authorities, which create obstacles and stall the transition to climate adaptation with regards to road maintenance.

> The knowledge that has been acquired all these years is not properly documented and has the form of tacit knowledge that has been gained after many years of experience of people in a specific position (personal communication, January 2023). After these people leave the organization, this knowledge evaporates, and the successors of that position need to build the same knowledge from scratch. In terms of data, no digital means are employed to carry out inspections and thus, digitized data are scarce, making the optimization of road maintenance scheduling with respect to climate adaptation a bigger challenge.

Survey criteria

This study is implemented primarily with experts in the field of road maintenance that work directly or indirectly with the road management authorities. The study focuses on the municipal, provincial roads and motorways which the **municipalities**, **provinces** and **Rijkswaterstraat** are in charge of respectively in the Netherlands.

The two former road maintenance authorities have been segmented based on two metrics, the **number of population** for the municipalities and the **population density** for the provinces. These metrics are being used since we want to validate if there are any similarities or differences in the climate adaptation strategies in the road maintenance sector based on the number of inhabitants, the budget and staff count. Thus, the following criteria are used for road maintenance authority selection.

- Municipalities
    - Population > 600,000 inhabitants
    - Population < 150,000 inhabitants
- Provinces
    - Population density > 1100 people / km2
    - Population density < 600 people / km2

Survey participants

The organisations that were selected and participated in this study are listed below, along with the role of the person that the interview was conducted with.

Table 1: Survey study participants

#	Organization	Role
1	CROW	Senior Advisor in Asset Management
2	Province of North Holland	Advisor in Road maintenance
3	Province of Zeeland	Road Surfacing Asset Specialist
4	Province of Gelderland	Policy officer for innovation and sustainability
5	Province of Overijssel	Road Asset Manager
6	Municipality of Leiden	Road Asset Manager
7	Municipality of Leiden	Program Manager
8	Municipality of Utrecht	Road Asset Manager
9	Municipality of Delft	Road Asset Manager
10	Municipality of Amsterdam	Road Asset Manager
11	Municipality of Alkmaar	Road Asset Manager
12	Municipality of Rotterdam	Road Asset Manager
13	Rijkswaterstraat	Climate Change Advisor
14	TNO	Innovation Orchestrator
15	Delft University of Technology	Assistant Professor | Faculty of Architecture

Validation phase participants

The organizations that participated in the validation phase to confirm the results and provide additional input are presented below:

Table 2: Validation phase participants

#	Organization	Role
16	Province of Gelderland	Policy officer for innovation and sustainability
17	Municipality of Utrecht	Road Asset Manager
18	Municipality of Rotterdam	Road Asset Manager

Analysis

In this chapter, the presentation focuses on the outcome of the survey interviews. The interviews were thoroughly analyzed and summaries from the interviews can be seen in Appendix G - Interview Summaries. The information derived from them was combined to deconstruct the road maintenance scheduling process and highlight the initiatives that have been undertaken to enhance its climate adaptability. Noteworthy observations were made regarding the similarities and differences among the various road maintenance authorities, which are subsequently presented below.

Cross-comparison of road maintenance authorities

In comparing the road maintenance and climate adaptation practices across different road maintenance authorities, a generalized comparison table can be observed in Table 3 and more information regarding the observed similarities and differences can be seen below.

Starting with the road maintenance process, all maintenance authorities follow a similar approach, as also stated by the road asset manager from the province of North Holland: *"We have a collaboration with other provinces and municipalities. We all follow about the same process for road maintenance"*. When assessing the quality of the pavement, they employ either condition-based or time-based maintenance strategies. Condition-based maintenance involves visual inspections to assess the quality, and if the pavement is deemed sufficient, no maintenance is planned. However, if degradation is observed, maintenance is scheduled. one primary distinction lies in the utilization of technology and data-driven methods for assessing pavement quality. Provinces and Rijkswaterstraat make greater use of new technologies, but still rely on visual inspections. In contrast, municipalities primarily rely on inspections conducted by human observers, with visual inspectors and daily maintenance crews responsible for identifying road degradation signs during their regular duties. The reason for that is because municipal roads, most of the time are made with tiles rather than asphalt which makes it difficult for smart inspection tools to properly assess the quality of the pavement due to the space that exist between them. This is also supported by the road asset manager of Leiden, *"I think there isn't a good inspection tool in the market for tile-based pavements, since I have to inspect most of the tiles independently sometimes to better assess their quality"*. Integrated asset maintenance is being performed widely across all road maintenance authorities, having asset managers of different assets collaborating together. They all work on joint plans whenever possible to find a cost-effective maintenance plan. The primary assets that affect the prioritization of the planning the most are the roads, bridges and sewage systems, as explained by several asset managers, with the road asset manager of Alkmaar saying: *"We have to prioritize our maintenance based on the sewage systems, roads and bridges. Then the* *greenery, electrical and other assets usually try to embed their maintenance on this planning"*. The rest of the asset managers tend to align their schedules to fit on the schedules of these three aforementioned assets, because the nature of these assets make the maintenance more expensive and more complicated.

Moving on to the initiatives taken with regards to climate adaptation, a notable distinction is the focus on climate adaptation measures. The primary measure that municipalities take to become climate adaptive is planting more green areas within the city. The greenery provide a nice shade that decreases the pavement's temperature but also works as a nice way to infiltrate rainwater. On the other hand, the provinces become climate adaptive primarily by innovating with new building material types that increase the permeability of water to the subsurface layers. Permeable pavements and new building material types aid towards climate adaptation. Specifically, they allow the road infrastructure to better infiltrate the water to soil through its material. Then, they create a better buffer system in the drainage and gives the infrastructure enough time to pass the water into the soil after a heavy rainfall without overflowing. Municipalities tend to be more proactive with climate adaptation and embedding it into their urban development departments. The reason for that is that municipalities invest a lot in new development projects, they try to make these new developments future-proof and thus research more on climate adaptation measures they can take to accomplish that. As stated by the road asset manager of Alkmaar: *"We plan to grow our municipality by 20.000 households by 2030 and we basically have to think ahead in becoming future proof"*. This knowledge is then shared across the different departments, including road maintenance. This enables municipalities to incorporate climate adaptation measures into their workflows more effectively. Furthermore, larger municipalities often have more personnel in general, including dedicated employees for sustainability and climate adaptation, providing them with additional resources to identify solutions for road maintenance and climate adaptation. However, it has not been observed that the size of the road maintenance authority influences the ability to become climate adaptive. There are smaller municipalities that lead in climate adaptation due to the determination of their asset managers, which invalidates the Hypothesis 3.

Budgetary constraints and prioritization challenges are experienced by all asset managers, creating common issues across different authorities. Although new funding opportunities are continuously being created, still, the budget is one of the biggest struggles the road maintenance authorities face right now, which supports the Hypothesis 2. There are also significant differences in the budget requirements for each authority. Municipalities and provinces typically receive smaller budgets compared to Rijkswaterstraat, primarily due to the higher maintenance costs associated with motorways. However, Rijkswaterstraat lags behind in climate adaptation measures, primarily due to the complex decision-making process across hierarchical levels within the organization. Despite these differences, there is an attempt among road maintenance authorities to collaborate and share knowledge regarding climate adaptation measures.

The biggest bottleneck that all road maintenance authorities face right now, which was not expected during the hypotheses generation phase, is the lack of a standardized policy or knowledge that enables asset managers to have a guide that helps them take the correct decisions related to climate adaptation. As the project manager of Leiden said: *"We don't know exactly what we should do with climate adaptation. Right now it's mostly trial and error and we observe how it goes and we learn from the process and use the things we learned in the next project"*. This topic will be extensively discussed later in Multiple Streams Model analysis chapter.

Table 3: Cross-comparison of road maintenance authorities

	Road maintenance process			Climate adaptation initiatives		Bottlenecks in climate adaptation		
	Standardized planning	Use of smart sensors for inspections	Integrated asset maintenance	Permeable pavement OR new building material	Adding more green areas	Budget restrictions	Lack of personnel	Lack of a standardized process
Province of North Holland	✓	✓	✓	✓				✓
Province of Zeeland	✓	✓	✓	✓		✓		✓
Province of Gelderland	✓	✓	✓	✓	✓	✓		✓
Province of Overijssel	✓	✓	✓	✓			✓	✓
Municipality of Leiden	✓		✓		✓	✓		✓
Municipality of Utrecht	✓		✓	✓				✓
Municipality of Delft	✓		✓		✓	✓		✓
Municipality of Amsterdam	✓		✓	✓		✓		✓
Municipality of Alkmaar	✓		✓		✓	✓		
Municipality of Rotterdam	✓		✓	✓	✓			✓
Rijkswaterstraat	✓	✓	✓	✓	✓			✓

Road maintenance scheduling process

Road maintenance scheduling is a multifaceted process that necessitates the expertise of asset managers to effectively plan and execute maintenance activities. This process comprises various stages, each contributing to the overall objective of preserving road quality, ensuring public safety, and optimizing the efficiency of road networks. The overall process is depicted in Figure 5.

The initial phase of road maintenance scheduling revolves around the discerning eye of asset managers, whose observations and assessments enable them to identify the pressing need for maintenance interventions. This identification can arise through two primary reasons: **time-based** and **condition-based** considerations.

Time-based maintenance acts as a proactive measure to safeguard road infrastructure by implementing regular assessments and replacements in accordance with predetermined intervals. These intervals are derived by the pavement's lifecycle. The lifecycle of a pavement is roughly 60 years. However, the number varies from organization to organization, as the asset managers of each organization often try to align the pavement lifecycle with the lifecycle of other assets (e.g. sewage system) to facilitate the asset management planning. By adhering to a pavement's life cycle, asset managers can promptly address any potential issues and prevent their escalation. Concurrently, intermediate maintenance actions are undertaken to sustain the quality of the road and mitigate deterioration risks. An example of a time-based road maintenance is presented in Figure 4, where the province of Overijssel visually depicts the road maintenance plan based on the pavement's lifecycle (*Begroting 2022 - Kapitaalgoederen*, n.d.). In the diagram, the y-axis represents the quality of the road and x-axis the time. When a new road (nieuwstraat) is built, the road's quality is perfect. Then, the road quality deteriorates based on the factors explained in the literature review "Pavement deterioration factors". As soon as the quality reaches the minimum accepted quality level (Minimaal kwaliteitsniveau), then a large maintenance (Groot onderhoud) takes place that restores the quality to a certain level, but less than the original quality. After a series of large maintenances, the road reaches at the end of its lifecycle (Einde levensduur) and has to be replaced by a new road. The battery of our smartphone works in a similar way. When we buy a new phone, the battery health is at 100%. When fully charged, the battery capacity is at 100%. At the end of a day, the capacity has been reduced by a lot, and thus we recharge it. However, whenever we charge the phone (road maintenance), the battery health decreases as well and even though the battery capacity is at 100% (road quality after maintenance), the maximum duration that we can use the phone (time-interval between two maintenance actions) is less than the time we first bought the device (initial road quality). After some years, our battery health has dropped to a level that does not allow us to use the device properly (end of road's lifecycle) and thus we have to replace the battery with a new one (road replacement).

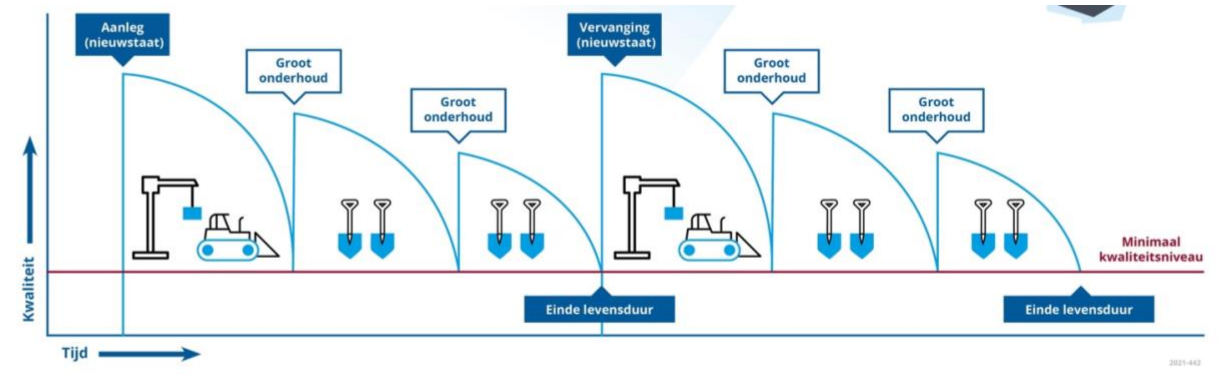


Figure 4: Road maintenance and lifecycle (Province of Overijssel)

In contrast, condition-based maintenance is based primarily on road inspections conducted periodically. These inspections are instrumental in determining the state of road segments and guiding the decision-making process. For provinces there are two distinct types of inspections that play an important role: global inspections and visual inspections, both implemented according to the CROW guidelines, where some of them are summarized in Appendix C - Road quality standards and guidelines. For municipalities there is no difference between global inspection and visual inspection.

Global inspections employ new technologies and specialized vehicles equipped with advanced sensors. These state-of-the-art tools facilitate an in-depth analysis of pavement conditions, thereby yielding quantitative data for a comprehensive assessment. Such objective measurements enable asset managers to gain a spherical understanding of the road's quality and make informed decisions regarding the necessary maintenance interventions.

While global inspections provide valuable quantitative insights, visual inspections offer a qualitative perspective that complements the data-driven approach. Visual inspections entail trained personnel physically visiting the road network to visually inspect the pavement and identify any visible defects, such as cracks, potholes, or other signs of wear and tear. Drawing upon their expertise and experience and usually training by CROW, these inspectors provide valuable qualitative assessments that enrich the overall evaluation process. In addition to inspections, citizen engagement serves as a crucial component of road maintenance scheduling. Members of the public are encouraged to voice their concerns and report any road-related issues they encounter. By actively soliciting and incorporating citizen feedback, asset managers gain invaluable insights into specific areas that require attention and prioritize maintenance actions accordingly.

As soon as the quality is determined, if the quality is sufficient and a maintenance was already planned based on time-interval maintenance, the maintenance is postponed for a certain duration, in order to avoid unnecessary costs and traffic disruption. In the case that the road quality of a road segment was insufficient, a road maintenance measure is scheduled. The complex process of road maintenance scheduling necessitates in general effective collaboration with external stakeholders. Asset managers engage consultants and contractors to leverage their specialized knowledge and expertise in determining the most suitable maintenance measures. These external collaborators contribute valuable insights and recommendations, ensuring that the maintenance plans align with industry best practices and meet the desired outcomes.

Furthermore, asset managers engage frequently with other asset managers responsible for managing other assets that are adjacent to road (Bridges, Lights and Electrical, Road elements, Greenery, Waterways and Sewage). This collaborative approach fosters the opportunity for integrated asset maintenance, where various assets are strategically coordinated to optimize resource allocation and enhance operational efficiency. By aligning maintenance plans and sharing knowledge across different assets, asset managers can collectively work towards achieving objectives and maximizing the impact of their maintenance efforts.

External advisors and political representatives are often involved to ensure that the maintenance plans align with the broader goals and vision of the city or region. By seeking additional input, asset managers can tap into a wider range of perspectives and expertise, allowing for a more comprehensive approach to road maintenance.

Budget planning serves as a critical aspect of the road maintenance scheduling process. Asset managers develop and propose budgets that align with the anticipated maintenance requirements. These budget proposals undergo evaluation by the financial department of the road maintenance authority, where decisions regarding funding allocations are made. In cases where the proposed budget is reduced, asset managers must reevaluate their plans, exploring alternative routes in their planning to streamline costs or enhance the efficiency of their maintenance activities, all while striving to uphold the integrity of the road network.

To ensure the seamless execution of maintenance activities, coordination with various internal and external stakeholders becomes paramount. Asset managers must notify or in some cases secure approval from emergency services, guaranteeing that their operations remain uninterrupted during maintenance interventions. This coordination is crucial to prevent any potential disruptions that may compromise public safety, such as impeding the access of emergency vehicles or hindering the response to critical situations.

Additionally, asset managers collaborate closely with the traffic department within the road maintenance authority. By seeking approval and guidance from this department, asset managers can effectively manage traffic rerouting strategies and ensure minimal disruption to the daily flow of vehicular movement. Clear communication channels are established to disseminate information regarding road closures and alternative routes, ensuring that motorists can navigate the affected areas without inconvenience or confusion. The availability and coordination of external contractors also play a pivotal role in the road maintenance scheduling process. Asset managers must assess the schedules and commitments of these contractors to ascertain their availability for the planned maintenance activities. Effective coordination with contractors ensures that the required resources and manpower are mobilized promptly, facilitating the timely execution of maintenance measures and minimizing any potential delays.

Once the comprehensive planning and coordination stages are completed, the maintenance measures are ordered and implemented. Depending on the nature and scale of the maintenance required, asset managers can deploy either their internal maintenance crew or enlist the support of external contractors. Small-scale interventions are typically handled by internal personnel, well-versed in rectifying specific pavement issues. On the other hand, larger-scale maintenance projects necessitate the expertise of external contractors who possess the necessary equipment, skills, and resources to execute complex interventions efficiently.

During significant road blockades resulting from extensive maintenance activities, police supervision often comes into play. The presence of law enforcement personnel ensures the smooth flow of traffic, safeguards public safety, and facilitates the overall maintenance process. By managing and directing traffic around the affected areas, police supervision minimizes inconvenience and potential hazards.

In summary, road maintenance scheduling is a complex process that demands the expertise and diligence of asset managers. By integrating time-based and condition-based considerations, conducting comprehensive inspections, engaging with stakeholders, and navigating budgetary constraints, asset managers can develop effective maintenance plans. Through collaboration with external advisors and contractors, consultations with other asset managers, and coordination with emergency services and traffic departments, asset managers ensure a coordinated and optimized approach to road maintenance. Ultimately, this extensive planning and execution contribute to the preservation of road quality, enhancement of public safety, and the efficient management of road networks.

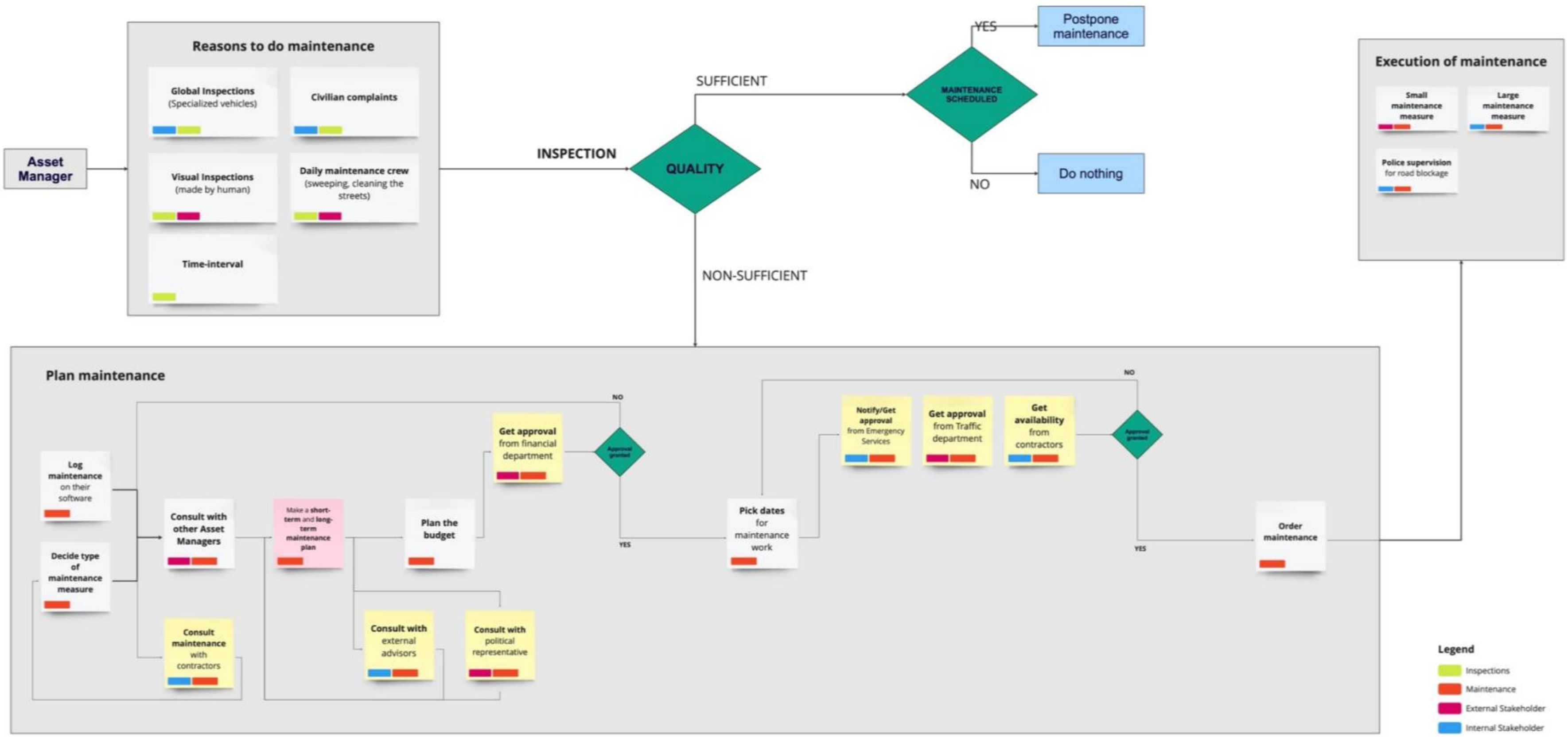


Figure 5: Road maintenance scheduling process

Multiple Streams Model analysis

In this section the decision-making process of road maintenance is analyzed using Kingdon's Multiple Streams Model (MSM), (Kingdon & Stano, 1984; Knaggård, 2015). The model consists of three streams as explained in Appendix A - Decision-making models, the Problem Stream, the Policy Stream and the Political Stream. When these three streams align, then policy windows are created. However, in this case, as observed from the interviews, these three streams cannot be properly coupled as it will be thoroughly explained in Policy Windows section, because one of the main struggles of asset managers is that they lack the knowledge in climate adaptation and there is no policy behind climate adaptation for road maintenance yet.

Problem Stream

In the effort to make road maintenance more climate adaptive, several interconnected problems create complexities and impede progress, which are also depicted in Figure 6.

Lack of technology & expertise

One significant issue revolves around technological challenges faced by asset managers. They are presented with the task of selecting the most suitable asphalt type to enhance climate adaptability. The rapid pace of innovation in asphalt materials poses a dilemma, as asset managers lack sufficient knowledge and evidence of the long-term effects and benefits of these new options. This uncertainty surrounding technological advancements aligns with Kingdon's emphasis on identifying and defining problems arising from changes in technology. Climate change emerges as a dominant force influencing road maintenance in North Holland, as explained by the province's policy officer of innovation and sustainability: *"So the pavements are the main factor for planning, and there is some discussion about it right now, and it has to do with the urgency of, let's say, climate adaptation. There are some water-related issues in one of our neighborhoods and leads to a number of accidents."*. The region's clay-based soil structure signals the impact of climate change, leading to increased maintenance requirements. The recognition of these adverse effects on road infrastructure reflects the problem stream linked to changes in the environment. As Kingdon suggests, problems can arise from shifts in environmental conditions and the need to address emerging challenges. The lack of expertise and familiarity with climate adaptive practices poses a substantial obstacle for asset managers. While they possess the desire to adopt climate adaptation measures, they struggle to identify and implement the appropriate tools and methods. The complexities surrounding climate adaptation in road maintenance contribute to the problem stream, highlighting the need for knowledge acquisition and capacity building. Kingdon acknowledges that problems can arise from knowledge gaps and the challenges of coordinating multiple actors with varying levels of expertise.

Lack of sufficient knowledge in climate adaptation

Controversial opinions and conflicting viewpoints further complicate the problem stream. Asset managers encounter debates with other members of their team and other project managers surrounding the compatibility of sustainability actions with effective climate adaptation. For instance, the use of trees as a climate change mitigation measure presents a conundrum. On one hand, trees provide shade, mitigate heat, and assist in water absorption during heavy rainfall. On the other hand, tree roots can damage the integrity of asphalt, leading to accelerated deterioration. Asset managers must navigate these conflicting arguments and make informed decisions that balance different perspectives and priorities. The source of this problem points also towards the lack of sufficient knowledge or standards regarding climate adaptation measures, as described by the road asset manager of Leiden: *"I think I believe but because of the whole movement to sustainability, biodiversity, climate adaptation, we say we also want to do that. But at the end of the road, we just don't know how."*. The absence of standardization and clear policies adds another layer of complexity to the problem stream. As climate adaptation in road maintenance is still a relatively new field, formal policies and guidelines are lacking. Asset managers are left to rely on fragmented sources of information, such as best practices shared through informal networks, publications, and expert advice. The need for standardized approaches and clear directives becomes apparent, emphasizing the role of policymakers in recognizing and addressing this problem. Kingdon highlights that problems can arise from the lack of established policies and guidelines, necessitating their inclusion in the policy agenda.

Lack of sufficient budget

Financial constraints form a critical problem within the problem stream. Insufficient budgets pose significant challenges for asset managers striving to implement climate adaptive measures effectively. When requested budgets are disapproved or reduced, asset managers must recalibrate their plans and prioritize their work accordingly. This necessitates resource allocation and project planning that align with the available financial resources. Kingdon emphasizes that problems can arise from budgetary limitations and resource constraints, underscoring the importance of securing adequate funding for climate adaptation initiatives.

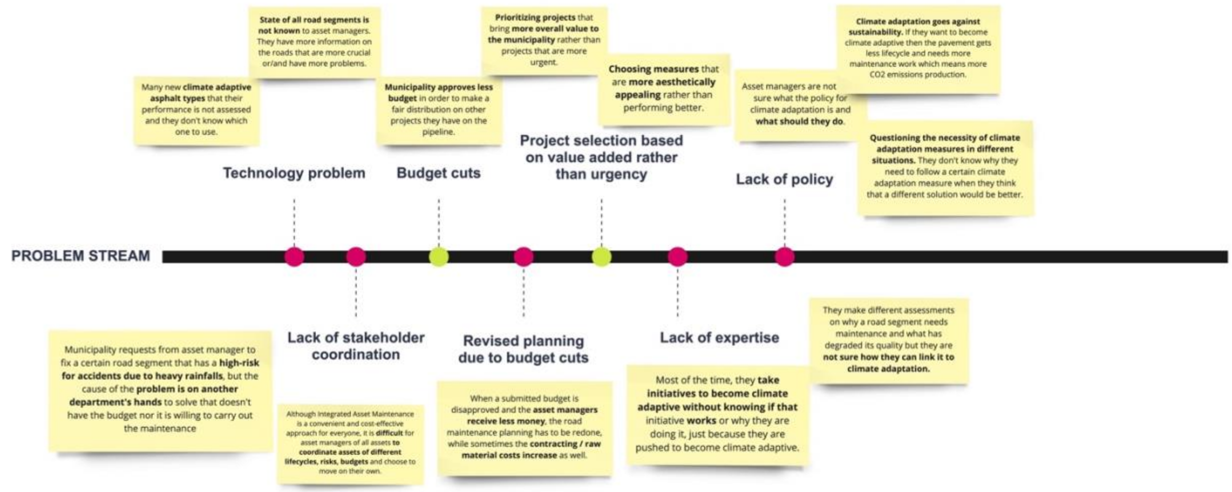


Figure 6: Problem Stream

Policy Stream

As also mentioned in the problem stream above, asset managers recognize the potential benefits of these innovations but are hesitant to adopt them due to the lack of knowledge regarding their long-term effectiveness. This uncertainty and the need for assessment and standardization indicate the existence of a problem that requires policy attention. A visual representation of the policy stream is presented in Figure 7.

Technology validation

To address this problem, CROW plays a crucial role in the policy stream, as it facilitates the technology / innovation validation and is responsible for assessing the technological readiness of new asphalt types. Their role is to provide asset managers with the necessary information and evaluations to make informed decisions about integrating these innovations into road maintenance activities.

Climate-related funding

In terms of funding, through the interviews it was derived that new funding opportunities have been introduced to accommodate pilot projects aimed at testing climate adaptation technologies. This allocation of resources provides municipalities and provinces with opportunities to explore innovative approaches in their road maintenance practices. These pilot projects can serve as policy windows, as we will see later, opening up new possibilities for experimentation and learning. By investing in these initiatives, policymakers demonstrate their commitment to addressing the challenges posed by climate change and seeking effective solutions. Further funding is requested by asset managers to be used specifically for climate adaptation which is on top of their nominal budget request for road maintenance. The road maintenance authorities acknowledge the fact that more budget is required to accommodate climate adaptation measures into the normal road maintenance process and thus it is not uncommon to allocate more resources into that. For example, the municipality of Delft requested €1.2M for road maintenance and another €1.2M for climate adaptation. Although the board did not approve the full amount for the climate adaptation, the asset managers received a budget around €0.6M for sustainability and climate adaptation measures.

Introduction of Environmental Models & Metrics

Furthermore, the integration of environmental models and indicators, such as the MKI, into contracts between municipalities and road maintenance contractors reflects a policy response to climate adaptation and sustainability goals. These models and indicators serve as measurable criteria to evaluate the environmental impact of maintenance actions. By incorporating them into contracts, municipalities promote sustainable practices and incentivize contractors to adopt climate-conscious approaches. This aligns with Kingdon's emphasis on problem definition and measurement as crucial factors in policy formulation.

Lack of standardization & policy

Although a number of elements has been mentioned in the policy stream, the absence of a comprehensive climate adaptation policy or guideline in the form of an operational handbook for asset managers is apparent. There are many initiatives taken by external organizations, coalitions between provinces and municipalities, and consortia between academia, public sector and the industry. These initiatives aim to share best practices and knowledge, informing municipalities and provinces about effective strategies for reducing CO_2 emissions and adapting to climate change in road maintenance. However, in order for these “best practices” to become a policy, more organizations need to adopt these practices and a sufficient amount of time needs to pass in order to verify that the selected policy indeed yields the right and positive results. This collaboration and knowledge-sharing resemble the policy-oriented learning processes described by Kingdon, where actors engage in dialogue, exchange information, and shape policy agendas through collective learning. Different arenas have been created in a short period of time. Climate change and sustainability matters are getting a higher priority as the time passes by. Regular meetups are held internally to discuss, organize and revise internal policies in the asset management department. New development projects (housing construction) pose a great opportunity for municipalities to invest more in researching climate adaptation methods, which are then shared and adapted in the road asset department.

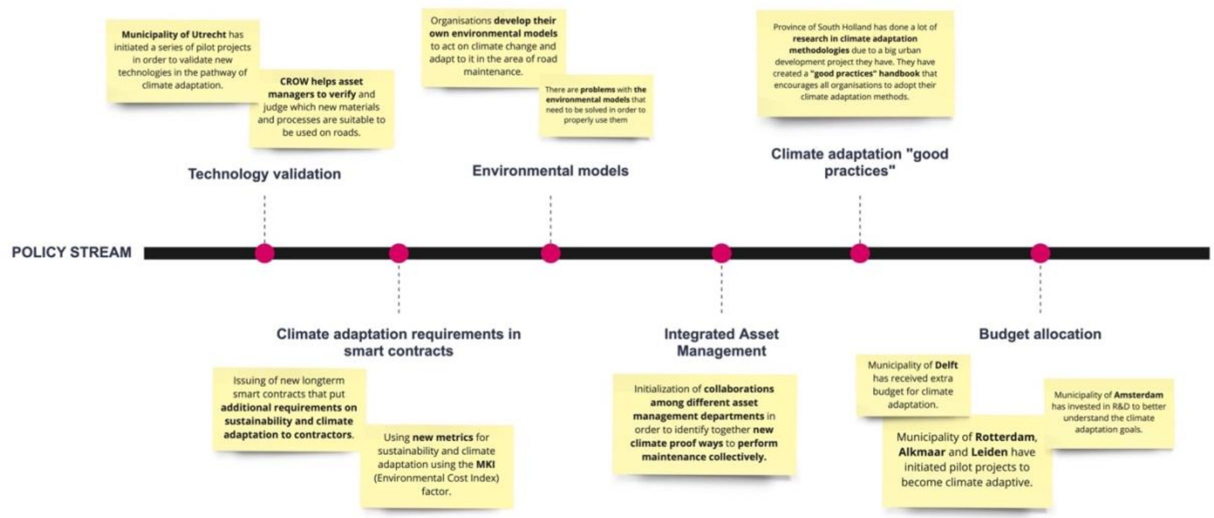


Figure 7: Policy Stream

Political Stream

Within the asset management team, the presence of various specialists, including a sustainability advisor, civil engineers, asset managers and project managers adds complexity to the decision-making process. Each team member brings their unique expertise and priorities to the table. The asset manager, responsible for long-term asset performance, emphasizes climate adaptation measures to ensure the longevity and resilience of the road infrastructure. On the other hand, the project manager focuses on the immediate visual appeal and aesthetics of the roads, considering factors such as streetscape and community satisfaction. These differing perspectives reflect the diverse policy preferences and objectives within the team.

Asset management team

The internal debate between the project manager and asset manager showcases the competition for attention and resources within the organization. Each team member tries to advocate for their preferred policy option, often employing persuasion techniques to influence the decision-making process. This highlights the role of policy entrepreneurs even at an operational level within the organization who seek to advance their own policy agendas. However, the absence of an objective performance measurement tool poses challenges for the asset management team. Without a clear framework for assessing the effectiveness and impact of their decisions, they have to rely on subjective opinions and expert judgment. This subjectivity can introduce biases and uncertainty into the decision-making process. It also emphasizes the limitations of the asset management team's ability to fully evaluate the potential outcomes and consequences of different maintenance options.

Public engagement

Moving beyond the asset management team, the political stream extends to interactions with external stakeholders, particularly the public. The interviews highlight controversies from the public side when there is major disruption in the traffic flow which forces people to take alternative routes in order to reach their destination and causes frustration. Within the cities, when there are significant road closures due to maintenance, the neighborhoods and shops are notified in advance to mitigate any issues that can arise from this disruption. There is also positive engagement from the public, when people encourage the improvement of the aesthetics in the urban areas by adding more nature to them. This also plays a significant role in the decision-making process of the asset manager when it comes to deciding which measure to select for climate adaptation (e.g. selection between a new asphalt type and planting trees). It might seem that the opinion of the public in planting more trees and adding more nature might be unanimous, but it isn't. There is the opposing opinion that is based on the trade-offs between environmental benefits and potential drawbacks, such as reduced parking space or play areas. This public debate further adds to the complexity of decision-making, as the asset management team must consider and navigate these diverse perspectives. The integration of community opinion into the road asset management plan becomes essential for legitimacy and public acceptance. While positive feedback can strengthen the team's decision-making, disagreements and conflicting opinions require careful consideration. The asset management team must account for these differences to ensure a balanced and inclusive approach to road maintenance. This highlights the importance of stakeholder engagement and participatory processes in shaping decision outcomes.

Political influence

The political stream also encompasses interactions among different asset managers and their coordination within the organization. Although in most cases minor disagreements between asset managers are easily resolved, major planning disagreements are escalated to the city council for resolution, indicating the involvement of political actors in the decision-making process. These political dynamics introduce another layer of complexity as decisions can be influenced by power dynamics, personal agendas, and competing priorities. Resource allocation and budgeting further exemplify the political nature of road maintenance decision-making. The process of budget approval involves presenting the proposed budget to the municipality board. However, obtaining the full requested amount is often challenging, requiring iterations and negotiations to align planning with the available budget. This aspect of the political stream highlights the need for the asset management team to justify their funding requests and demonstrate the value and importance of road maintenance to secure necessary resources. Political influence is also evident in the connection between road maintenance and broader political goals and campaigns. During the election period, the alignment of road maintenance goals with the political campaign of a candidate can facilitate funding requests. If the candidate can profile himself with the actions of the infrastructure development or specific asset projects, it becomes easier for the asset management team to justify their budget requirements. This illustrates how political contexts and goals can shape and influence decision-making processes.

“Green” legislation

Lastly, the existence of legislation and regulations plays a crucial role in defining the boundaries and framework within which road maintenance decisions are made. The United Nations guidelines on sustainability and climate adaptation serve as a global reference point, influencing national and regional legislation. In the Netherlands, these guidelines are translated into specific Dutch legislation, which municipalities adopt and integrate into their agendas. The compliance with legislative requirements guides the decision-making process and reinforces the importance of aligning road maintenance plans with broader policy objectives. The green legislation and the goals set by the relevant road maintenance authorities are integrated into the political stream and presented in Figure 8.

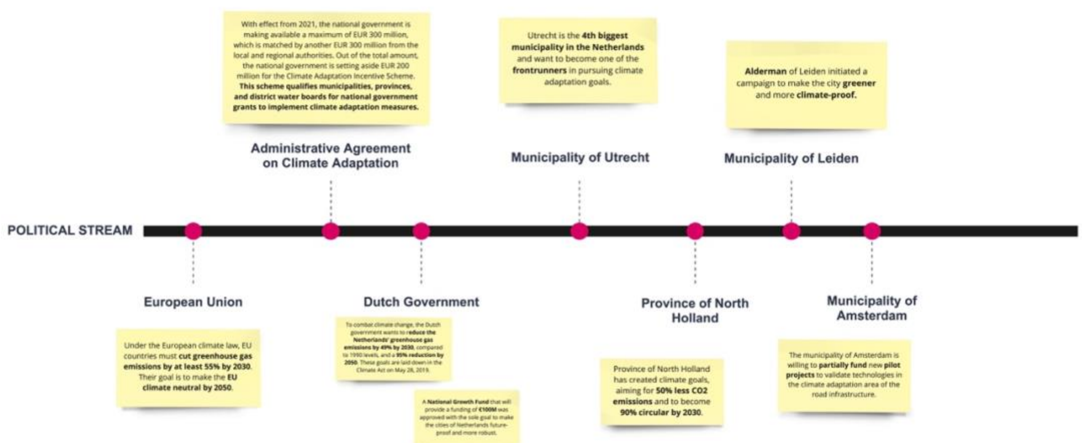


Figure 8: Political Stream

Policy Windows

The outcome of the interviews highlights the scarcity of policy windows in the context of road maintenance and climate adaptation. This scarcity can be attributed to the absence of a comprehensive policy that provides clear guidelines and operational procedures for implementation. According to Kingdon, policy windows often emerge when a confluence of the problem, policy, and political streams occurs. In this case, the lack of a well-defined policy stream, as seen in Figure 9, hampers most of the time the alignment of these streams and limits the opportunities for policy windows to open. Without a policy framework in place, decision-makers may struggle to identify and seize appropriate moments for policy change and innovation.

However, one cannot disregard the presence of a policy window in the form of budget allocation. The increased funding allocated specifically for climate adaptation purposes, politicians getting behind climate adaptation during their campaigns and new arenas created specifically to ignite a discussion over climate adaptivity present an opportunity for municipalities and road maintenance authorities to address the challenges posed by climate change. This budgetary policy window aligns with Kingdon's concept that policy windows can open when problems gain more attention and political conditions favor certain policy responses. The allocation of additional resources reflects the coupling of the problem stream (climate change impacts on road maintenance) and the political stream (resource allocation decisions). This new available funding allows decision-makers (asset managers) to invest in innovative approaches and technologies that enhance climate resilience in road infrastructure, which will eventually create robust policies for embedding climate adaptation in the road maintenance process.

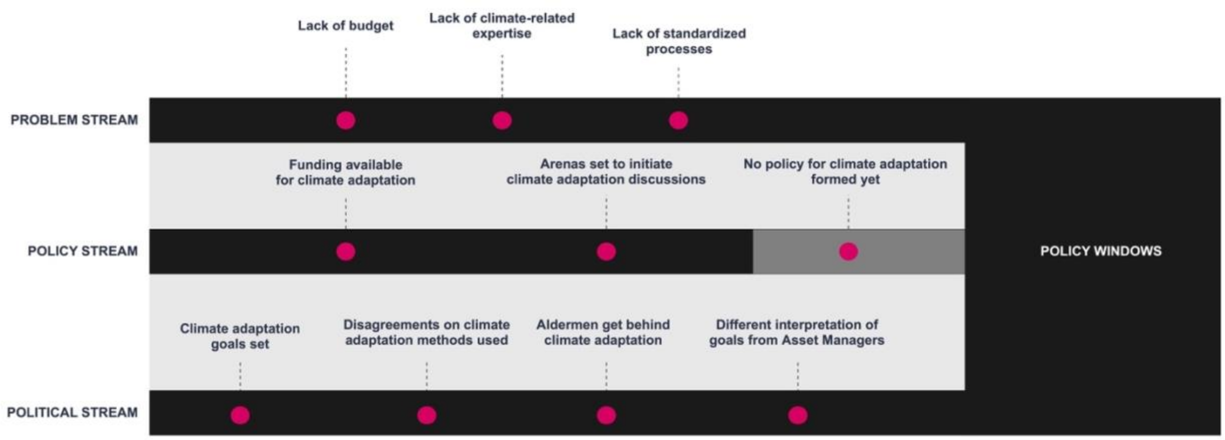


Figure 9: Policy windows

Validation Phase

The validation phase aimed to ensure the accuracy of the results derived from the interviews on the road maintenance and climate adaptation decision-making process. This phase involved conducting three interviews, each lasting approximately 30 minutes, with a total of three participants. The structure of the validation phase was as follows: First, the interviewees were shown a flowchart illustrating the road maintenance scheduling workflow. They were asked if there were any missing elements or misinterpretations that needed to be addressed. Then, the interviewees were presented with six conclusions, depicted in Table 4, which were derived from the interview results and were asked to validate them. Essentially, they were requested to provide feedback on whether these conclusions accurately reflected the reality of the situation or if there were any deviations.

Table 4: Conclusions presented in Validation Phase

#	Conclusion description
1	Asset managers struggle in identifying which climate adaptation measures to take because there is no policy yet to help them understand which action should they take on each occasion.
2	Although asset managers try to achieve the climate adaptation goals their organization has set, it's difficult to measure, based on their actions, how well these actions perform in the long-term.
3	The climate adaptation strategy focuses primarily on adapting towards the heavier rainfalls (higher precipitation).
4	The road maintenance plan sees many iterations as asset managers need to align their schedules with other asset managers or when the budget request is approved for a lower amount.
5	It is often difficult to judge how well a pilot project performs, as there is no method yet to validate how well a new technology would perform in the long-term.
6	Solution providers often present technologies that are either very expensive or / and do not solve a crucial problem asset managers have at that moment.

Regarding the flowchart, it effectively captured the general idea of how asset managers plan and execute road maintenance. However, some comments focused on the reasons for conducting maintenance. Since the daily maintenance crew varies across municipalities, the type of work they perform also differs. Additionally, these crews log the road's quality, noting any cracks or potholes, and inform the respective asset manager. In the case of Rijkswaterstraat, global inspections take place, however another group from Rijkswaterstraat is conducting daily observations driving through their entire road network to identify abnormalities or potential safety risks for the road users. Moving on to the maintenance planning phase, the overall concept and workflow were deemed correct. One discrepancy identified was the approval process for funding. The entity responsible for approving the budget varies among municipalities, rather than solely relying on the financial department. Furthermore, for small maintenance tasks, there is no requirement to seek approval from emergency services unless the maintenance significantly impacts traffic. As for police supervision during maintenance execution, it is typically unnecessary unless the work is being carried out on a high-speed road. In such cases, provisions are in place to prevent major accidents during the maintenance activities.

Turning to the conclusions, all six of them were validated. However, there was a minor comment regarding the interpretation of climate adaptation goals. While all road maintenance authorities establish their own goals based on national and United Nations objectives, each asset manager tends to interpret these goals differently. Consequently, assessing the long-term achievability of these goals becomes challenging. Additionally, CROW has developed a tool to estimate the CO_2 emissions resulting from maintenance work, although it is still in its early stages. Another newly introduced metric is the “MKI”, which measures the Environmental Cost. One conclusion emphasized that the climate adaptation strategy primarily focuses on mitigating rainfall-related issues, which is accurate. However, the impact of heat stress and drought resulting from climate change is also crucial and deserves increased attention in adaptation efforts.

Concerning pilot projects, one conclusion highlighted the difficulty in evaluating their success in the long term due to the absence of a validation method. An example was provided where a cycling lane was constructed using a circular concrete made from geopolymer material. However, the quality of the material quickly deteriorated, but it was unclear whether heavy rain conditions or a fault in the product caused this degradation.

Lastly, the final conclusion stated that solution providers often present technologies that are either overly expensive or fail to address crucial problems faced by asset managers. While the overall idea of the conclusion was correct, there was a comment indicating that some pilots are suitable for their initial purposes. However, the solution providers often struggle to scale up these projects after the pilot phase successfully concludes. Solution providers tend to focus on selling their products or services and frequently latch onto popular themes like heat stress or climate adaptation. Another opinion expressed was that it is not solely the solution providers' responsibility for presenting unwanted solutions. Municipalities also struggle to determine which pilots they should invest in since their current workflow relies on trial and error, lacking means to effectively evaluate these pilots' suitability for climate adaptation, particularly in the long term.

Discussion

The findings of the study shed light on the multifaceted nature of road maintenance scheduling, underscoring the intricacies that arise from the involvement of various stakeholders with divergent objectives. The qualitative-driven approach to inspections further emphasizes the complexity of the process. Currently, inspections primarily rely on human observers traversing the road network, relying on personal judgment and subjective perspectives to assess road quality and identify abnormalities. The scarcity of sensor utilization, except in specific cases, further contributes to the subjective nature of inspections.

One of the most pressing challenges in road maintenance is the limited budget allocated for these activities. With insufficient funding, asset managers are unable to schedule and implement all the necessary maintenance actions, necessitating prioritization. This means that critical incidents and segments posing safety risks to vehicle owners are given priority over other areas in need of maintenance. While this prioritization helps mitigate safety concerns, it inevitably compromises the overall maintenance of the road network. Identifying the right balance between safety and maintenance requirements presents a delicate and complex task for asset managers.

What also increases the complexity is the iterative nature of the planning process, which demands frequent revisions throughout the planning phase. Asset managers must repeatedly review and refine their plans, as they need to collaborate and coordinate with other asset managers to identify opportunities for integrated asset management. The coordination process, aimed at aligning schedules for joint actions, adds further layers of time-consuming efforts and coordination challenges, as different assets have different needs, have different lifecycles and different budgetary requirements. Budgetary constraints can further disrupt the planning process. When asset managers must operate within a reduced budget, they are compelled to adjust their workflow and downsize their plans to accommodate the allocated funds. This necessitates finding more efficient ways to achieve maintenance goals or prioritizing certain activities over others.

The emergence of climate adaptation as a crucial consideration in road maintenance further complicates the planning process. While asset managers have acknowledged that climate change has begun to impact pavement deterioration and introduce safety risks in various road segments, integrating climate adaptation measures into their practices remains relatively new to them. The need for climate adaptation primarily stems from new legislation that emphasizes sustainability and climate resilience, pushes asset managers to modify their working methods and adopt a more climate-conscious approach to road maintenance. As this legislation filters down from the international to national level and eventually reaches the road maintenance authority, asset managers are tasked with achieving specific climate adaptation goals in a prescribed manner.

Among the large number of climate adaptation measures available, asset managers face the challenge of limited knowledge to effectively assess their long-term performance and impact. Additionally, many of these measures come with significant costs, making it difficult for asset managers to accurately calculate the return on investment for each option. Consequently, decision-making in climate adaptation becomes an iterative process of trial and error, lacking a clear view of the long-term outcomes and benefits of chosen measures. Some may argue that this approach is inefficient and necessitates restructuring to enhance decision-making processes.

Based on the study's interviews, asset managers express a primary inclination toward integrating nature near road areas, particularly through tree planting. This measure offers a twofold advantage: firstly, it enhances the aesthetics of the cityscape and receives favorable reception from the public. Secondly, trees play a crucial role in absorbing rainfall, mitigating drainage system overflow from heavy precipitation, and providing shade to counteract high heat and drought, especially during the summer period. An opposing opinion see on this regard is that the selection of tree species with robust and extensive root systems can accelerate the pavement deterioration, leading to more frequent maintenance requirements. Consequently, while tree planting represents a promising climate adaptation measure, the increased maintenance caused by tree roots poses challenges to sustainability and has a negative effect on the overall carbon footprint of the process.

The abovementioned challenges faced by asset managers can be solved, according to them, through the introduction of certain policies and standardization regarding climate adaptation measures in road maintenance. They require comprehensive frameworks or guidelines that help them navigate the selection and implementation of appropriate climate adaptation measures for each specific situation. Lastly, asset managers emphasize the need for expanded knowledge and resources that would empower them to evaluate and judge the effectiveness of different climate adaptation options more easily.

In comparing the findings of this study to the existing literature, several notable differences and additional insights can be observed. While the literature reviewed highlights the importance of climate adaptation measures and the impact of climate change on pavement deterioration, it primarily focuses on the road itself as an asset, neglecting the broader context of road maintenance scheduling (Ali & Khan, 2017). In contrast, this study emphasizes the complexity of the road maintenance process, involving numerous stakeholders, including several different asset managers, the public opinion and political bodies, and encompassing various considerations beyond pavement deterioration. The literature often advocates for a perspective that centers on identifying deterioration factors specific to the pavement itself (Dawson & Gomes Correia, 1996). However, this study reveals that road maintenance scheduling is a multifaceted process influenced by factors such as budget constraints and political dynamics. The availability of adequate budget plays a crucial role in determining the extent to which maintenance needs can be fulfilled while simultaneously implementing climate adaptive measures. The intricate interplay between asset managers and the higher management team of the road maintenance authority, particularly in the iterative process of budget approval and revisions, is an aspect not extensively addressed in the literature. For example, in the publication of Santos and the rest of the authors, the discussions between asset managers is discussed for integrated asset maintenance, however, there is no mention of the interaction with the decision-makers of the proposed budgets (Santos et al., 2021).

Moreover, politics within the road maintenance authority can impact the prioritization of specific maintenance actions. Certain actions may receive higher priority based on their perceived value and contribution to the city or province. This aspect of decision-making, driven by political considerations, has not been extensively explored in existing literature. Integrated asset maintenance, which involves collaborative planning among asset managers, has gained attention in recent literature. However, the study findings indicate that the current collaborative process is not yet highly efficient due to differences in workflows, budget schedules, and variations in asset lifecycles among different managers. This highlights the challenges of achieving effective collaboration in the context of road maintenance.

While the literature generally identifies three pillars of asset management—increasing asset utility, reducing overall costs, and enhancing the asset's lifetime (World Economic Forum, 2014), as seen also in Figure 2— the interviews conducted for this study uncovered a **fourth significant goal** that redefines the asset management perspective. Asset managers also prioritize the enhancement of aesthetics, particularly in the road sector. The aesthetic aspect serves as a decision-making factor, not only for climate adaptation and sustainability measures but also for garnering support and favor from decision-makers within the municipality and the public who utilize these assets. Increasing the aesthetics can also be translated into increasing the "user experience" of the people who use these assets. Therefore, we can say in confidence that a fourth pillar in asset management is "Increasing the user experience" and then the Figure 2 can be transformed.

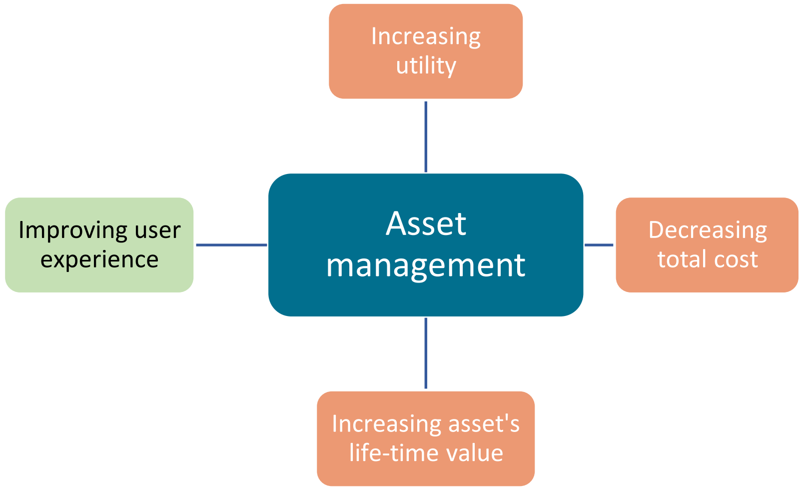


Figure 10: The revised pillars of asset management

Conclusion

The purpose of the study, as described in the Research Objective chapter, was to analyze the decision-making process of asset managers in road maintenance and understand what initiative they have taken to make this process more climate adaptive. To analyze that, it was needed to identify the different stakeholders that play a role in this decision-making process and the criteria that weigh into the decisions. To answer those questions a number of hypotheses were developed to validate or invalidate them through interviews with various experts in the field of road maintenance and climate adaptation. These hypotheses emphasized that climate adaptation is hindered by the shortage of budget, knowledge in climate adaptation within the organization, availability of data to drive informed decisions, sufficient number of personnel and that the push for climate adaptation comes from internal policies that the road maintenance authorities have created.

The study has provided valuable insights, as seen in the Analysis into the multifaceted nature of road maintenance scheduling, highlighting the complexities arising from the involvement of various stakeholders with divergent objectives. The process starts with the asset manager that issues inspection activities to understand the state of the road network. Internal and external visual inspectors are involved in this action, as well as daily maintenance crews or/and public participation through complaint filing for areas that present pavement degradation signs. The asset manager also consults with external advisors and contractors to find the most appropriate maintenance measure that needs to be taken, in order to form his road maintenance plan for the coming year(s). Asset managers from assets adjacent to road sit together to identify integrated asset maintenance opportunities and align their schedules in an iterative manner to accommodate the different needs in timeline, budget requirements and other availability of resources. Communication with the upper management is mandatory in order to receive the necessary (usually budgetary) approvals in order for the asset manager to proceed with the execution of the maintenance plan. Finally, emergency services and the traffic department are kept in the loop constantly to avoid heavy disruptions in their operations and the traffic respectively.

As far as the data availability is concerned, the inspections mostly follow a qualitative-driven approach which emphasize the subjective nature of the process, primarily relying on human observers. Limited budgets pose a significant challenge, forcing asset managers to prioritize critical incidents and safety risks over overall maintenance requirements. Currently, in the Netherlands there is a significant amount of neighborhoods that were initially built around 60 years ago, which means that the road infrastructure approaches into the end of each lifecycle, rendering it in need of replacement in the coming years. Road replacement can also be translated into increased budgetary requirements, a problem they already had. Thus, more budget is allocated to maintenance which leaves no room for budget allocation for additional climate adaptation measures, which are also costly.

The iterative planning process, coordination efforts, and budgetary constraints further contribute to the complexity and necessitate efficient ways to achieve maintenance goals. The emergence of climate adaptation as a crucial consideration adds another layer of complexity, as asset managers face challenges in assessing the long-term performance and impact of measures while dealing with cost considerations. Integrating nature near road areas, particularly through tree planting, is favored by asset managers, but concerns about increased maintenance and pavement deterioration exist. Policy standardization and expanded knowledge and resources are identified as crucial for addressing these challenges and improving decision-making processes.

Comparing the findings of this study to the existing literature, notable differences and additional insights have been identified. While existing literature focuses primarily on the road itself as an asset and deterioration factors specific to the pavement, this study highlights the broader context of road maintenance scheduling. Factors such as budget constraints and political dynamics significantly influence the process, which has not been extensively explored in the literature ((Dawson & Gomes Correia, 1996; Santos et al., 2021). The interplay between asset managers and the road maintenance authority, including the iterative budget approval process and political considerations, adds complexity to decision-making. Collaborative planning among asset managers, although recognized in the literature (Kuliczkowska, 2016b; Santos et al., 2021), faces challenges due to differences in workflows, budget schedules, and variations in asset lifecycles. Additionally, the study reveals the importance of aesthetics or the user experience as a decision-making factor, which is not extensively discussed in existing literature (World Economic Forum, 2014).

To advance the field of road maintenance scheduling, future research can focus on several areas. Firstly, exploring the integration of sensor technologies and data-driven approaches can enhance the objectivity and efficiency of road inspections, reducing reliance on subjective judgments. Investigating advanced analytics and artificial intelligence techniques for decision-making processes can lead to improved allocation of limited budgets and effective prioritization of maintenance actions. Developing standardized policies and guidelines for climate adaptation measures specific to different regions can support asset managers in their selection and implementation. Research on the long-term performance and environmental impacts of climate adaptation measures, particularly tree planting, can provide insights into their sustainability and inform implementation strategies. Moreover, exploring innovative financing models and public-private partnerships can offer new approaches to overcome budget constraints and facilitate comprehensive road maintenance practices.

By addressing these research gaps, the field of road maintenance scheduling can evolve toward more effective, efficient, climate adaptive and sustainable practices. Finally, this will ultimately lead to better road conditions, enhanced resilience to climate change, and improved aesthetics of the cities.

Appendices

Appendix A - Decision-making models

Complex systems, networks, and chains, such as the management of the Dutch road network, have unstructured problem-solving processes. "Formulating difficulties," "designing," and "deciding" are actions that are intricately interwoven and have the characteristics of a process of strategic engagement where analysis and the use of power are crucial (Enserink & Hermans, 2010). To analyze these complex systems and understand the work dynamics and the steps taken towards reaching to a decision, a decision-making model shall be employed. A number of decision-making models is analyzed below.

Garbage can model

A radical approach of policy-making known as the garbage can model examines complex circumstances without a set hierarchy of goals and values. This approach is designed to examine how many different parties contribute to decisions on public infrastructure. The contents of such a garbage can vary depending on the time of day, the amount of waste produced, the proximity of other garbage cans, and how quickly the cans are emptied. The Trash Can Model of Decision-Making was established in 1972 and is applicable to complex circumstances where conventional procedures do not appear to be missing and where it is unclear even who is involved in the process (Cohen et al., 1972). This garbage can idea can be used to explain why decision-makers sometimes arrive at unexpected or unforeseen results.

How the model works

According to the concept, decision-making in companies is a disorganized and unpredictably chaotic process, similar to a garbage can where various issues, potential solutions, and decision-makers are thrown together. According to the concept, decision-making is a process that develops when four streams — problems, solutions, participants, and choice opportunities — come together.

These four streams operate independently in the garbage can model, and decision-makers are continually seeking for ways to connect participants with options and issues with solutions. Organizational culture, power relationships, and the availability of resources are some of the variables that affect this process. According to the Trash Can Model, decision-making in companies is frequently unexpected and chaotic, with choices being based more on luck than on logical reasoning. The model does, though, also emphasize the significance of adaptability and flexibility in decision-making procedures, as well as the necessity for businesses to continuously review and tweak their decision-making procedures in order to respond to shifting conditions.

Figure 11: Illustration of the Garbage Can model

In the Trash Can Model, decision-making is understood as a process of random occurrences, where problems, solutions, participants, and choice chances collide in unanticipated ways. The road maintenance division, for instance, can address the requirement to give particular roads top priority for repairs during a regularly scheduled meeting. An unexpected budget decrease, however, may compel the department to reevaluate its objectives, resulting in a whole new set of priorities.

Streams model

The streams model was introduced by Kingdon, which makes reference to streams of issues, solutions, participants, and decision-making chances (Howlett et al., 2015). It serves as a metaphor for the policy window, which alludes to the interconnection of individuals, issues, and political developments. As they must communicate issues and draw others' attention to them, the actors or players in the streams model are situated within and between the streams. No matter how pressing an issue may be or how good a design may seem, decision-makers will not act due to the coupling of these streams. "Policy entrepreneurs," such as actors looking for answers to their problems or problems looking for solutions to their problems, produce policy windows.

How the model works

According to the Streams Model, three main streams of information are used in decision-making:

- **Problem Stream:** The decision-relevant issues and worries that make up the problem stream are many. These problems might be particular or more generic in nature, and they could result from internal or external forces.
- **Policy Stream:** The policy stream is made up of alternatives for the issues mentioned in the problem stream. These suggested solutions might have been created by policymakers, specialists, interest groups, or other parties.

- **Political Stream:** The decision-making context's larger political landscape is covered by the political stream. This includes elements like public opinion, pressure from interest groups, and the political environment.

According to the Streams Model, these three streams must be "coupled" or "aligned" in order for decisions to be made. Thus, alignment between the problem stream, policy stream, and political stream is necessary for efficient decision-making.

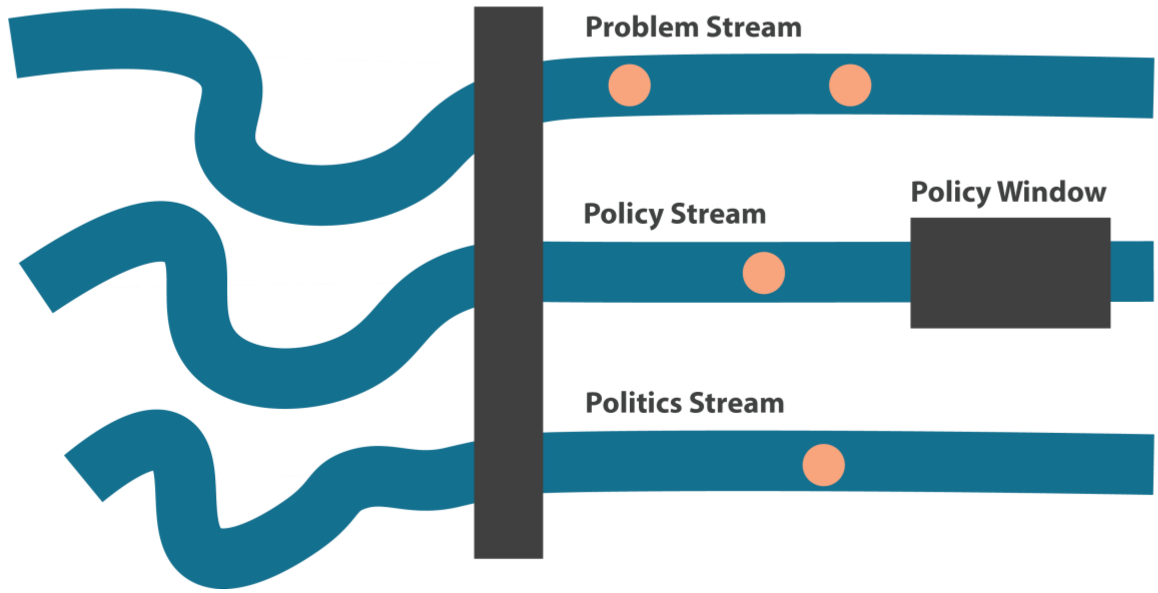


Figure 12: Illustration of the Streams model

Arenas and Rounds

Rounds and arenas are defined by decision-making that follows a zigzag path with ups and downs and iterations. A "crucial decision" is made at the conclusion of a round of negotiations, and it has an impact on the subsequent rounds of discussions. The problem-solving procedure in the rounds model is comparable to a boxing match, where the outcome of each round can vary, and the winner is only made clear at the conclusion. There may be numerous simultaneous venues where parties argue about issues and potential solutions in several locations at once. These spaces are where decisions are made or where participants create, bargain, and decide on issue formulations and solutions.

How the model works

Several phases and participants are involved in the Arenas and Rounds Model's decision-making process. Here's how it functions:

- **Identify the arenas:** The first phase in the process is to identify the various arenas or forums where the decision-making will take place. These arenas may include formal meetings, casual talks, and other possibilities for communication and cooperation.
- **Set the laws of the game:** Once the arenas have been defined, the following stage is to determine the rules of the game. This might entail creating communication channels, setting decision-making criteria, or deciding how choices will be made.
- **Determine the participants:** The players or participants are recognized during this phase. They could include stakeholders, experts, decision-makers, and other persons who have a vested interest in the choice being made.
- **Implement the rounds:** Following then, a number of rounds are used to make decisions. Every round takes place in a separate arena or forum, and every round entails the application of the game's rules. Each round gives participants the chance to share their opinions, justifications, and ideas.
- **Evaluate the proposals:** Proposals are reviewed and edited after each round. This might be making changes to suggestions in response to comments made, attending to issues brought up by other participants, or adding new material.
- **Make the decision:** Making a decision is the last step in the process. This conclusion is based on the suggestions, arguments, and judgments made in the preceding rounds.

The Arenas and Rounds Model emphasizes that decision-making is a complicated process that incorporates various parties and views. The concept enables a more open and participatory approach to decision-making by dividing the decision-making process into many rounds and arenas. The model also recognizes the need of discussion and cooperation in decision-making, as well as the necessity of defined standards and procedures.

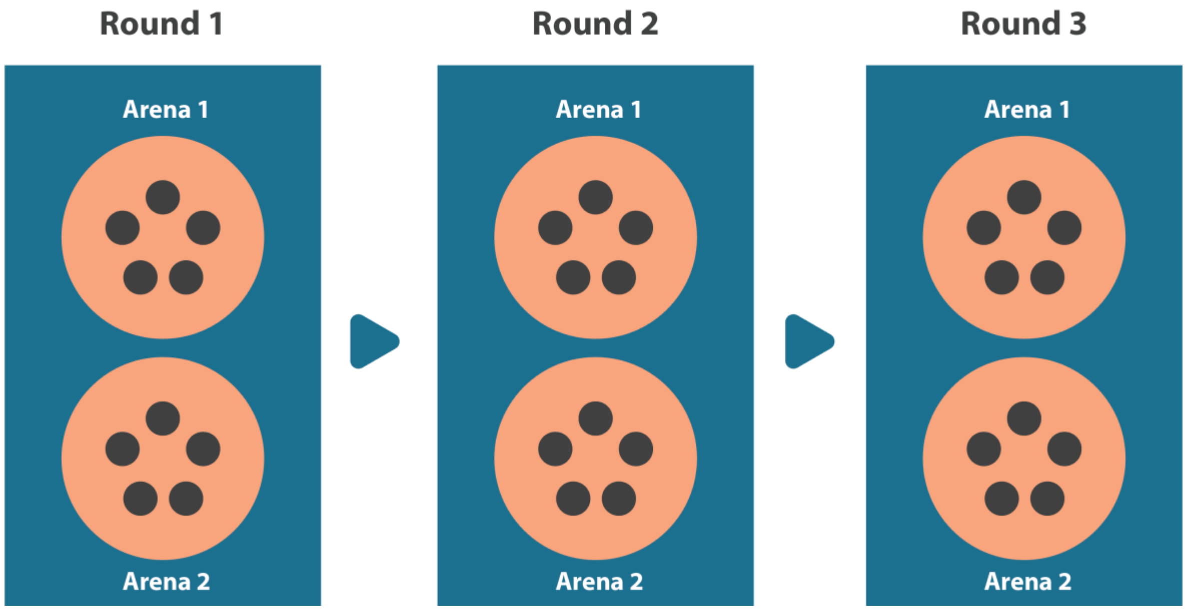


Figure 13: Illustration of the Arenas & Rounds Model

Advocacy Coalition Framework

Sabatier and Jenkins-Smith created the Advocacy Coalition Framework (ACF) in 1988 to clarify the functions of formal analysis and technical data in the policymaking process (Weible & Sabatier, 2006). It is predicated that advocacy coalitions are created by groups of stakeholders that hold similar beliefs and that policy decisions are made inside policy subsystems made up of many theoretical components. Coalitions utilize lobbying techniques to change public policy and hold varying opinions about how the world functions and what is right for the world. The ACF gives the argumentation aspect of policymaking a larger role and contains particular elements that deal with the more political aspects of employing resources strategically to advance one's own goals.

How the model works

The Advocacy Coalition Framework is segmented into different groups, including the policy subsystems, advocacy coalitions, core beliefs, policy change, policy learning and policy stability. More specifically:

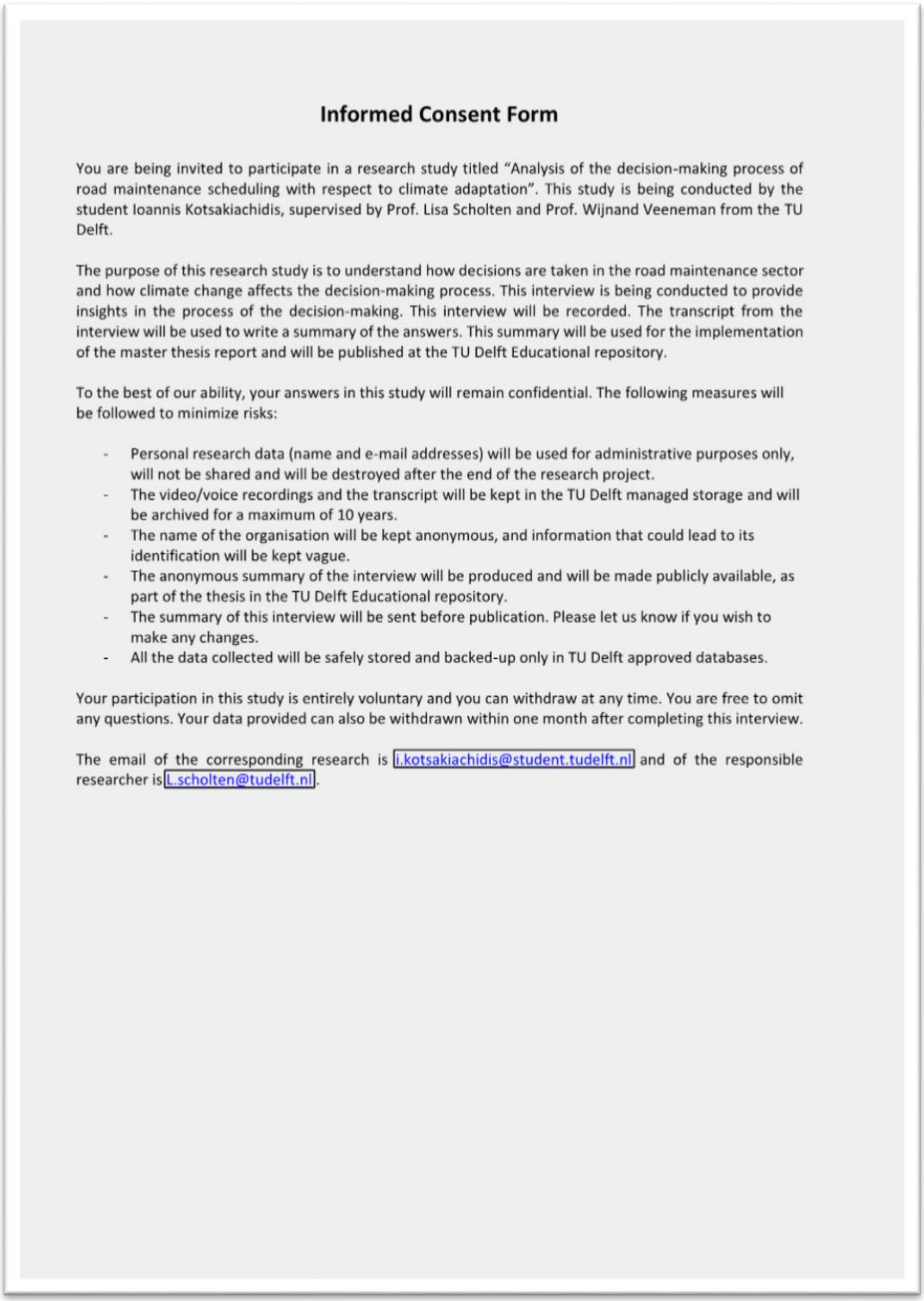
- **Policy Subsystems:** A policy subsystem is a collection of individuals (such as policymakers, bureaucrats, interest groups, and professionals) involved in developing and carrying out policy in a certain domain. Each subsystem has a unique set of ideas, norms, and practices that have an impact on how policies are developed and carried out.

- **Advocacy Coalitions:** In a certain policy sector, an advocacy coalition is made up of individuals who hold similar opinions and advocate certain courses of action. Advocacy coalitions are created around a particular policy issue and are made up of different players including interest groups, lawmakers, bureaucrats, and specialists who all have a similar view of the issue and how to address it.

- **Core beliefs:** An advocacy coalition's fundamental principles are the strongly held ideals and presumptions that influence its policy choices. These ideas are deeply held and frequently guide the coalition's choices and activities.
- **Policy Change:** A change in policy happens when an external event (such a change in administration or a serious crisis) disrupts the status quo and creates a window of opportunity for it. Advocacy coalitions participate in policy discussions and employ their resources to sway the decision-making process in this situation.
- **Policy Learning:** When participants in a policy subsystem interact and discuss a policy problem, policy learning takes place. Advocacy groups may use policy learning to influence decision-makers and other players to alter their opinions on a particular policy issue.
- **Policy Stability:** When the opinions and desires of the players in the policy subsystem remain constant and the status quo is upheld, policy stability prevails. It is unlikely that policies will change in this situation until the policy subsystem is seriously disrupted.

In conclusion, the Advocacy Coalition Framework describes how the interplay between advocacy coalitions, policy subsystems, and outside events leads to policy change. Policymakers can identify the major actors and interests engaged in a policy problem and devise tactics to influence the policy process by knowing the preferences and opinions of various actors in the policy subsystem.

Appendix B - Informed Consent Form



Informed Consent Form

You are being invited to participate in a research study titled "Analysis of the decision-making process of road maintenance scheduling with respect to climate adaptation". This study is being conducted by the student Ioannis Kotsakiachidis, supervised by Prof. Lisa Scholten and Prof. Wijnand Veeneman from the TU Delft.

The purpose of this research study is to understand how decisions are taken in the road maintenance sector and how climate change affects the decision-making process. This interview is being conducted to provide insights in the process of the decision-making. This interview will be recorded. The transcript from the interview will be used to write a summary of the answers. This summary will be used for the implementation of the master thesis report and will be published at the TU Delft Educational repository.

To the best of our ability, your answers in this study will remain confidential. The following measures will be followed to minimize risks:

- Personal research data (name and e-mail addresses) will be used for administrative purposes only, will not be shared and will be destroyed after the end of the research project.
- The video/voice recordings and the transcript will be kept in the TU Delft managed storage and will be archived for a maximum of 10 years.
- The name of the organisation will be kept anonymous, and information that could lead to its identification will be kept vague.
- The anonymous summary of the interview will be produced and will be made publicly available, as part of the thesis in the TU Delft Educational repository.
- The summary of this interview will be sent before publication. Please let us know if you wish to make any changes.
- All the data collected will be safely stored and backed-up only in TU Delft approved databases.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. Your data provided can also be withdrawn within one month after completing this interview.

The email of the corresponding research is i.kotsakiachidis@student.tudelft.nl and of the responsible researcher is L.scholten@tudelft.nl.

Appendix C - Road quality standards and guidelines

Asset management in the sphere of road maintenance is highly influenced by the road quality standards and guidelines that have been set by certain organizations or even the government. Inspecting and managing the roads in the Netherlands begins with the national CROW guideline for safe and sustainable road management (Overheid, 2020). CROW is the technology platform for transport, infrastructure and public space and its role is to transfer knowledge and guidelines to all actors in those fields (CROW). The CROW Directive is a technical approach that calls for expert knowledge and may be used as a starting point for cost estimations. The BOR technique has been utilized to make the policy nonnegotiable and transparent to non-technical people. There are two categories for road maintenance planning as proposed by the CROW directive, the short-term planning, which spans from 1-5 years and follows a qualitative approach, and the medium-long term planning, which refers to the planning for a duration of over 5 years and follows the cyclical methodology. Cycle-based planning and budgeting is used to determine the maintenance needs for the whole life of the roadways, while the estimated annual maintenance expenses are determined using the qualitative approach.

The quality levels are used as the foundation for creating the quality scenarios. The CROW quality yardstick, which is included in the standard quality catalog, uses a 5-scale to describe the quality of diverse public spaces. To guarantee a specific standard in the public sphere, many levels of ambition are available. Following are some examples of the options for the intended quality levels of the public space:

Table 5: Pavement quality level scale

Quality Level description	Grade
Very high (A+): excellently maintained, like new.	> 9.5
High (A): well maintained, almost nothing to criticize	7.5 – 9.4
Basic (B): sufficiently maintained, something to criticize	5.5 – 7.4
Low (C): austere to sufficient, some delays in maintenance	3.5 – 5.4
Very low (D): insufficiently maintained, large backlogs, broken	< 3.4

According to the policy plan, all roads must be maintained in the Netherlands on average at a “B-level”, so as to ensure proper quality and safety.

Appendix D - Research method approach

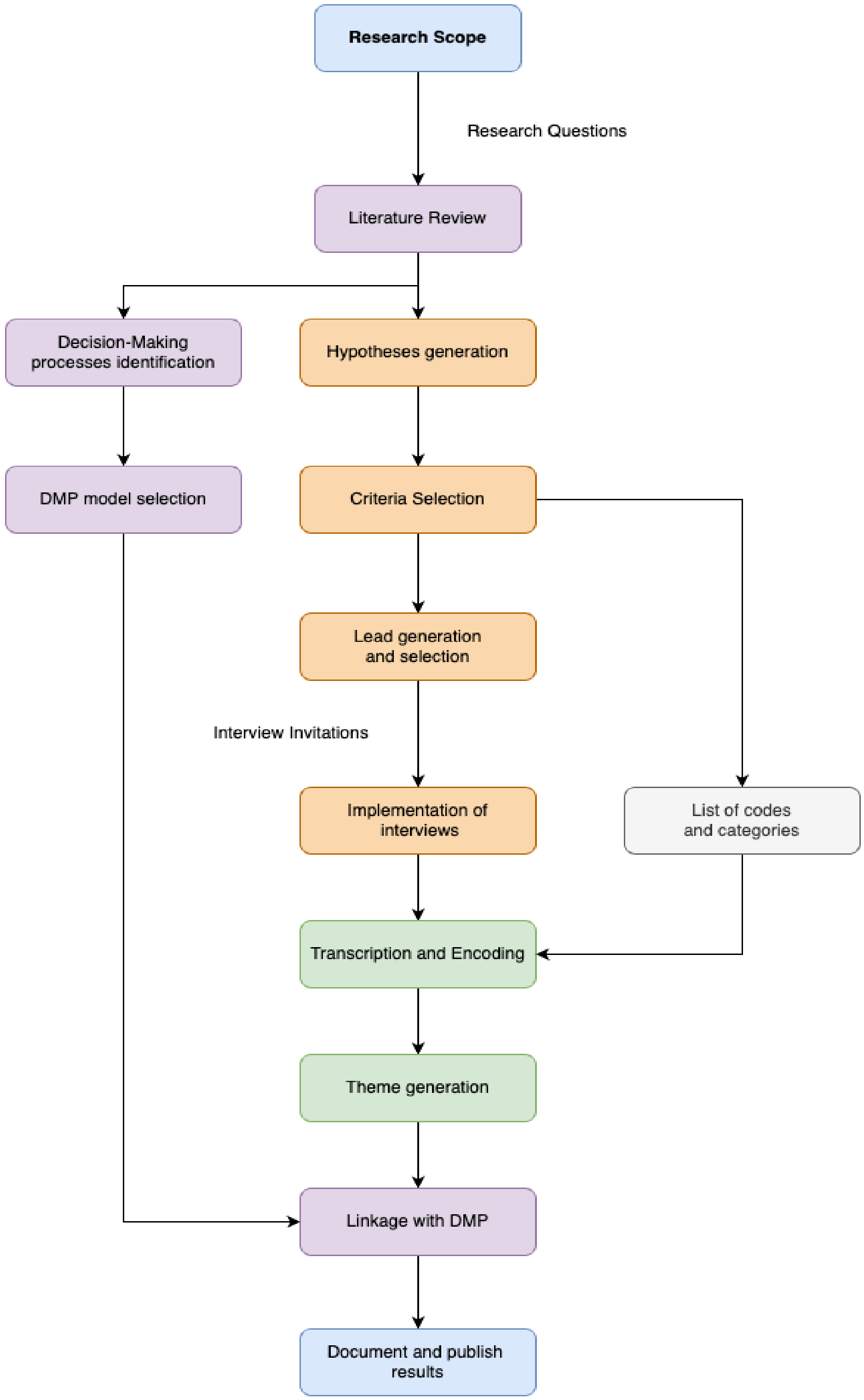


Figure 14: Diagram of the Research Process

Appendix E - Interview guide

The interviews had a semi-structured format and a duration of approximately 1 hour. For the implementation of each interview, the following operational guide has been created that covers all phases.

Before the interview

A. (Online) Meeting invitations are sent.

B. Informed Consent Forms are sent.

During the interview

A. **Personal introduction:** Introduction from the researcher's side, the purpose of the research, remind the content of the consent form and that the meeting will be recorded.

B. Questions to be asked

1. General questions

i. Can you please introduce yourself and describe your role and responsibilities within your organization?

ii. What is the first thing that comes to mind when you hear about climate adaptation in the road maintenance?

2. Specific questions

i. Is there a specific process that you follow every time in order to decide which road segments should be maintained first or does the process change to adjust to every project?

I. Can you take an example of an ordinary road maintenance project that you were involved in and describe to me step-by-step what actions were taken?

II. With which other departments or organizations did you collaborate with to decide and implement the maintenance?

III. Based on which aspects (or criteria) do you decide which roads should be maintained (first)?

IV. Do you use any (digital) tools or data-driven approaches to monitor and decide which road segments do you need to maintain?

ii. What are the current initiatives within your organisation to make road maintenance more climate adaptive?

iii. What factors influence your capability to become more climate adaptive in road maintenance?

I. How much does the policy (external pressure from government, municipality, etc) of any level influence the strategy for climate adaptation?

II. How much does the available budget affect the strategy for climate adaptation?

III. How much does the number and expertise of people in your organization influences the transition to climate adaptation?

3. Unstructured question

i. In your opinion, what should be changed first to transform the road maintenance process in becoming more climate adaptive?

C. Conclude the interview

1. Thank you for the interview!

2. Mention that a summary of this interview will be shared with the interviewee and if there are any questions or requests for changes, they are welcome to do so.

3. Ask if they have any contacts that they could share with you to conduct another interview.

4. Ask if they would be willing to be contacted again in the future for further questions.

After the interview

A. Save the recorded file to the designated folder.

B. Share the interview summary with the interviewee.

Appendix F - Data analysis methodology

After each interview, the recorded material was saved in a designated folder. The recording was immediately transcribed with an automatic transcription software, Grain.com. The final transcribed text was reviewed manually, and the transcript was imported to the Atlas TI software. There, quotes derived from the interview data were initially deductively coded based on a predetermined list. With the help of the coding system and personal notes kept in Slab.com, similarities and differences were identified among the interviewees from the road maintenance authorities.

Categories and codes

The following categories and codes are derived for the purpose of the interview analysis:

A. Stakeholder and Partners

a) Traffic management department

b) Financial department

c) Maintenance specialists

d) Maintenance contractors

e) External consultants

f) Public

g) CROW

B. Road maintenance criteria

a) Volume of traffic

b) Number of complaints

c) Available budget

d) Contractor availability

e) Inspection data

C. Tools used in road maintenance scheduling

a) Visual Inspection

b) GIS software

c) Internal Platform

D. Climate adaptation initiatives

a) No climate adaptation initiatives

b) Permeable pavements

c) Green infrastructure

d) Stronger pavement

e) Stronger drainage systems

f) Climate-responsive maintenance scheduling

E. Factors for climate adaptation in road maintenance

a) Regional policies

b) Low budget

c) No expertise

d) Not enough personnel

e) Not enough time

As soon as quotes were deductively coded, an inductive coding process followed to enhance the quality of the analysis. The Atlas TI software has introduced an automatic AI inductive coding feature that imports the transcripts, analyzes the text and comes up with different codes and code groups to assist the researchers in their own analysis. In the case of this thesis, a highlight of the analysis that needs to be mentioned is that the AI coding managed to accurately detect the parts in the transcripts where the interviewees expressed a “challenge” or a “problem” they were facing. Giving more emphasis on those parts with these two aforementioned codes helped a lot in identifying the moments in the transcripts where key points were discussed.

Theme creation

The codification outcome of Atlas TI was used as input again to Grain.com to categorize the coded parts as themes and form stories later on based on the created themes. Codified quotes were given a highlight name and description for each interview. Thus, each interview in the end had a set of highlights and notes. Highlights from different interviews that pointed towards a certain theme were grouped together and were allocated into a certain story. For example, when an interviewee mentioned that a barrier that hold his organization back from becoming more climate adaptive was a shortage of budget, there was already a code “budget” in the transcript in Atlas TI, that specific quote was selected in Grain.com and a small description was added as highlight. That highlight was added in the theme “Lack of budget”, which was one of the themes under the “Problem Stream” story. The Problem Stream story contained different themes or categories with obstacles that the interviewee faced in their workflow. All highlights carried timestamps that pointed to the audio recording of the respective interview. This feature was really helpful when just reading the transcript was not sufficient and needed to quickly listen again the conversation to help on the analysis. A visual representation of the analysis workflow is presented in Figure 15.

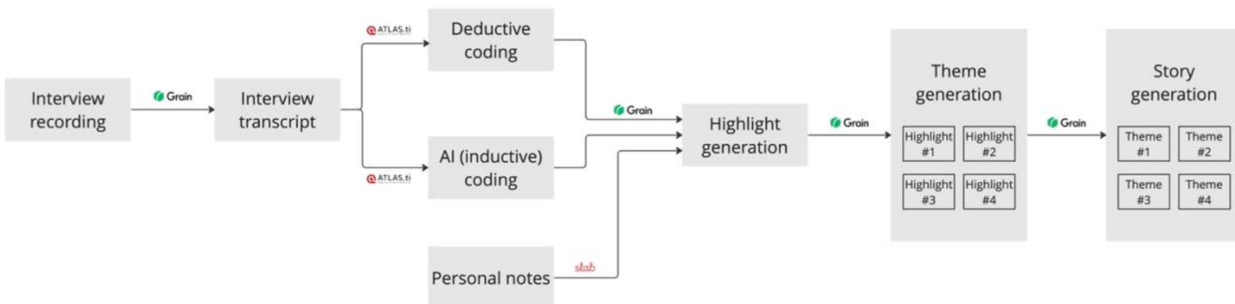


Figure 15: Visual representation of analysis workflow

Appendix G - Interview Summaries

Table 6: Interview Summary - CROW

Organization:	CROW	Interview #:	1
Role:	Senior Advisor in Asset Management		
Summary:	The interview was conducted with a senior asset management advisor from CROW, who has extensive experience in asset management, particularly for publicly owned assets. The interviewee focused primarily on integrated asset management, emphasizing the importance of capitalizing on opportunities to combine maintenance actions across different assets. For instance, when maintenance is required for trees, plants, or electrical systems within the road infrastructure (such as traffic lights), the asset managers aim to integrate these actions with the road maintenance schedule. This approach allows for more efficient decision-making regarding the prioritization of road segments or projects. The involvement of the municipality or the road maintenance authority plays a significant role in determining the value added by a particular project, influencing its prioritization over others. To illustrate this, let's consider two projects: one involving road construction with a cost of approximately €10 million and another aimed at enhancing the sustainability of a city's infrastructure, also costing around €10 million. In such cases, the decision-makers must determine which action delivers the greatest value for the city. These discussions shed light on how asset managers collaborate to achieve integrated asset maintenance, emphasizing the potential for cost reduction when combining maintenance actions across different assets. By combining activities, there is the opportunity to reduce costs. For instance, if one asset requires maintenance costing €5 million and another asset requires maintenance costing €3 million, by performing these actions together, they can request a combined budget of €6 million. This approach avoids duplicating activities and ultimately saves money. However, the challenge lies in the fact that each asset has its own unique life cycle, planning requirements, and specific needs, making it difficult to seamlessly integrate different asset maintenance activities. Consequently, many asset managers choose to pursue alone their maintenance projects. It is worth noting that if an asset manager requests a specific budget but is granted a reduced amount, they must revisit the planning process, which is both time-consuming and challenging.		

Table 7: Interview Summary - Province of North Holland

Organization:	Province of North Holland	Interview #:	2
Role:	Advisor in Road maintenance		
Summary:	The interview was conducted with a road maintenance advisor representing the province of North Holland. Throughout the interview, the interviewee provided insights into the decision-making process involved in road maintenance. Specifically, they discussed how inspections are implemented to determine when a maintenance is required. To assess the quality of the roads, the province relies on global inspections and the data derived from these inspections. If the quality meets the required standards, no maintenance is performed. However, if the quality falls short, a maintenance plan is established. The asset managers utilize an Excel format to organize and schedule all maintenance activities. With this software, they assign specific maintenance types to be implemented within designated timeframes. As a general guideline, the province aims to conduct maintenance actions approximately every 15 years. In the first 15-year period, the top layer of the road is replaced. Over the next 15 years, both the top layer and middle layer are replaced. At some point, a noise reduction layer is also added, which does not have the same life cycle as the regular asphalt layers. Global inspections are carried out annually, with more comprehensive investigations conducted every five years to facilitate layer replacements. This involves drilling and extracting small samples of the road for further analysis. Regarding climate adaptation, asset managers currently face uncertainties regarding the selection of asphalt types that are more suitable for enhancing climate resilience. To address this, CROW assists asset managers in evaluating the technical feasibility of various asphalt types. Climate change significantly impacts road maintenance in North Holland due to the presence of clay in its soil structures, which differ from those found in southern regions. Consequently, more frequent maintenance is required as climate change accelerates pavement deterioration. In terms of goals, the organization aims to reduce CO2 emissions by 50% and achieve a circularity rate of 90% to 100% by 2030. Dedicated funding has been allocated to promote climate adaptation and enhance the durability of North Holland's roads. One notable introduction is the implementation of the Environmental Cost Index, also known as MKI, which is utilized in new maintenance contracts submitted by contractors.		

Table 8: Interview Summary - Province of Zeeland

Organization:	Province of Zeeland	Interview #:	3
Role:	Road Surfacing Asset Specialist		
Summary:	An interview was conducted with a road surfacing asset specialist representing the province of Zeeland. The interview initially focused on explaining the process of road maintenance scheduling. This process involves global inspections and the utilization of software for analysis. They employ tools such as Excel and specialized software to log, track, and analyze the maintenance plan for the road infrastructure. The asset manager receives valuable input from colleagues, particularly regarding policy considerations related to road maintenance. The asset manager highlighted the existence of different types of inspections. Visual inspections are carried out three times a week, while global inspections occur less frequently and employ automated vehicles equipped with specialized sensors such as lasers and LiDAR. These global inspections take place once a year, covering one side of the road and the year after that the other side of the road. With the results of these inspections, the asset manager gains an overview of the road conditions and can easily identify which parts of the road network under their responsibility require maintenance. Based on the assessment, they develop a plan and budget, which they then request from the financial department. In terms of climate adaptation, the interviewee mentioned that their province is committed to becoming more climate adaptive. They have introduced an environmental cost indicator in the new contracts and have already considered the use of recycled materials and electric vehicles in road maintenance projects. The impetus for climate adaptation comes from regulations set by both the European Union and the Netherlands. These regulations drive their organization's interest in enhancing climate adaptation efforts and setting specific goals to achieve them.		

Table 9: Interview Summary - Municipality of Utrecht

Organization:	Municipality of Utrecht	Interview #:	4
Role:	Road Asset Manager		
Summary:	The interview was conducted with a road Asset Manager representing the municipality of Utrecht. He is in charge of the scheduling of inspections and maintenance planning of the road infrastructure. Inspections are performed annually for primary roads and every two years for other roads. Following the guidelines of CROW, they employ their own system to assess pavement quality. They use an alphabetic scale to evaluate the levels of degradation or the state of the road. Their primary focus is on the main roads within the city, and they aim to carry out less frequent but more comprehensive maintenance actions. To execute such actions, they require permission from the traffic department to implement traffic rerouting and assignments in coordination with emergency services. This is essential to ensure the safety of their operations, as blocking crucial road sections during maintenance could pose serious risks. The municipality's workflow prioritizes quality rather than being solely driven by budget considerations. Currently, due to a recent budget overhaul, the municipality has sufficient funds for various maintenance activities, eliminating budget constraints. Consequently, their focus lies on improving the quality of the road network in terms of climate adaptation. The municipality has taken steps toward infiltrating rainwater into the soil, separating sewage and rainwater streams, and creating buffers within the drainage system. These measures enable the drainage system to handle heavier rainfall resulting from climate change by buffering and infiltrating the water instead of causing it to overflow. Overflowing water on roads can lead to serious accidents. The municipality also emphasizes circular economy principles and has made efforts to reuse materials such as ceramic and concrete stones. They are currently in the process of procuring a storage area for storing old materials. Their main tools for climate adaptation stem from both national and municipal climate goals. As one of the largest municipalities in the Netherlands, Utrecht strives to be at the forefront of climate adaptation initiatives in the region.		

Table 10: Interview Summary - Province of Gelderland

Organization:	Province of Gelderland	Interview #:	5
Role:	Policy Officer for Innovation & Sustainability		
Summary:	The interview was conducted with the Policy Officer for Innovation & Sustainability Advisor from the province of Gelderland. The interviewee provided insights into the road maintenance planning process, which involves collecting information about pavement quality through required road inspections. Based on this data, a five-year plan is developed to determine the necessary maintenance actions. During the planning phase, the main focus is on minimizing traffic disruptions and avoiding closures of significant road sections. There are six assets that are connected to the road infrastructure. These assets include roads, bridges, electrical systems, greenery, road elements (such as safeguards and guardrails), and waterways. The aim is to integrate maintenance activities across these assets. Initially, the primary reasons for maintenance are identified from the road and bridges. Once the planning for these assets is established, efforts are made to explore if maintenance actions can be combined with the other assets as well. The organization is divided into two parts. One part is responsible for operational activities, such as asset maintenance, while the other focuses more on strategic policymaking. Currently, they operate in a reactive manner, addressing problems as they arise. However, there is a shift towards adopting a more strategic policy approach to climate adaptation. This includes allocating a budget to climate adaptation projects and conducting improved risk assessments related to climate change. To illustrate an example of a climate change problem, there is a specific area in the province where rainfall has become heavier and more frequent, resulting in road flooding and numerous accidents. In response to the increased accidents in that particular road segment, the decision was made to take action. Consequently, additional budget allocation has been directed towards enhancing the climate resilience of that area.		

Table 11: Interview Summary - Municipality of Leiden (Asset Manager)

Organization:	Municipality of Leiden	Interview #:	6
Role:	Road Asset Manager		
Summary:	The interview was conducted with a road asset manager from the municipality of Leyden. The manager discusses three primary reasons for scheduling road maintenance: time-based maintenance, condition-based maintenance, and end-of-lifecycle maintenance. Time-based maintenance involves segmenting the road's full lifecycle and performing maintenance actions in specific road segments roughly every 15 years. Condition-based maintenance relies on yearly inspections to identify road sections requiring maintenance due to degradation or accidents. Finally, end-of-lifecycle maintenance involves replacing the entire road with a new one. In recent years, there has been increased attention given to sustainability, climate adaptation, and biodiversity in road maintenance. The municipality is striving to find ways to address these new thematic areas. A significant challenge they face in terms of climate change is maintaining permeability in the pavement while determining acceptable levels for the road infrastructure. However, the municipality does not yet have a policy in place for climate adaptation, making it difficult to determine the appropriate actions to take in each situation. The interviewee reflects on the need for clarity in the municipality's climate adaptation goals and the implementation of climate adaptation policies. They also highlight the challenges of balancing sustainability and maintenance concerns. Specifically, there is a debate regarding the most effective climate adaptation methods. For example, introducing plants or trees to enhance the road infrastructure's climate adaptability is not straightforward. Some trees with larger roots can degrade and deteriorate the pavement, increasing the need for maintenance. This maintenance requirement translates into additional CO_2 emissions.		

Table 12: Interview Summary - Municipality of Leiden (Program manager)

Organization:	Municipality of Leiden	Interview #:	7
Role:	Program Manager		
Summary:	The interview was conducted with a program manager at the municipality of Leiden, with a focus on policymaking rather than road maintenance scheduling. The municipality's motivation to become climate adaptive stems from a gradual process that has evolved over several years. To successfully achieve climate adaptability, they aim to avoid investing money on projects that do not consider climate adaptation. One way to achieve this is by changing their decision-making process to prioritize projects that support the climate adaptive initiative. The role of the municipality and the aldermen is crucial in driving this process forward. They can leverage their positions to secure additional budget for climate adaptation projects. The program manager typically presents their goals and plans in a booklet format, and if these align with the politicians' objectives, it gets easier to receive funding for future projects. Aesthetics play a significant role in the decision-making process. The municipality aims to make their cities more visually pleasing, and they seek solutions for climate adaptation that enhance the aesthetic appeal of the city. Therefore, if a climate adaptation solution also improves the visual aesthetics, it becomes a preferred option and is more likely to be approved. Incorporating community involvement is another important aspect of the decision-making process. The municipality includes the opinions of residents living near the areas requiring maintenance. They actively seek feedback, complaints, or objections to the proposed plans from the community members. Overall, the municipality of Leiden recognizes the importance of climate adaptation and has integrated it into their policymaking process. They aim to align their projects with climate adaptation goals, secure funding through political support, prioritize aesthetics, and engage with the community in decision-making processes.		

Table 13: Interview Summary - Delft University of Technology

<table>
<tr><td>Organization:</td><td>Delft University of Technology</td><td>Interview #:</td><td>8</td></tr>
<tr><td>Role:</td><td colspan="3">Assistant Professor, Faculty of Architecture</td></tr>
<tr><td>Summary:</td><td colspan="3">The interview was conducted with an assistant professor from the Delft University of Technology, who is actively involved in a new artificial intelligence algorithm to improve efficiency in road maintenance planning. The professor mentions that there is currently significant government funding aimed at making cities and its roads future-proof. They have engaged in discussions with municipalities and asset managers about integrating artificial intelligence technology into their maintenance scheduling workflow.

Although asset managers have shown great interest in exploring new technologies and solutions, the adoption of these technologies is not yet widespread. Municipalities are presented with various projects and pilot studies, and they need to select which ones to proceed with, with the funding that they have received from the government. The professor's technology may be one of these pilot projects, but there is a possibility that it may not be chosen because it disrupts the current workflow of asset managers.

According to the professor, another approach would be to take sequential, small steps to make the technology more appealing and easily adopted by asset managers. They suggest avoiding an immediate and drastic change, even though their technology has the potential to yield promising results and revolutionize road asset management.

The professor acknowledges the enthusiasm from asset managers and the interest in new technologies. However, they emphasize the need for careful consideration and gradual integration to ensure successful adoption and avoid resistance to change.</td></tr>
</table>

Table 14: Interview Summary - Province of Overijssel

Organization:	Province of Overijssel	Interview #:	9
Role:	Road Asset Manager		
Summary:	The interview was conducted with a road asset manager from the province of Overijssel. The asset manager begins by explaining the process of road maintenance planning, which involves both global inspections conducted with specialized equipment and visual inspections to assess pavement quality. They emphasize the importance of collaboration with various stakeholders, including different departments, organizations, water companies, municipalities, and provinces, to ensure efficient road maintenance planning. When it comes to climate adaptation, the asset manager highlights several challenges. One major challenge is the lack of funding, making it difficult to secure resources for road maintenance projects, let alone investing in climate adaptive measures. Additionally, there is a shortage of human resources, with insufficient personnel available to perform necessary road maintenance actions. To address these challenges, they express the need for more personnel to improve road maintenance practices, as well as to enhance climate adaptation and sustainability efforts. The asset manager mentions specific goals related to reducing CO2 emissions and increasing circularity. In line with these goals, they have initiated pilot projects to implement sustainable practices and achieve their objectives. They have also introduced a new software that creates a map highlighting areas within the province's road network that are particularly susceptible to heavy rainfall. By utilizing this data, they can identify areas that require additional attention and allocate resources and budget to minimize the risks of accidents caused by climate-related issues on the roads.		

Table 15: Interview Summary - Municipality of Delft

Organization:	Municipality of Delft	Interview #:	10
Role:	Road Asset Manager		
Summary:	The interview was conducted with the asset manager from the municipality of Delft. The asset manager provides insights into the road maintenance planning process in the municipality, which involves various types of inspections and collaboration with different departments, particularly when undertaking larger projects. They specifically highlight the collaboration with the Green and Water departments to explore new ways of integrating climate adaptation into road maintenance. In efforts to make the city more climate adaptive, the municipality has undertaken initiatives such as reducing the use of pavement tiles and incorporating more green spaces. These green spaces provide shade and help mitigate the heat and drought resulting from climate change. They also serve as a means of mitigating heavy rainfall. While the current budget primarily focuses on road maintenance, the asset manager has requested additional funding to enhance the municipality's climate adaptation efforts. Although they did not receive the full amount they requested, they have been allocated with a budget to carry out specific actions related to climate adaptation. Interestingly, the asset manager notes that the policies on climate adaptation typically originate from new development projects rather than road maintenance. Due to the significant investments in these projects, there is a proactive approach in making them climate-proof and future-proof. The knowledge gained from climate adaptation in new development projects is then applied to integrate such practices into road maintenance. Monthly meetings in Delft are held to discuss climate adaptation, yet the overall limitation lies in the budgetary constraints faced by the municipality.		

Table 16: Interview Summary - Municipality of Amsterdam

Organization:	Municipality of Amsterdam	Interview #:	11
Role:	Road Asset Manager		
Summary:	The interview was conducted with the Asset Manager of Amsterdam, who is responsible for the maintenance of roads, pavements, street elements, playgrounds, art monuments, and bus stations in the city. The Asset Management Department of Amsterdam has several sub-departments and divisions dedicated to performing the required maintenance tasks. Funding for maintenance projects is typically obtained through a proposal format, with decisions made around November for proposals submitted in May. Based on the approved budget, the Asset Manager determines the scope of work. If the full amount requested is received, the proposed activities are carried out as planned. However, if the budget is reduced to less than 70% of the initial request, adjustments must be made. This could involve increasing workflow efficiency to accommodate all proposed activities or downsizing the project and prioritizing actions within the approved budget. In such cases, some maintenance actions may be postponed to future years. Regarding climate adaptation initiatives, the Asset Manager explains that Amsterdam is currently in a phase of understanding and investing time and resources to identify the meaning and goals of becoming climate adaptive. Once they have a clear understanding of the required measures, they can allocate more funds to climate adaptation. Currently, they are introducing rain layers in roads to enhance the drainage system's capacity and actively collaborating with the green department to incorporate green spaces during reconstructions. Amsterdam also emphasizes sustainability and climate adaptability in their contracts with contractors. They encourage their contractors to adopt circular and sustainable practices and introduce electric vehicles for small to medium-sized maintenance vehicles. However, due to budget constraints, they have not been able to transition larger machinery to electric vehicles.		

Table 17: Interview Summary - Municipality of Rotterdam

Organization:	Municipality of Rotterdam	Interview #:	12
Role:	Road Asset Manager		
Summary:	The interview was conducted with the Asset Manager from the municipality of Rotterdam. The asset manager explains the process of road maintenance scheduling, which involves a visual inspection of the road infrastructure every four years to assess its quality and determine maintenance needs for the next four years. To enhance climate adaptability, Rotterdam has initiated a series of pilots derived from their own network. They collaborate with professors, research teams, contractors, and solution providers working on climate adaptation projects in the road infrastructure. Requests for pilots are received, approved, and different projects are undertaken to test new solutions. However, there is currently no clear policy on how to become climate adaptive. The municipality first needs to understand the concept of climate adaptivity and define their goals before actively incorporating climate adaptation into their processes. One climate adaptation initiative they have implemented is the Aqua Flow system, which includes infiltration crates and the planting of more green areas to mitigate heavy rainfalls and provide shade. Despite these efforts, several challenges arise in their pursuit of climate adaptability. One challenge is determining responsibility for specific actions and which department should address certain climate adaptation issues. For example, planting more trees typically falls under the responsibility of the green department, but it directly addresses climate change issues faced by the road department. This lack of clarity hampers decision-making and budget allocation. During election periods, the asset managers leverage the opportunity to request additional funding for their department by aligning their proposed projects with the goals of politicians' campaigns. This strategy allows them to accelerate climate adaptation in the road infrastructure and secure funding. However, disagreements between the maintenance team and the development and design team present another challenge. The design team often prioritizes aesthetics, which can impede the asset managers' ability to maintain the assets effectively. In some cases, a better design may require increased maintenance efforts.		

Table 18: Interview Summary - TNO

Organization:	TNO	Interview #:	13
Role:	Innovation Orchestrator		
Summary:	The interview was conducted with the Innovation Orchestrator from TNO, an organization with extensive experience in the road maintenance sector. The interviewee explained the road maintenance scheduling process followed by provinces in the Netherlands. The process begins with inspections and includes considerations such as time-based maintenance and the lifecycle of the road. The quality of the road is assessed, and based on this assessment, the maintenance measures to be taken are decided. Collaboration with other contractors and consultation with asset managers are common to ensure integrated asset maintenance. External advisors, including climate change advisors and political representatives, are also involved in the decision-making process. When it comes to funding, municipalities and provinces typically have separate accounts for road maintenance. The exploitation account is dedicated to condition-based maintenance, while the investment account covers time-based maintenance, including pavement replacement. The interviewee highlighted that the decision to integrate climate adaptation measures often occurs late in the project planning and road maintenance planning stages. After the schedule has been drafted and approved, considerations for climate adaptation and more efficient actions are made during the execution phase.		

Table 19: Interview Summary - Municipality of Alkmaar

Organization:	Municipality of Alkmaar	Interview #:	14
Role:	Road Asset Manager		
Summary:	The interview was conducted with the road asset manager from the municipality of Alkmaar. The asset manager explained the process of road maintenance scheduling, which begins with inspections. Once the quality of the roads has been assessed, the asset manager plans the necessary maintenance actions, including both condition-based maintenance and time-based maintenance, with a focus on climate adaptation. The municipality of Alkmaar has a long-term plan to increase the number of households by 20,000 over the next 30 years. This will require the construction of many houses in rural areas. As a result, the municipality is already considering climate adaptation measures to make these future developments resilient. This approach will also contribute to the road maintenance department's efforts to become more climate adaptive. Currently, the municipality's focus is on reducing road space and incorporating more greenery in its place. This not only enhances the aesthetics of the city but also provides shade and helps prevent overflowing of roads during heavy rainfall. The municipality is in the process of formulating its own policy for strategic asset management and climate adaptation. They have introduced a handbook that serves as a strategic asset management plan. To enhance their knowledge in climate adaptation, the asset manager actively engages with other asset managers, advisors, and participates in events and meetings.		

Table 20: Interview Summary - Rijkswaterstraat

Organization:	Rijkswaterstraat	Interview #:	15
Role:	Climate Change Advisor		
Summary:	The interview was conducted with the climate change advisor of Rijkswaterstaat, specifically in the regional department of East Netherlands, which is located near the provinces of Gelderland and Overijssel. The interviewee provided insights into the road maintenance planning process. Regular inspections are carried out to identify road issues, and a timeline is created to determine when these issues need to be addressed based on the road's condition. There is a national department within the organization that handles the tender process for maintenance actions. Contractors submit their proposals, and the department also assists in requesting the budget from the Ministry of Transportation. Flexibility is granted for actions costing less than 62 million, allowing the organization to proceed without a tender. For larger projects, a tender is required to select a contractor. Contracts with contractors typically span 40 to 50 years, during which the contractors are responsible for inspecting and maintaining the roads. However, the organization conducts its own inspections to ensure the contractors are fulfilling their obligations. Regarding climate adaptation, efforts are being made to introduce more permeable asphalt, which aids in efficient water drainage. However, this type of asphalt is noisier compared to conventional asphalt. Another initiative involves redesigning resting stations along the motorways, such as gas stations and coffee shops, to make them more climate adaptive. This includes incorporating more trees and greenery to provide shade and cooling opportunities for travelers. Climate change is significantly impacting their operations. Although the organization has a current availability goal of 98% on the roads, climate change and heavier rainfall pose challenges. However, they believe that the road availability will not drop below their target of 95% due to climate change, so it is not their top priority at the moment. Additionally, they are focusing on introducing more greenery alongside the roads and conducting research to select plant species that are less prone to wildfires. With higher temperatures caused by climate change, there is an increased risk of wildfires, and they aim to mitigate this risk by selecting less flammable trees.		

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