Enhancing sustainability in Gelderland's maintenance operations: A Systems Engineering approach for translating ambitions into concrete measures

Ing. H.R. Beumer

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Author	Ing. H.R. Beumer (Edwin)
Student number	s2873044
Institution	University of Twente
Faculty	Engineering Technology
Department	Construction Management & Engineering
Supervisor University of Twente	Dr.ir. R.S. de Graaf (Robin) University of Twente Faculty of Engineering Technology
Supervisor University of Twente	Drs.ing. J. Boes (Hans) University of Twente Faculty of Engineering Technology
Supervisor Province of Gelderland	E. Dekker Msc (Erik) Provincie Gelderland Department of 'Gebiedsontwikkeling & Uitvoering'
Supervisor Province of Gelderland	Drs.ing. R. Trommel (Reinier) Province of Gelderland Department of 'Beheer & Onderhoud'

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Preface

Presented before you is the thesis titled 'Enhancing sustainability in Gelderland's maintenance operations: A Systems Engineering approach for translating ambitions into concrete measures'. This research is conducted to obtain the Master of Science degree in Construction Management & Engineering at the University of Twente in Enschede, the Netherlands.

This research was aimed to contribute to the province of Gelderland achieving its sustainability goals. The organization 'Province of Gelderland' (referred to in this research as 'the province of Gelderland' or 'the province') is a public entity responsible for managing provincial assets, among other duties. The challenges the province faces with becoming sustainable and achieving the sustainability goals set for 2030 and 2050 led to the commissioning of this research.

The personal motivation for the research comes from my interest in organizational structures and urge to assess and optimize processes. In addition, the civil engineering industry interests me because of the large-scale operations and impact on society. I want to thank the province of Gelderland for the opportunity to conduct my master thesis research project. I want to thank the supervisors from the province of Gelderland and the University of Twente for their guidance, constructive feedback, and support. Their knowledge and insights shaped this research and optimized its potential benefit for the province's operations. Lastly, I would like to thank my family and friends during this research by providing support and guidance during this research period.

I hope this research attributes to the implementation of sustainability within the operations of the province and the challenges faced by constructing a sustainable future.

Summary

As national governments commit to sustainability ambitions, organizations like the province of Gelderland also develop ambitions and include them in their infrastructure operations. Sustainability implementation is complex and has its challenges, necessitating the adoption of novel methodologies and innovations that change existing processes and organisational structures. In sustainability implementation, the societal view on sustainability takes precedence, supported by data-driven research and performance indicators. Research is needed to develop a comprehensive approach to sustainability implementation in maintenance operations to balance the ambitions and construct a cohesive plan to achieve sustainability ambitions. This research investigates the potential of using Systems Engineering (SE) for this objective. This research focusses on the operations of the division 'Asset Green & Water', responsible for maintaining all vegetation and water objects of the province.

This research answers the research question – *'To what extent can Systems Engineering help the province structure the process of decomposing high-level sustainability ambitions into project requirements and measures for their maintenance operations?'* – in four phases.

The first phase consisted of establishing the theoretical framework by using SE literature and guidelines to translate stakeholders' needs into a design and its implementation, ensuring that the system meets these needs. This involved development of a fifteen-step process for the development and implementation process of sustainability ambitions. The essence of the process is defining abstract ambitions stepwise into operational measures while using feedback steps to ensure alignment between measures and ambitions and ensure the final system meets the stakeholders' needs. Role allocation is an important aspect within SE for which the RACI methodology (Responsibility, Accountability, Consulted, Informed) is used to adequately define roles. By using SE, the process becomes traceable, and trade-offs are substantiated through structured documentation. SE's approach ensures that resources can be used more efficiently, measures have a clear connection with ambitions and negative side effects on ambitions are mitigated. Additionally, real-world feedback is integrated into the process and sustainability measures can be adapted to changing ambitions. By looking at roles, it is ensured that the prescribed process is executed by the appropriate individuals.

The second phase consisted of identifying the current sustainability implementation process. The data collection was done through document analysis, fifteen interviews, and observations at two meetings. To aid in investigating the current process of sustainability implementation, five measures from maintenance contracts of the division 'Asset Green & Water' were examined. Afterwards, the data was analysed, and the provincial process was compiled based on the fifteen-step process described in the theoretical framework.

In the third phase, a comparison was made between the theoretical framework established in the first phase and the empirical provincial process observed in the second phase. Pattern matching was used to analyse the similarities and differences between the ideal according to theory and the practical reality. Based on this analysis, preliminary conclusions were formulated, resulting in twenty-one statements. These statements were then discussed and validated through a focus group consisting of previous interviewees from the second phase. Twenty-one statements were presented, and feedback was collected using a 5-point Likert scale. The results were discussed afterwards to ensure accuracy and clarity.

The key challenges that the province faces that have been identified are:

1. The development and implementation process lacks traceability and transparency due to minimal documentation of the decision-making process.
2. Sustainability development in maintenance operations lacks a foundation in ambitions due to unclear accountability for achieving these ambitions and the absence of measurable indicators for their development.
3. Measurement development is directly based on abstract ambitions without assessing its effects. This leads to a challenging development process as the decision making during the development process is not based on weighted policy and objective data but on individual expertise.

4. Roles are not structurally assigned to individuals. The development and implementation process relies heavily on individuals' motivation and expertise, which renders the process highly implicit, and continuity of sustainability implementation is not ensured.

In the fourth phase, six recommendations have been defined to face the identified challenges faced by the province. The recommendations are arranged based on their relevance to improve the current process:

1. Implement a structured documentation strategy: Ensure traceability and transparency in the development process by adopting a systematic approach to documentation. This solves the issue of the development and implementation process not being traceable and allows for referencing during the multiple stages of the process.
2. Appoint an asset owner: Appoint a primary stakeholder responsible for defining ambitions in maintenance operations, as well as for validating both the development and implementation processes. This addresses the issue of accountability for achieving sustainability ambitions through maintenance operations not being defined.
3. Translate ambitions into requirements and functions: Develop requirements and functions derived from ambitions as intermediate steps to effectively bridge the gap between strategic goals and measure development. This addresses the problem of measures being developed without knowing the impact and the side effects on the ambitions.
4. Clarify roles and responsibilities: Establish clear roles and responsibilities for sustainability implementation to enhance the process's resilience, reducing dependence on individual motivation while ensuring accountability for these roles.
5. Adopt a risk-based inspection approach: Introduce a risk-based method for inspections to assess contract work more effectively. This approach helps address the province's uncertainty about the impact of implemented measures on its sustainability ambitions. By focusing on the effect of deviations from measure specifications on the ambitions, rather than merely the execution of the contract, this method enhances the overall effectiveness of inspections in achieving sustainability goals.
6. Create a comprehensive sustainability implementation plan: Develop an integrated plan for all infrastructure operations to optimize resource use and enhance sustainability efforts, considering the impact of each department and asset. Moreover, this establishes a solid foundation for sustainability implementation in the work related to the provincial infrastructure.

Based on these recommendations, it is concluded that applying a SE framework offers advantages for sustainability implementation, as the recommendations address the identified challenges. How the SE methodology should be integrated into the maintenance process still needs to be investigated, as this research only examined the gap between the ideal process according to SE theory and the province's sustainability implementation process. Future research should focus on creating an implementation plan for SE within the maintenance process. Prior to integrating sustainability across provincial infrastructure through SE, it is essential to explore challenges in other departments and assets.

Samenvatting

Nationale overheden committeren zich steeds meer aan duurzaamheidsambities. Ook de provincie Gelderland stelt duurzaamheidsambities vast en verwerkt deze in de werkzaamheden rondom haar infrastructuur assets. Het implementeren van duurzaamheid is complex en kent uitdagingen. Hiervoor worden nieuwe methodes en innovaties toegepast waardoor mogelijk ook bestaande processtructuren veranderen. Bij de implementatie van duurzaamheid staat de maatschappelijke visie op duurzaamheid centraal. Deze wordt ondersteund door data-gedreven onderzoek en prestatie-indicatoren. Dit vraagt om een integrale aanpak voor het afwegen van duurzaamheidsambities en het opstellen van een samenhangende aanpak om deze ambities te bereiken. In dit rapport wordt het potentieel van Systems Engineering (SE) onderzocht voor het verbeteren van duurzaamheidsimplementatie in het onderhoudsproces. Het onderzoek richt zich op de afdeling 'Asset Groen & Water', verantwoordelijk voor het onderhoud van alle vegetatie- en waterobjecten die onderdeel zijn van de provinciale infrastructuur.

Dit onderzoek beantwoordt de vraag – *'In hoeverre kan Systems Engineering de provincie helpen bij het gestructureerd ontwikkelen van provinciale duurzaamheidsambities naar projecteisen en maatregelen voor onderhoud?'* – in vier fasen:

In de eerste fase is er een theoretisch kader opgesteld op basis van SE literatuur en richtlijnen, om op basis van behoeften van stakeholders een ontwerp te maken, die vervolgens na uitvoering voldoet aan hun wensen. Er zijn 15 stappen opgesteld die gezamenlijk het proces van de ontwikkeling en implementatie van duurzaamheidsambities doorlopen. In dit proces worden abstracte ambities stapsgewijs gedefinieerd in operationele maatregelen. Hierin zijn feedbackstappen opgesteld om de afstemming tussen maatregelen en ambities te waarborgen en te zorgen dat het systeem voldoet aan de behoeften van de stakeholders. Een ander belangrijk aspect van SE is de taakverdeling waarbij voor dit onderzoek de VERI-rollen (Verantwoordelijk, Eindverantwoordelijk, Raadplegen, Informeren) worden gedefinieerd. Door het gebruik van SE wordt het proces traceerbaar en door gestructureerd te documenteren kunnen afwegingen onderbouwd worden. Door SE toe te passen wordt er efficiënt omgegaan met middelen, hebben maatregelen een duidelijk verband met ambities en worden negatieve neveneffecten op ambities geminimaliseerd. Daarnaast wordt real-world feedback geïntegreerd in het proces en duurzaamheidsmaatregelen aangepast worden naar mate ambities veranderen. Door de taakverdeling hierin mee te nemen, wordt ook verzekerd dat elke taak aan de meest geschikte persoon wordt toebedeeld.

In de tweede fase is het huidige proces van duurzaamheidsimplementatie in het onderhoudsproces van de provincie onderzocht. De informatie voor dit onderzoek is verkregen door documenten te analyseren, vijftien interviews te houden en twee overleggen bij te wonen. Als onderdeel hiervan zijn vijf maatregelen binnen onderhoudscontracten van de afdeling 'Asset Groen & Water' geanalyseerd om het huidige proces van duurzaamheidstoepassing in kaart te brengen. Vervolgens is de informatie geanalyseerd waarna er het proces is weergegeven volgens de vijftien stappen van het theoretische kader.

In de derde fase is er een vergelijking gemaakt tussen het theoretisch kader uit de eerste fase en het empirische provinciale proces uit de tweede fase. Om vast te stellen theorie en praktijk overeenkwamen of verschilden, is de patroonvergelijkingsmethode gebruikt. Op basis van deze analyse zijn voorlopige conclusies geformuleerd in de vorm van 21 stellingen. Deze stellingen zijn besproken en gevalideerd in een focusgroep, samengesteld uit de geïnterviewden uit de tweede fase. Tijdens dit overleg hebben de aanwezigen de stellingen beoordeeld aan de hand van een 5-punts Likertschaal. De resultaten zijn tijdens dit overleg gepresenteerd en bediscussieerd om de stellingen te verduidelijken en waar nodig te herdefiniëren.

Uit de analyse komen de volgende uitdagingen naar voren waar de provincie voor staat:

1. Het ontwikkelings- en implementatieproces is niet traceerbaar en transparant omdat het besluitvormingsproces minimaal gedocumenteerd wordt.
2. Duurzaamheidsimplementatie in het onderhoudsproces heeft geen fundament in ambities omdat eindverantwoordelijkheid voor het behalen van deze ambities onduidelijk is en ambitie-indicatoren ontbreken.
3. De ontwikkeling van maatregelen is direct gebaseerd op de abstracte ambities zonder de effecten te analyseren. Dit leidt tot een uitdagend ontwikkelingsproces, aangezien de besluitvorming tijdens het proces niet gebaseerd is op afgewogen beleid en objectieve gegevens, maar op individuele expertise.
4. Rollen worden niet officieel toegewezen aan personen. Het ontwikkelings- en implementatieproces is sterk afhankelijk van de motivatie en expertise van individuen. Hierdoor is het proces zeer onduidelijk, en is de continuïteit van het bijdragen aan de duurzaamheidsambities niet gewaarborgd.

In de vierde fase zijn zes aanbevelingen geformuleerd om de uitdagingen van de provincie aan te pakken. De aanbevelingen zijn gerangschikt op basis van hun relevantie om het huidige proces te verbeteren:

1. Implementeer een documentatiestructuur: Zorg voor traceerbaar en transparant ontwikkelingsproces door het documenteren van het besluitvormingsproces systematisch aan te pakken waardoor het proces van duurzaamheidsambities inzichtelijk wordt. Bovendien kan er hierdoor gerefereerd worden naar eerder genomen besluiten omdat deze zijn vastgelegd.
2. Wijs een ‘asset owner’ aan: Benoem een ‘asset owner’ als primaire stakeholder die duurzaamheidsambities vaststelt voor het onderhoudsproces, en die geraadpleegd kan worden voor het valideren het ontwikkelings- en implementatieproces. Hierdoor wordt het probleem van het ontbreken van de eindverantwoordelijkheid opgelost en kunnen de ambities worden verduidelijkt.
3. Vertaal ambities naar eisen en functies: Implementeer tussenstappen om de kloof tussen strategische doelstellingen en het opstellen van maatregelen te overbruggen. Hierdoor wordt duidelijk wat de impact en neveneffecten van het implementeren van maatregelen op de ambities zijn.
4. Verduidelijk rollen en verantwoordelijkheden: Stel duidelijke rollen en verantwoordelijkheden vast voor het implementeren van duurzaamheid in het onderhoudsproces om het proces te verbeteren te wortelen in het proces en de afhankelijkheid van individuele motivatie te verminderen.
5. Doe inspecties op basis van een risico-inventarisatie: Gebruik een risicogestuurde strategie om de uitvoering van maatregelen te inspecteren op basis van het effect van het afwijken van de maatregel voor het behalen van de duurzaamheidsdoelen. Door te focussen op de effecten van het afwijken van maatregelenspecificaties op de ambities, in plaats van enkel de uitvoering van het contract te handhaven, wordt de bijdrage van de inspecties aan het bereiken van duurzaamheidsdoelen vergroot.
6. Stel een integraal duurzaamheidsimplementatieplan op voor de provinciale infrastructuur: Door ambities toe te wijzen aan afdelingen en assets die het meest kunnen bijdragen aan het behalen van de betreffende ambitie, kunnen financiële middelen effectiever gebruikt worden. Bovendien worden de duurzaamheidsambities geborgd in de werkzaamheden rondom de provinciale infrastructuur.

Op basis van deze aanbevelingen is geconcludeerd dat door het toepassen van de SE systematiek de provinciale uitdagingen voor het implementeren van duurzaamheid kunnen worden opgelost. Hoe de SE systematiek moet worden geïntegreerd in het onderhoudsproces moet nog worden onderzocht, aangezien dit onderzoek zich aan heeft gericht op het verschil tussen de SE theorie en huidige manier waarop de provincie duurzaamheid implementeert. Daarom zal toekomstig onderzoek zich moeten richten op het ontwikkelen van een implementatieplan voor SE binnen het onderhoudsproces. Voordat een integraal duurzaamheidsimplementatieplan opgesteld kan worden, is het essentieel om uitdagingen van andere afdelingen en assets te inventariseren.

Contents

1. Introduction

As national governments commit to sustainability ambitions (UN-SDG, 2015) and include them in their policies, provinces develop sustainability goals in their strategy documents, such as the province of Gelderland (Provincie Gelderland, 2018). The province developed ambitions based on national sustainability goals to further specify what these broad goals mean for the organisation's operations (Provincie Gelderland, 2018). Infrastructure management departments have difficulties in translating these provincial sustainability ambitions from the strategy documents, which are the basis of infrastructure asset management, into operational measures (Hossain et al., 2020). This requires the province to change their processes to implement new methods and innovations, that leads to the province becoming more sustainable and meet their goals (Ayarkwa et al., 2022; Pries & Janszen, 1995).

Sustainability implementation has two aspects that make decision-making challenging. Firstly, decision-making on these topics requires subjective input, such as policies and weighing of assessment criteria, and objective input, such as research and Key Performance Indicators (KPIs). According to Kemp and Martens (2007), sustainable development is inherently subjective because it is about the vision of how society aims to preserve and better the world. The subjective nature of sustainability has its effect on sustainability policies (Pitton & McKenzie, 2022). These subjective goals are then guided by objective sustainability science to aid in reaching these goals (Kemp & Martens, 2007). Sustainable development covers various aspects attributed to the dimensions of “the triangular concept with the three pillars ‘economy’, ‘environment’, and ‘society’” (Kemp & Martens, 2007). This study focusses on the environmental pillar of sustainability.

Secondly, decision-making for sustainability implementation is dependent on context and perspective (Martin, 2015). According to Arvai et al. (2012), this causes decision-making in sustainability implementation to be susceptible to biases and errors and harms the success of sustainability implementation. Adopting a clear structure and increasing the transparency of the decision-making process can aid in negating these negative effects (Martin, 2015; Nawaz & Koç, 2018; United Nations Environment Programme, 2014). Since different measures can have both positive and negative impacts on ambitions, sustainability implementation requires a holistic and integrated approach to effectively meet these ambitions and policies (Wan Alwi et al., 2014).

This research is based on the premise that sustainability implementation is highly subjective and influenced by differing visions and contextual factors. Despite this, it is grounded in objective research, KPIs, and evidence-based decision-making. This viewpoint is underpinned by the statement of Brown et al. (1987): “Setting the priorities for sustaining or being sustained, and at what costs, is a value-laden process that can only be accomplished within the context of a clearly stated definition of sustainability. Deciding what actions and policies should be taken to achieve sustainability can only be accomplished with appropriate measures and indicators of sustainability.” Combining the subjective and objective elements of sustainability into a cohesive implementation plan and adhering to this implementation plan requires a holistic structured approach (Voß & Kemp, 2006; Wan Alwi et al., 2014).

Sustainability in asset management covers several topics. Some topics have clear indicators that can be measured or calculated and are widely adopted. The reduction of greenhouse gasses and reducing the use of virgin material use the environmental cost indicator and percentage of reused or recycled material respectively (Stichting BouwKwaliteit, 2019). However, indicators for biodiversity and climate adaptation are being developed but have not yet been widely adopted (Addison et al., 2020; Fraixedas et al., 2020), as is the case for the province of Gelderland. This is because measures that enhance biodiversity involve multiple aspects that are not immediately or uniformly quantifiable (Stevenson et al., 2021). Consequently, there is a bigger challenge to implement measures that meet ambitions set on topics that do not have KPIs (Eriksen & Kelly, 2007). In addition, sustainability topics such as biodiversity and climate adaptation have lower priority, as the impact of measures on these areas yields less immediate returns (Zuluaga et al., 2021). Most studies and decision-making methods focus on reducing emissions (Bueno et al., 2015; Suprayoga et al., 2020). Maintenance practices, especially maintenance of greenspaces, have an impact on biodiversity and climate adaptation topics. Therefore, research is needed on a comprehensive approach to implementing biodiversity and climate adaptation ambitions.

1.1. Relevance

Within infrastructure assets of the province of Gelderland, sustainability is implemented in two ways, each managed by separate departments. Large maintenance and new construction projects of the province of Gelderland are issued by the area development and execution department. In these projects, sustainability implementation is systematically addressed through the adoption of a clear structure for the exploration, development, and execution phases. During this process, various parties are included to aid in the implementation of sustainability. Once infrastructure projects are completed, the assets are transferred to the management and maintenance department, which issues multiyear maintenance contracts to achieve their objectives. However, sustainability implementation in maintenance operations is less structured compared to the construction phase. The management and maintenance department is mainly self-reliant. As a result, there is no clear overview of the ambition realisation in maintenance operations. Additionally, the relevance of maintenance works for the sustainability goals of the province is partially unclear. When looking at the available literature, research on the sustainability of maintenance operations is limited. Most studies focus on construction phases for meeting sustainability objectives (Khan & McNally, 2023). However, all phases of the assets should be included for the infrastructure to be sustainable, so the maintenance operations should be addressed (Khan & McNally, 2023). The province acknowledges the potential for enhancing the integration of sustainability practices by structuring sustainability implementation within maintenance operations. They aim to achieve significant improvements in this area, recognizing it as an opportunity for substantial gains. The province views the primary challenge in implementing sustainability as relating to biodiversity and climate adaptation goals. However, this research will address sustainability implementation in its entirety, as these goals overlap with other sustainability objectives.

A systematic approach can aid organisations in implementing sustainability ambitions into their works (Nawaz & Koç, 2018). Systems Engineering (SE) is such a systematic approach that seems to be a good method of going from abstract sustainability ambitions and policies to concrete measures. The essence of SE is Systems Thinking, looking at a problem as part of a system and factoring in the relationships and interactions between individual aspects (Driscoll et al., 2022). SE uses lifecycle thinking which includes the whole lifecycle of a system including the maintenance phase of a system (Defense Acquisition University, 2001). In addition, it considers organisational and management aspects as process structuring and role allocation (Defense Acquisition University, 2001). Hossain et al. (2020) synthesised SE literature and derived the following general definition: *"SE is a management-based holistic interdisciplinary approach that addresses the entire product life cycle which involves designing and integrating the system elements in order to meet the consumer demand."*. In civil engineering, SE is mostly adopted in large and complex infrastructure projects. In the Netherlands, the two major public clients of infrastructure assets, Prorail and Rijkswaterstaat, stimulate the use of SE in their infrastructure construction projects (Prorail et al., 2013). Consequently, other regional public clients, such as the province of Gelderland, are starting to adopt SE in their working structures for construction projects (de Graaf et al., 2017; Hoeber & Alsem, 2016).

Maintenance in infrastructure asset management is an ongoing process spanning decades. However, public organisations manage maintenance operations as projects with contracts spanning a few years, in the province's case two to four years. Every new iteration of the maintenance contract allows the province to adjust the maintenance operations by incorporating measures to emphasize different aspects of the assets for example increasing the sustainability based on new ambitions and policies. The development and execution of maintenance contracts share several process similarities with infrastructure construction projects. SE has shown benefits in tackling large and complex infrastructure construction projects (de Graaf et al., 2016; de Graaf & Loonen, 2018; de Graaf et al., 2017; Prorail et al., 2013). The goal of this research is to investigate the potential benefits SE has for the management and maintenance process of the province of Gelderland.

The application of SE in non-complex work such as infrastructure maintenance operations is not featured in the examined literature. It is observed in literature and guidelines that SE in the civil engineering industry get the most attention for use in complex construction projects (Blockley, 2013; de Graaf et al., 2016; de Graaf et al., 2017; Herrera et al., 2020; Locatelli et al., 2014; Matar et al., 2017; Uludag, 2017). However, the challenges of sustainability implementation in maintenance operations require a more systematic method for assessing sustainability measures to get a broader view of sustainability (Kiani Mavi et al., 2021). Moreover, there is a call in research to develop a system to evaluate interrelationships among factors of sustainability and there is a need for strategies that manage projects transcending sustainability ambitions (Aarseth et al., 2017; Kiani Mavi et al., 2021; Rebelo et al., 2015). Looking at the characteristics, SE seems to be a good method for improving sustainability implementation in maintenance operations. Applying SE in management and maintenance of infrastructure assets is innovative as it differs from construction projects because the work is less complex and more homogeneous (van Steveninck, 2013) instead of the one-off nature of construction projects (de Graaf et al., 2016; Walden et al., 2015).

1.2. Research objective

This research aims to analyse the process of sustainability implementation in maintenance operations within the province of Gelderland and identify areas of improvement. By addressing this process, this research helps the province meet its sustainability ambitions. This implies improving the process to achieve the 'short-term' sustainability goals set for 2030 and 2050, as well as the need for 'long-term' adaptability in response to changing political policies. In line with statement, the objective of this research is:

> *'To identify opportunities for improving the process of implementing sustainability in maintenance operations of the province of Gelderland to aid in meeting their sustainability ambitions.'*

1.3. Research question

The Systems Engineering (SE) methodology serves as the foundation for developing a systematic approach to implementing sustainability in the province's maintenance operations. The aspects of the SE methodology are explored and detailed further in the theoretical framework of this report. The findings from this study provide tools for both the development stages of developing abstract ambitions into concrete measures and the quality assurance steps that verify whether these ambitions are being met. Based on the research objective and this starting point, the main question for this research is:

> *'To what extent can Systems Engineering help the province structure the process of decomposing high-level sustainability ambitions into project requirements and measures into their maintenance operations?'*

Based on this main research question, four sub-questions are formulated. These sub-questions are shortly introduced to specify their role in this research.

SE has been successfully adopted in large and complex infrastructure construction projects. However, as implementing sustainability in maintenance operations differs from these projects, it is essential to determine how SE should be applied to the maintenance process and address its unique characteristics. The first sub-question seeks to determine how the SE methodology should be utilized for this purpose. Therefore, the first sub-question is:

> *A. 'What is Systems Engineering and how could it be applied to the process of implementing sustainability in maintenance operations according to theory?'*

Part of answering the main research question involves examining the maintenance operations of the province of Gelderland. Investigating the current process is crucial to determine how SE can address the sustainability implementation challenges faced by the province. Therefore, the second sub-question is:

> *B. 'What is the province's current process for implementing sustainability in maintenance operations?'*

After examining the process and identifying the challenges faced by the province, theory and practice are compared. By analysing where the province's process is similar or deviates from the theoretical framework, the causes of the challenges faced by the province are identified. Therefore, the third sub-question is:

> *C. 'What are the similarities and differences between Systems Engineering as described in theory and the practices used by the province, and how does the province perceive these?'*

Lastly, to address the main research question, a comprehensive conclusion is drawn from the analysis. This leads to recommendations for the province to enhance their practices by addressing their challenges with suggestions from the theoretical framework. Therefore, the fourth sub-question is:

> *D. 'What can, and what should the province do to improve the current situation?'*

The answers to these sub-questions provide a clear research structure to explore the potential benefit SE can have for the sustainability implementation in maintenance operations. The research structure is visualized in Figure 1. Structuring the research accordingly allows theory to be aligned with the practical challenges faced by the province. The chapters are structured accordingly with a methodology chapter after the theoretical framework stating the methods used for collecting and analysing the current practices of the province.

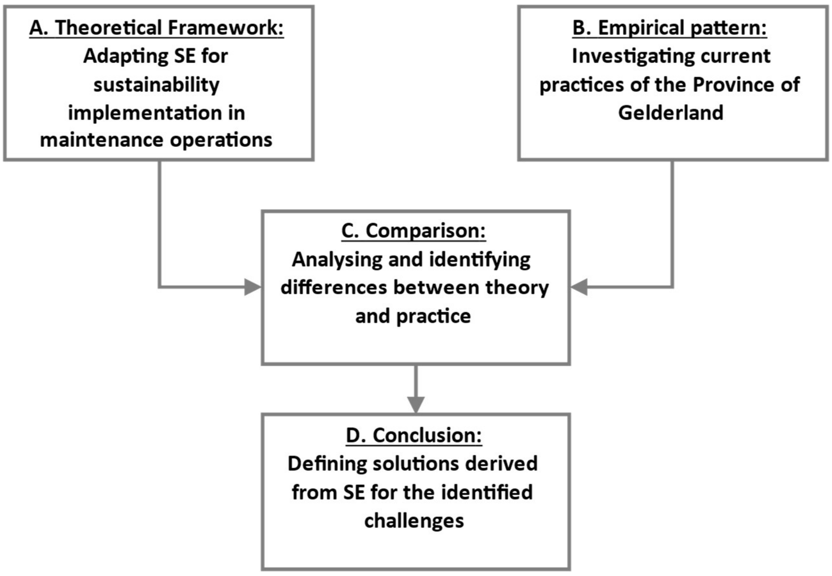

Figure 1 – Research process.

1.4. Research scope

The province prioritizes biodiversity and climate adaptation as focal sustainability topics for this research due to their perceived potential. For this reason, the division 'Asset Green & Water' is the focus area for this research because they are perceived to be affected the most by biodiversity and climate adaptation ambitions. The division 'Asset Green & Water' is part of the management and maintenance department and responsible for maintaining all objects related to 'Green & Water', such as verges, trees, ditches, and waterways among others. As part of the assessment of the current practices of the province, five measures have been selected. These measures are selected from current maintenance contracts issued by the management and maintenance department because of their potential connection to biodiversity or climate adaptation. Specification of these measures is elaborated upon in the methodology and results chapter. As the theoretical basis for this research, only the SE methodology will be used for defining a process structure. This research evaluates the added value of SE as a method for translating abstract ambitions and policies into concrete implementations.

2. Theoretical Framework

The theoretical framework answers part of the following sub-question: *'What is Systems Engineering and how could it be applied to the process of implementing sustainability in maintenance operations according to theory?'*. This chapter covers the theoretical model of Systems Engineering (SE) on how to develop and implement a system that complies with stakeholders' needs and expectations following literature. The next chapter goes into the application of this model for sustainability implementation in the maintenance operations of the province. This is done by analysing the province's maintenance process and the characteristics of sustainability implementation and adapting the theoretical model accordingly.

The goal of using SE is to develop a general idea into a validated solution. To achieve this objective, the top-down and bottom-up approach, part of the SE methodology, is used as the theoretical model in this research. This approach ensures that the developed and implemented system meets the needs and expectations of the stakeholders. The approach is also known as the 'Vee model' (Locatelli et al., 2014) and can be seen in Figure 2.

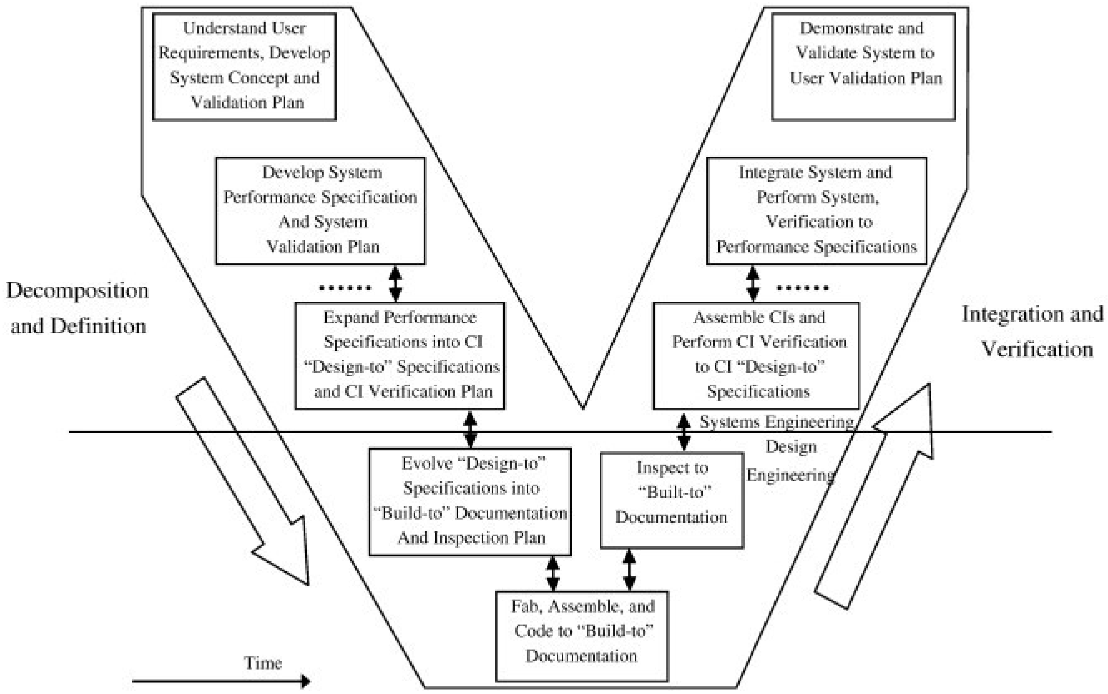

Figure 2 – The architecture Vee model (Locatelli et al., 2014).

The first section covers the left side of the model, describing the 'top-down' development component. This consists of the decomposition and definition of stakeholders' needs into a detailed design. This process is illustrated and elaborated upon in Figure 3. The second section of this chapter covers the right side of the model, describing the 'bottom-up' implementation component. This consists of the integration and verification of the detailed design into an integrated system that complies with the stakeholders' needs. In the last section, the role allocation of the process is elaborated upon as this is an important aspect of SE (Defense Acquisition University, 2001).

2.1. Decomposition & definition

For the development component, the adapted SE development model for infrastructure projects is used. For this model, the guidelines from the U.S. Department of Defence are used as a basis (Defense Acquisition University, 2001), together with literature on the use of SE in civil engineering (de Graaf et al., 2016; de Graaf et al., 2017) and a SE handbook for use in infrastructure projects in the Netherlands (Prorail et al., 2013). The model is visualized in Figure 3. This model elaborates on the left side steps (top left to middle bottom) of the Vee model in Figure 2.

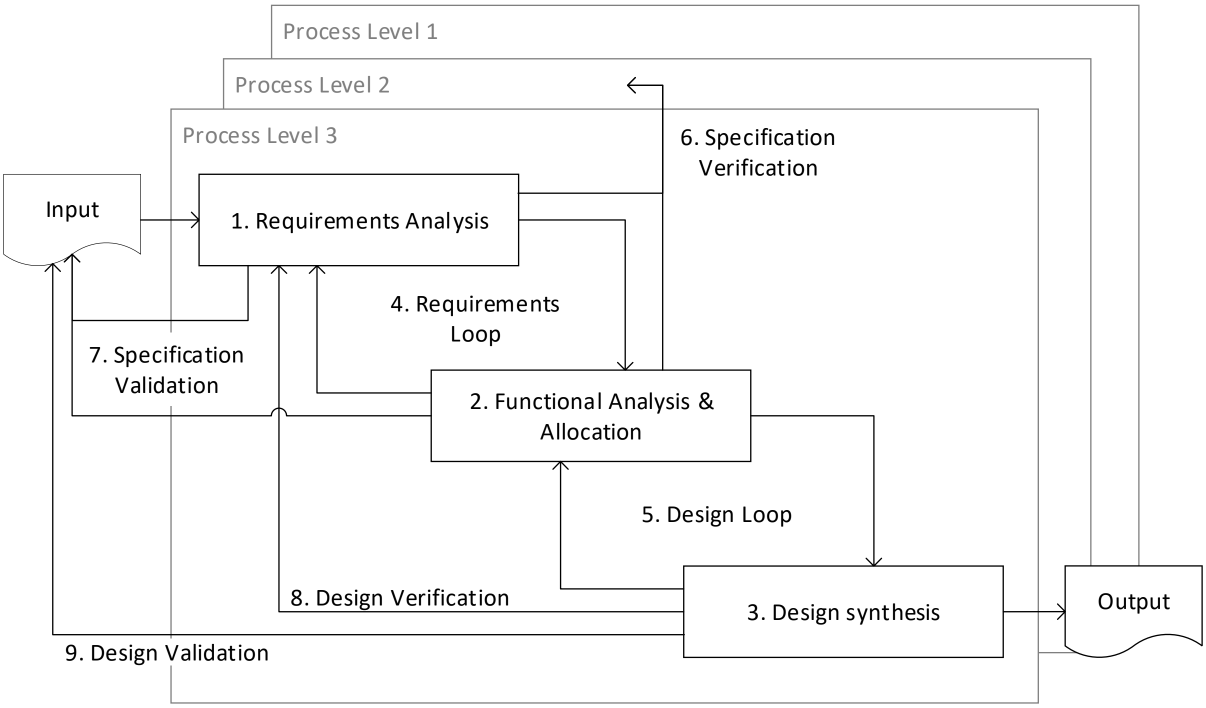

Figure 3 – SE development model adopted for infrastructure projects (de Graaf et al., 2016; de Graaf et al., 2017; Defense Acquisition University, 2001; Prorail et al., 2013)

The SE development model consists of three core process steps (elements 1-3) and six feedback steps (elements 4-9) as can be seen in Figure 3. These elements describe the process from the input to the output of the system development phase. The input of this phase includes all relevant information which includes stakeholder demands, laws and regulations, policies, and more. The output of the development process is a designed product, which depends on the required level of detail. Low levels of detail result in product descriptions or concept designs, while high levels of detail yield product specifications at the component level or technical designs. Depending on the required level of detail or the system's complexity, the process is iterated, as visualized by multiple process levels. The output of a process level can either serve as input for the next iteration of the process or as the final product once the desired level of detail is reached. The output products and the level of detail required are industry dependent.

The nine development process steps are elaborated on below and are based on the literature of Figure 3.

1) Requirements Analysis

During the Requirements Analysis (1) phase, the system's input is turned into measurable requirements. This process is documented in a Requirements Breakdown Structure (RBS), which contains all input information and is structured hierarchically. The RBS is formulated in a SMART (Specific, Measurable, Acceptable, Realistic, Time bounded) way as this enables the requirements to be verified. Additionally, to be able to perform verification and validation of requirements at a later stage, a verification and validation (V&V) plan is initiated. The requirements need to be traceable, so a referencing system needs to be adopted.

2) Functional Analysis & Allocation

By performing the Functional Analysis & Allocation (2), the requirements are translated into system functions and documented into a Function Breakdown Structure (FBS). The functions in the FBS describe what the system should do, so the functions must not contain solutions. During this step, functions are assigned to objects and a System Breakdown Structure (SBS) is developed. The development of the SBS is aimed at structuring and dividing the system into objects to make the process more manageable. This is achieved through analysing all relevant information to an object. This included requirements, functions of that object and interfaces with the other objects.

3) Design Synthesis

The translation from the functional specifications into design solutions is done in the Design Synthesis (3). Deciding on a design requires the development alternatives from which the best is selected to be implemented. The best is defined as the alternative that best aligns with the requirements and functions stated in the previous steps. Decision-making for the best alternative should be done transparently and traceable. This can be achieved by using a multicriteria analysis or trade-off analysis and documenting the decision-making process.

4) Requirements Loop

The first feedback loop is the Requirements Loop (4). When developing functions from requirements, it is expected that this leads to revisions of requirements because of conflicts between functions, conflicts between functions and regulations and standards, or the development of new ideas. The development process is continuous, so requirements may need to be updated throughout its duration.

5) Design Loop

The second feedback loop is the Design Loop (5). This loop ensures consistency between the design solutions and functions. Because of issues between measures and functions or the development of new ideas, functions or even requirements may need to be revised. Even as the Requirements Loop (4), this process is continuous, so the functions are updated throughout the process.

6) Specification Verification

During the Specification Verification (6), the lower-level requirements, functions and objects are checked to be in line with the higher-level requirements, functions, and objects. This ensures that the previous decisions made between the different levels are aligned.

7) Specification Validation

Specification Validation (7) is the process of assessing the developed requirements, functions, and objects against the input. During the process functions can be developed that do not adhere to the stakeholders' needs, although they were verified in the previous process steps. This step ensures that the requirements, functions, and objects comply with the stakeholders' intentions.

8) Design Verification

Design Verification (8) is done to check if the decisions during the development of measures meet the requirements. The verification plan is developed during the process of setting the requirements and in this step, this plan is used to verify the synthesis.

9) Design Validation

Design Validation (9) is done to evaluate the design against the expectations, interests and needs of the stakeholders. This step is the last step before the design is finalized or the design is fed into the next iteration of the process.

The revisions that result from the feedback steps (elements 4-7) should be documented with argumentation and linked correctly to make the development process traceable.

2.2. Integration & verification

The implementation component describes the process of implementing the output of the development phase. The final output of the development model shown in Figure 3 serves as the basis for the implementation process. In the development phase, specifications are specified SMART to evaluate the performance during the implementation process. The ability to verify and validate the implemented design relies on the verification and validation methods established during the development process.

The implementation phase consists of three levels of verification and validation with each two elements. The first level consists of Implementation Testing and Verification (elements 10,13), verifying the design is build according to specification. The second level consists of Performance Testing and Verification (elements 11-14), verifying the requirements and functions are met by the integrated system. The third and last level consists of System Testing and Validation (elements 12,15), validating the integrated system meets the stakeholders' needs and expectation. These three levels correspond with the right side (middle bottom to top right) of the 'Vee model' shown in Figure 2.

The implementation process is industry dependent. Integration is done in one or multiple stages depending on the system. Verification takes place during, shortly after, or long after the integration process, depending on the requirement or function that is being verified. Ideally, the verification should be done as early as possible and should run alongside the integration process, allowing for adjustments when elements do not meet specifications. Verification of the implementation process is crucial for determining the system's success.

The six implementation process steps are described below and are based on Forsberg and Mooz (1991); Mooz and Forsberg (2006)

10) Implementation Testing

Implementation Testing (10) is done during implementation of the design on all elements of design specification as stated during the (3) Design Synthesis. Testing results are documented systematically to enable the Implementation Verification (13).

11) Performance Testing

Performance Testing (11) is done to collect data about the design parameters of the multiple levels of specification. This step is done for all requirements and functions from the development phase. This step enables the Performance Verification (14).

12) System Testing

System Testing (12) tests the performance of the system. This process serves as input to validate the expectations, interests and needs of the stakeholders and leads to the System Validation (15).

13) Implementation Verification

Implementation Verification (13) is done by evaluating the findings from the Implementation Testing (10). Deficiencies between the design specification and the implementation are identified and documented. These deficiencies are corrected to adhere to the specification. Uncorrectable deficiencies are assessed on impact for the integration. When the deficiency is non-compliant, the design is to be adjusted to be compliant to the specification.

14) Performance Verification

Through (14) Performance Verification, the successful integration of the design can be verified through compliance to the functions and requirements. This requires determining verification methods of the measures' performance during the Requirements Analysis (1) and Functional Analysis & Allocation (2). Deficiencies are handled the same as in the Implementation Verification (13). This step is done for all requirements and functions from the development phase.

15) System Validation

Through (15) System Validation, the alignment of the system's performance with the stakeholders' needs is determined. Deficiencies are handled the same in the Implementation Verification. This step is the final step before it can be stated that the developed and integrated system meets the expectations, demands and needs of the stakeholders.

2.3. Role allocation

Specifying roles, authority, and basic responsibilities is a crucial aspect of Systems Engineering (SE) and should be clearly defined to effectively manage the SE process (Defense Acquisition University, 2001). How stakeholders are associated with the process is specified using the RACI methodology. RACI is commonly used in project management for stakeholders associated with the project (Costello, 2012; Project Management Institute Inc, 2021). The RACI methodology defines four roles for process tasks: those who are responsible, accountable, being consulted, and being informed. Table 1 describes how the roles should be defined, together with the constraints that must be adhered to.

Table 1 – RACI roles specified (Costello, 2012; Smith et al., 2005)

Roles	**Specification**
Responsible	*Stakeholders who are responsible are assigned to completing the task. This role can be shared among stakeholders. Having no stakeholders responsible, results in no one taking initiative and the task not being completed. However, the opposite is also true as having too many responsible stakeholders negates the sense of responsibility and thus has the same effect as no one being responsible.*
Accountable	*The stakeholder accountable for a task makes the ultimate decision for the task. This includes a veto power. This role can only be assigned to one stakeholder. To be assured of performance accountability, someone must be accountable for a task.*
Consulted	*Stakeholders that are consulted are usually experts on a subject. Consulting needs to happen before the decision is made as input from a stakeholder to be consulted is required. It is important to consider the added value of input from the stakeholders. Too many stakeholders that need to be consulted result in an inefficient process and time loss. Having no one to be consulted can result in tasks being unaligned and unfounded.*
Informed	*This is assigned to stakeholders who need to be informed after task completion as they need the information for a sequential task. When stakeholders are to be informed frequently, it must be considered why they need to be informed and if this can be reduced to for example unexpected occurrences. Similar to the latter role, having no one to be informed can result in unaligned tasks.*

Setting the different roles in a matrix provides insight into the role behaviour in a process and makes the process more predictable (Smith et al., 2005). Smith et al. (2005) state that RACI solves the problem of unaligned role conception, role expectation and role behaviour. RACI aligns these three perceptions by structuring and visualizing roles in a process (Smith et al., 2005). For every process step of SE, RACI roles must be specified according to the conditions stated in Table 1. The roles should be assigned and fulfilled appropriately according to the hierarchical structure of the process (Smith et al., 2005).

This theoretical framework describes how the development and implementation of stakeholders needs should be done following the SE methodology. This is done by defining fifteen process steps and setting prerequisites for defining role allocation of these process steps. The following chapter goes into adapting this theoretical framework for sustainability implementation in maintenance operations of the province.

3. Methodology

3.1. Research strategy

This research takes a qualitative research approach to examine the current process of sustainability implementation in operations of the management and maintenance department. This method is effective for exploring real-life phenomena (Yin, 2018). Various data collection methods are used to get an in-depth look into the inner workings of the organizational process (Schoch, 2020; Yin, 2018). To complement this research, a case study is used to provide valuable insights in the organizational practices (Schoch, 2020).

The validity of research is increased by using multiple data collection methods, a process known as triangulation (Yin, 2018), and by validating the research findings. Triangulation is achieved by using three types of data collection methods: document analysis, interviews, and observations. These three methods are used to verify and underpin each other to improve the quality of the data. The document analysis serves as a basis for understanding the process and the case study selection. Solely relying on documentation for data collection can lead to wrongly interpreting data as documents are written with a purpose which can lead to information being changed to fit that purpose and nuances are negated as documents can lack context and need explanation to be interpreted correctly (Yin, 2009). Interviews serve to clarify the findings during the document analysis and construct a comprehensive understanding of the process. Observations allow the researcher to collect data based on his own perspective instead of the perspective of the interviewees. The analysis of data answers the sub-question: *'What is the empirical pattern of the province's process for implementing sustainability in maintenance operations, and what are the challenges?'*.

Pattern matching is used to compare the empirical process to the theoretical process. This is a suitable method because it aims to link theoretical patterns, like the SE process, to empirical patterns observed at the province. (Trochim, 1989). By comparing the empirical to the theoretical pattern, the sub-question *'What are the similarities and differences between Systems Engineering as described in theory and the practices used by the province, and how does the province perceive these?'* is answered. The research findings are validated by presenting the results to a focus group composed of the interviewees.

3.2. Exploratory case study

This research uses an exploratory case study to provide insight into the current process of sustainability implementation within the management and maintenance department. Using a case study in research "is a way of investigating an empirical topic by following a set of prespecified procedures."(Yin, 2018, p. 16). This type of case study is chosen as "the exploratory study contributes to clarify a situation where information is scarce" (Quintão et al., 2020, p. 268). The case study uses an embedded single-case design (Yin, 2012). The context for this study is the organization of the province of Gelderland. The case of this research is the current practice of implementing sustainability ambitions in maintenance operations by developing abstract ambitions into concrete measures. As embedded units of analysis, five sustainability measures are selected. The development and implementation of the measures is looked at in order to develop a general understanding of the current practice of ambition implementation (Stake, 1995). These measures serve as empirical data to provide supporting evidence for general statements about the process. The steps taken for implementation are examined by analysing these measures from the initialization phase through to a few years into the realization phase.

According to Eisenhardt and Graebner (2007), the case should be carefully chosen in qualitative research as this allows for theory building. This research uses purposive sampling for the selecting the units of analysis as purposive sampling is "used to select respondents [i.e., units of analysis] that are most likely to yield appropriate and useful information" (Kelly et al., 2010, p. 317). For this research, contracts issued by the management and maintenance department were analysed to select five measures. These measures are chosen because of their clear or potential connection with the biodiversity or climate adaptation ambitions. The aim is to get a broad picture of the implementation process of sustainability goals by analysing the measures' origin and implementation process. The five measure that have been selected for this research are:

1. Ecological roadside management
2. Circular use of waste materials
3. Oak processionary caterpillar control
4. Selection of tree species for replanting
5. Maximal tracking depth in verges

What these measures imply is stated in chapter 4.

3.3. Data collection

For the data collection of this research, the maintenance operations are cross-referenced to the elements of the theoretical framework. It is examined how the current sustainability implementation process is executed in comparison to the SE process. Additionally, the current process' role allocation is judged against parameters set by the RACI methodology.

3.3.1. Document analysis

The document analysis is conducted on all available stored documents of the maintenance contracts development and the maintenance operations. The following documentation was analysed: (1) strategic and tactical documents, (2) contract specifications and (3) measure documentation. The documents served as a baseline understanding of the process. The document analysis was the main input for the interview questions.

3.3.2. Interviews

Interviews were conducted as the primary source of collecting data. This study aims to generalize findings between units of analysis which requires questions to be predetermined in the design stage (Yin, 2018). The interviews were semi-structured to allow for free flow of the conversation (Hansen, 2021). This gave room to the participants to elaborated about their expertise and view on the process while all relevant questions could be addressed (Easwaramoorthy & Zarinpoush, 2006). The focus of the interviews is to assess the practises of implementing sustainability measures at the province. The questions focus on whether each process step's elements are in place and if their core aspects are being addressed as specified in the theoretical framework. The questions were constructed based on these process steps and results from the document analysis.

The interviews were opened by asking the participants about their role and responsibilities within the process. Secondly, the participants were required to select measures they could elaborate on. Questions about the measures were aimed at why and how measures were implemented. Thirdly, general questions were asked to gain insight into connection between ambitions and measures and use of control instruments. The interviewees were also able to elaborate on their view of the process. All questions were designed to examine how the process steps from the theoretical framework were used. The interview protocol consisted of twenty questions with additional sub questions and is added in Appendix II. Not all interviewees were able to provide answers to all questions. The interviews were 45 to 60 minutes each and conducted in Dutch. The interview protocol resulted in no questions being forgotten during the interview.

The interviewees consisted of individuals that are involved in the asset maintenance process. Individual from all levels of the process within the province were interviewed. Elaborating, interviews were conducted with all available five strategic policy managers within the department of management and maintenance, the asset manager responsible for the 'Asset Green & Water', two asset specialists responsible for roadside verges and trees, two project leaders, one contract developer, two contract managers and two supervisors. This resulted in complete overview of the process from strategic policy development to the execution of maintenance contracts. In total fourteen interviews were conducted with fifteen individuals as the two supervisors were interviewed together. Most interviewees were selected in advance with the aid of the two supervisors. Five interviewees were selected by asking other interviewees who would be suitable for participating in the interviews.

3.3.3. Observations

During the research period, the researcher attended two meetings which assessed implementation of sustainability measures. First, a meeting was attended assessing the sustainability possibilities for the next iteration of integral maintenance contracts. Second, a meeting was attended about a potential mismatch between provincial policy and execution of maintenance contracts. These meetings served as input for questions to be asked during the interviews and conformation of statements of interviewees. Observations served partly as confirmation of statements as some parts of the process were seen in action as prescribed by the interviewees.

3.4. Data processing

The initial phase of data processing involved analysing the interviews and observations. Verbatim transcriptions were used to analyse the interview. The data was analysed and processed using the ATLAS.ti software. This program uses data coding to identify patterns. The coding was done in two phases. First, the data was coded for each individual measure to define the process steps taken within each measure. The analysis of the measure clarified how they were developed and being implemented. Secondly, the data was coded by role and process step. This clarified how the process of the management and maintenance department is structured. Subsequently, the codes were combined to examine how the sustainability implementation aligns with the overall operations of the management and maintenance department. Additionally, the interviewees' experiences, opinions and other comments were coded to identify reoccurring themes or conflicting viewpoint about the processes.

3.5. Data analysis

After the data was processed, pattern matching was used to compare the theoretical framework and the observed process. Pattern matching is an appropriate method aimed at linking theoretical patterns, such as the SE process, to empirical patterns, such as observed at the province. (Trochim, 1989). Cao et al. (2004) states: "If the two patterns differ, then insights into the differences and similarities between the two patterns help develop new assumptions and concepts." This method is appropriate for this research as the aim is to provide insight into how to improve the process of the province.

The theoretical pattern for this analysis is derived from the adapted theoretical framework presented in chapter 0. The empirical pattern is based on the validated results from the document analysis, interviews and observation of the current sustainability implementation process in province's maintenance operations. Pattern matching is conducted for each of the fifteen process steps defined in the theoretical framework. Each process step is evaluated using a three-level match scale: a complete match is indicated by a '+', a partial match is indicated by a 'o', and a mismatch is indicated by a '-' (Cao et al., 2004). How these scores are determined is explained in chapter 6.1. These scores form the foundation of the analysis. Based on these comparisons, areas for improvement are identified and conclusion and recommendations are developed for the province to implement in the current process.

3.6. Data validation

As a validation step, a focus group meeting with interviewees was held to validate the empirical pattern. Seven interviewees attended this session excluding the researcher and his supervisor. For this session, twenty-one statements were drawn up about the current process of sustainability implementation in the works of the management and maintenance department. These statements were based on the pattern matching results shown in 6. This method increases the objectivity of the data as interviewees were able to express their view on the interview results.

The participants were asked to assess the statements on a 5-point Likert scale to assess the level of agreement. This assessment was done via Microsoft Forms. After the statements were assessed by the researcher a discussion was held about ten statements that had a minimum of one attendee disagree with the statement. The attendees were asked to elaborate on their view on the statement. This resulted in redefinition of statements or attendees changing their view on statements. The statements and following discussion were in Dutch.

Afterwards, the interviewees who did not assess the focus group meeting were asked via email to assess the same statements. They had the possibility to elaborate on their view on the statements via email. Two of the eight interviewees who did not attend the focus group meeting responded, with one providing their detailed perspective. Their input was consistent with the views expressed in the focus group.

4. Measures described

The measures examined in this study are shortly introduced to give background context. Hereafter, the origin, development, and implementation are explained. This all is to give context to the next chapter defining the empirical pattern of sustainability implementation within the maintenance operations.

4.1. Measure 1: Ecological roadside management

Ecological roadside management (ERM) is a combination of measurements aimed at impoverishing verges and sustaining the fauna ecosystem while mowing. ERM is included in all four integral maintenance specification of the contracts. The aim is to extract nitrogen from the soil by removal of clippings to create a situation where plants grow who thrive by impoverished soil. This way, diversity of plants will increase because verges are not overwhelmed by a few plants which thrive by nitrogen-rich soil. This in turn improves the living environment for insects. Additionally, ERM includes a phased mowing policy to sustain the living environment for insects and animal while maintaining the verges and preventing saplings from growing. ERM has been implemented and modified in all integral contracts for several iterations and is an established measure within maintenance contracts of the province (Asset manager).

The origin of ERM stems from the then asset manager 'Asset Green & Water' who was technically oriented (Policy manager 1). She developed ERM without input from higher authorities as implementation did not require increased funding. As the implementation was stepwise and not many departments were involved, it is not possible to determine what the exact development path of ERM is. ERM in its current form was implemented five years ago in integral maintenance contracts. At that time, the 'Kleurkeur'-guideline was developed about the importance of mowing policy for increasing biodiversity in verges. From then on, the contractor was obligated to have a 'Kleurkeur'-certification. Additionally, the maintenance department attended a course about the 'Kleurkeur'-guideline and improved the implementation of the measure (Asset manager; Asset specialist 2; Project leader 1).

During this process, the asset specialist develops a mowing plan partially based on the nectar index, provided by the contractor, and monitoring done by third parties on the status of the verges (Asset specialist 2). However, there is no evaluation done based on the monitoring. The evaluation is mainly focused on the practical implications of ERM (Project leader 1; Asset specialist 2). For example, safety is decreased because of the increased operations consequence of phased mowing. During contract evaluation, these practical implications result in the adaption of ERM in favour of other interests of the province (Asset manager, Asset specialist 2).

ERM is perceived to contribute to the ambition of the province to increasing biodiversity, but the exact effect is unknown.

4.2. Measure 2: Circular use of waste materials

Circular use of waste materials (CUWM) is a measure aimed at upcycling green waste. This measure was selected because it could have a harmful effect on the soil life by removing all green waste for use in upcycling. CUWM is included in all four active integral maintenance contracts as a Most Economically Advantageous Tender (MEAT) scheme. This MEAT scheme has been assessed by determining five levels of recycling waste materials where the higher the level, the more sustainable the province assert it to be. The tendering contractors have drawn up a plan at which level they aim to recycle the waste products. The contractors that aim at the highest level receive the highest fictitious discount on his bid amount. This increases the likelihood he will win the bid. CUWM has been implemented in the most recent iteration of integral and pruning contracts and is in the preliminary stage of implementation in contracts of the province (Project leader 1).

The origin of upcycling green waste stems from the then asset manager 'Asset Green & Water'. Several iterations have been analysed and proposed the last few contract iterations. The latter was implemented using a MEAT scheme. A company in Gelderland proposed to use grass cuttings in their products. The measure was not successful due to practical implications. The maintenance department was not able to verify the receipts of the contractor. This led to the suspicion that the contractors were not being honest about the processing locations and origin of the waste materials. The maintenance department had no ability to verify the contractors after the waste materials were removed from site and relied on the receipts for payment. (Project leader 1, 2)

In addition, it is not possible to make a clear and objective assessment of which processing method is better. The sustainability of a method depends on the products it is used for, what happens to the product afterwards, and how long it is used. The province has no insight into these aspects (Asset specialist 2).

4.3. Measure 3: Oak processionary caterpillar control

Oak processionary caterpillar control (OPCC) is a combination of measures aimed to controlling the infestation of the oak processionary caterpillar. All four pruning contracts includes OPCC measures. The OPCC measures include the use of biological chemicals to prevent caterpillars from growing, vacuuming nests and enhancement of natural enemies such as the bird species tit and other insects.

The origin of OPCC stems from the governmental responsibility for public health. As long as these types of caterpillars have caused inconveniences, the province have been implementing control measures to mitigate their effects. Preventative measures using biochemicals increased because of a major spike in quantities in 2019. The European-funded LIFE-project was started to develop methods to promote natural enemies of the oak processionary caterpillar because of the biochemicals affected all caterpillar types. This pilot has started in collaboration with provinces and municipalities in the Netherlands and the municipality of Antwerpen in Belgium. To get funding for this project, higher authorities of the province have been involved (Asset specialist 2).

The biological and mechanical control measures have a clear framework for consideration. The status of the nuisance is being monitored yearly and acted upon. The framework for consideration is based on a national guideline. The new measure of the LIFE-project is currently in its pilot phase. The proposed effects of this measure and the methods for verification are not well known (Asset manager; Asset specialist 1).

4.4. Measure 4: Selection of tree species for replanting

Selection of tree species for replanting are incorporated in replantation contracts. Replantation contracts originate from the legal obligation to replant a tree when felled. The selection is based on native trees that have been planted in recent years and are deemed to be appropriate for the climate and soil condition of Gelderland. This measure is chosen because of its potential link with the ambition to diversify the ratio of tree species.

The primary purpose for the selection of trees is not to serve a sustainability ambition of the province. However, when replanting trees, the biodiversity ambition of the province to diversify its tree composition influences the outcome. The trade-off between trees species to be replanted is being made on the tactical level by asset specialist. When replanting, many interests are involved. Municipality has a say in the characteristics of tree that must be replanted because they give out permits to cut down and replant trees in their municipality. Municipality and estate managers have an interest to preserve the composition of trees to preserve the cultural history of the area which results in half of trees along provincial roads being oak (Asset specialist 1).

4.5. Measure 5: Maximal tracking depth in verges

The maximal tracking depth in verges is standardized in all contracts from the department of management and maintenance. The maximal tracking depth was reduced for recent contracts. The reason to select this measure is that this could be because of a sustainability objective.

When asking interviewees about the reduction of the maximum tracking depth in verges, the interviewees of the operational department were not aware of the change. The tactical department were also not able to provide information about this measure. Because of this, it is unknown to the researcher what the purpose the measure is. When asked about this, interviewees gave their own interpretation, with preserving integrity of the verge being the main consensus.

5. Current sustainability implementation process

The results of the data analysis are presented in the next chapter. This chapter will answer the following sub-question: *'What is the empirical pattern of the province's process for implementing sustainability in maintenance operations?'*. The empirical pattern of the current process of sustainability implementation in the maintenance process is mapped by covering each process step from the theoretical framework. The first section outlines the current process and provides context to the empirical pattern presented chapter 6.

5.1. Empirical pattern

1) Requirements Analysis

The policy managers develop the strategic asset management plan (SAMP) which contains a summary of all provincial ambitions that interface with the provincial assets. This sampling of provincial ambitions results in requirements for the provincial assets. The SAMP is the main document for sustainability implementation in the management and maintenance department. In the latest iteration of the SAMP, policy managers were unable to specify new policies, resulting in no new policy document (Policy manager 1, 2, 3, 4, 5). The Mobility Programming department is responsible for all mobility within the province and should therefore be the main stakeholder (Policy manager 1, 2, 5). This department did not want to be bound to an additional policy document as this does not fit their workflow (Policy manager 2, 4, 5). Therefore, since the SAMP is no policy document, there is no obligation for implementing requirements set in this document (Policy manager 5). This document mainly serves as an overview of all matters regarding the provincial infrastructure without a developed vision of how the provincial ambitions are dealt with (Policy manager 1, 2). Development of sustainability ambitions into the SAMP is insufficiently done in SMART terms (Policy manager 1, 5; Asset manager; Asset specialist 2). This statement is supported by the researcher's analysis of the SAMP documents (doc. SAMP). Policy manager 5 said: "Verification and validation are not being considered during this phase". This statement is supported by the document analysis of the SAMP which indicates a V&V plan is not initiated at this stage (doc. SAMP).

Accountability for provincial ambitions is not in place for the setting of requirements. The province uses the asset management theory for its asset management. Following this theory, the asset owner is accountable for setting requirements. However, there is no asset owner for the provincial infrastructure assets (Policy manager 1, 2, 4, 5; Asset manager; Asset specialist 2). The department of Mobility Programming most closely resembles the role of asset owner. They can use the provincial infrastructure to meet their goals or choose to use other methods to achieve their goals (Policy manager 2, 4). The role of asset owner is attributed to the Mobility Programming department by the management and maintenance department. However, the Mobility Programming department has not taken on its role as asset owner (Policy manager 1, 2, 5).

Additionally, input from other stakeholders, such as the other Programming departments, is limited (Policy manager 1, 2, 5). As with the Mobility Programming department, each Programming department is responsible for achieving ambitions connected to a specific theme. "They are responsible for achieve their sustainability theme in the whole of the province, not solely the provincial road network" (Policy manager 4). Policy managers aim to align the objectives of these departments with the infrastructure asset (Policy manager 1, 2, 5). Their goal is to create a mutually beneficial scenario where both parties can achieve their respective goals (Policy manager 2, 5). Policy managers experience major challenges in involving the Programming departments to implement their sustainability objectives into the maintenance process (Policy manager 1, 2, 5).

The management and maintenance department is not required to report the results of their sustainability measures to the Provincial Council as with the quality of the provincial infrastructure (Policy manager 2). There is no direct consequence for the management and maintenance department when they do not implement their sustainability policy (Policy manager 2). Consequently, no team is directly responsible for achieving sustainability goals with operations of the management and maintenance department (Policy manager 1; Asset specialist 2).

Additionally, no prioritization has been made among sustainability ambitions (Policy manager 1, 5; Asset specialist 2). This observation is supported by the analysis of the SAMP document, which lacked a structured approach to documenting and prioritizing stakeholders' needs (doc. SAMP). Since the infrastructure assets are already utilized to serve various interests, this results in increased conflict of interests during implementation and execution (Asset specialist 2 about Measure 1; Asset specialist 1 about Measure 4). It is observed that these conflicting interests cause the sustainability measures to be less effective as implementing many measures into small area prevents them from reaching their full potential (, Asset specialist 2 about Measure 1; Asset specialist 1 about Measure 4).

2) Functional Analysis & Allocation

The development of the asset management plans (AMPs), and the multiyear maintenance plan (MYMP) aligns with the Functional Analysis & Allocation (2) step. In the AMPs, requirements are made specific for each asset. The MYMP is a continuation of the AMPs and contains asset specifics for each year. The AMPs show limited development of requirements into functions. It is observed and stated by Policy manager 5 that sustainability plans in the AMPs are largely direct copies of the SAMP (doc. SAMP; AMP). Policy manager 5 said, "I see that asset managers are struggling with making sustainability concrete for their assets." This statement is confirmed by the asset manager. The researcher observes that the AMPs include some developed functions related to the asset's objects (doc. AMP). However, these functions are not solution-free, and not connected to requirements. Additionally, the developed functions are not consistently assigned to specific objects or made object specific. It is observed that the measures already being implemented for sustainability are described, along with how these will evolve over the coming years (Policy manager 2, 5; Asset manager). The AMP and MYMP of the division 'Asset Green & Water' demonstrate minimal progress in detailing how to achieve the overarching ambitions set by the province. They lack comprehensive information on addressing these goals. (Policy manager 1, 5; Asset manager).

Asset managers are mainly responsible for the AMPs. The role of asset manager is clear and implemented (Policy manager 1). They establish the AMPs with their team of asset specialists. They are guided by the policy managers to develop the sustainability requirements from the SAMP into their AMPs (Policy manager 5; Asset manager). However, the tactical level experiences insufficient support for developing the requirements into functions for sustainability implementation (Asset manager; Asset specialist 1, 2). This results in limited progress developing the province's ambitions into the plans of management and maintenance department.

3) Design Synthesis

During this step, measures are developed. Within the province, design specifications are called measures. These broadly refer to a set of operations for maintaining objects, such as all actions involved when it comes to pruning trees, or a change in the way of working, such as only using electric machines. The origins of the measures have no direct connection to sustainability ambitions through stepwise development of these ambitions into requirements and functions. It is observed by the interviewees that measures arise from individuals' desire to act and contribute positively to an ambition, as with the ERM and CUWM-measures (Policy manager 1; Asset manager; Asset specialist 2 about Measure 1 origin & Asset manager; Asset specialist 2 about Measure 2 origin). As the measures are being developed, the aim is to align them with the overarching ambitions (Policy manager 1; Asset manager; Asset specialist 1, 2; Project leader 1, 2). This is in line with observation made during the project startup meeting (obs. project startup).

Differences in measure development and implementation between clear and unclear goals are identified. Clear objectives, such as combating invasive species and replanting trees, result in a direct approach (Asset manager; Asset specialist 2 about Measure 3, 4). These goals can be achieved through measures that mainly affect one asset and the path to success is clear. For example, OPCC-measure has a clear goal of preventing nuisance and benefitting public health. The cause of the problem is clear, and the measures taken have a direct effect on achieving the goal. For clear goals, it is determined when the effectiveness is proficient (Asset specialist 2 about Measure 3). However, these objectives do not originate from environmental sustainability ambitions. Examples are the OPCC-measure, that primarily serve the public health (Asset specialist 1 about Measure 3), and the replantation contracts, which serves the legal obligation for replanting trees (Asset specialist 2 about Measure 4). Their contribution to the environmental sustainability ambitions is a byproduct of addressing other objectives (Asset manager; Asset specialist 2). No functions are established during the development process, but their solution space is clear and multiple alternatives are drawn up if the implemented measures do not achieve the desired results (Asset manager, Asset specialist 2).

Unclear goals, such as benefitting the biodiversity or becoming climate adaptive, result in an ad hoc approach to measure development (Policy manager 1, 5 about Measure 1, 2), as observed with the ERM and CUWM-measures. It is perceived that achieving these goals is challenging because these are not quantifiable (Policy manager 1, 5; Asset manager; Asset specialist 1, 2). Measures developed for these goals are mainly implemented out of the professional fanaticism and desire to do the right thing by the management and maintenance department (Policy manger 1; Asset manager; Project leader 1). The measures stem from opportunities perceived by individuals in the process based on their expertise and knowledge in their field of work (Asset manager, Asset specialist 2, Project leader 1, 2). This leads to a strong dependence on personal commitment. One example is the transition period between the previous long-term asset manager and the current asset manager, 'Green & Water,' which resulted in minimal sustainability implementation because there was no personal commitment due to changing positions (Policy manager 1). These measures are established without a direct connection to an ambition (Asset manager, Asset specialist 2, Project leader 1), thus without referencing asset requirements. During the attended project startup meeting for a maintenance contract, there was no mention of asset requirements. Instead, the discussions focused directly on proposing measures and deciding on implementing them in the contract specifications.

The measure's expected effect is not actively weighed based on the sustainability ambitions and conflicting interests (Asset manager; Asset specialist 2 about Measure 1, 2). Decision-making between sustainability measures relies primarily on individuals' expertise and motivation, and the availability of funding (Asset manager; Project leader 1). After selecting a measure, the contract specifications are drawn up for integration in the maintenance contracts (Technical specifier). The process of decision-making and the final decisions made are not being documented apart from meeting notes and email communications (Project leader 1, 2; Technical specifier).

It is perceived that in the decision-making process, sustainability measures are sometimes disregarded beforehand because of conflicts with more important objectives of the province (Asset manager). Sustainability measure development occurs within the confines set by other goals of the province and third parties (Policy manager 1; Asset manager; Asset specialist 1, 2; Measure 1, 4). One example is the obstacle-free zone, which prohibits planting trees in verges close to the road to enhance road safety. This effectively decreases the available space for planting trees and complicates the objective to maintain the number of trees within the provincial assets (Asset manager; Measure 4).

During the establishment of the contract specifications, verification methods for verifying contractors' work are perceived to be underdeveloped (Project leader 1, 2; Contract manager 1; Supervisor 1, 2). The CUWM-measure was discontinued due because it was not possible to verify its execution (Asset manager; Project leader 1, 2; Contract manager 1 about Measure 2). Additionally, the control instruments and work plans included in the contract are not always used as intended (Project leader 1, 2; Contract manager 1).

The asset managers, asset specialists and project leaders originate these measures (Policy manager 1, Asset manager; Asset specialist 2; Project leader 1, 2). It is perceived that the role of service provider as stated by the asset management theory is clear and implemented which concerns the responsibility of the operational department (Policy manager 1, 5). The entire tactical and operational level is involved in the development and evaluation of sustainability measures (Policy manager 1; Asset manager; Project leader 1). The asset manager and asset specialists are leading in this process (Policy manager 1; Asset manager; Project leader 1 about Measure 1, 2, 3, 4). The technical specifiers and project leaders construct the contract with input from the asset specialists and asset managers (Asset manager; Asset specialist 1,2; Project leader 1; Technical specifier).

4) Requirements Loop

Requirements are not changed for the development of functions, as they are minimally developed (Policy manager 5, Asset manager). The asses specific requirements defined in the AMP have limited development as mentioned in the functional analysis and allocation step. This leads to minimal conflicting requirements in this stage. Additionally, there is no documentation of the development of AMPs influencing the SAMP (Policy manager 1, 5; Asset manager). This is also observed by the researcher (doc. SAMP).

However, it can be assumed that the SAMP has been revised based on asset managers' input. The asset managers are consulted by the policy managers during the setting of requirements in the SAMP (Policy manager 1, 5; Asset manager). However, the impact that the asset managers had on the requirements and if that lead to revisions is unknown due to the lack of documentation.

5) Design Loop

Functions have not been established during the functional analysis and allocation phase, so feedback from the measure development did not lead to revision of the functions. Functions have no direct connection with the measures as mentioned in the design synthesis step. Consequently, this does not lead to the revision of functions because of conflicting interest during the design synthesis step.

Feedback from the operational level influences the AMP as they are established by the asset managers with involvement from the project leaders (Policy manager 1, 5; Asset manager). Additionally, the AMPs specify what is already been implemented so it contains feedback from the operational level (doc. AMP). It is assumed that the functions that have been stated are influenced by the design synthesis. However, this process step is not documented (Asset manager), thus the effects of this feedback loop is unknown.

6) Specification Verification

Requirements and functions are not verified to higher level requirements and functions as they do not exist for the maintenance operations. The development process adheres to a three-step sequence: from the SAMP to the AMPs, and then to measure development (Policy manager 1, 4). This sequence aligns with the three stages of the SE development process. The input of the process are the provincial ambitions, and the output are the measures incorporated in the maintenance contracts, so no additional process levels are identified.

In addition, verification would not be possible. The SAMP and AMPs are perceived to align with the ambitions (Policy manager 1; Asset manager; Asset specialist 2). However, the requirements cannot be verified as the expected impact of the requirements from the SAMP and AMPs is not being mapped (Policy manager 1, 5; Asset manager; Asset specialist 2). Additionally, verifying the SAMP and AMPs is challenging because sustainability ambitions are not defined in SMART terms, as stated before, leaving them open to interpretation.

7) Specification Validation

The SAMP and AMPs are not being validated through consulting stakeholders (Policy manager 1, 2, 5). As mentioned earlier, the expected impact of the requirements on sustainability ambitions has not been mapped. Additionally, as noted before, there is no validation of specifications due to the lack of an accountable individual or department responsible for implementing sustainability in maintenance operations. This results in the SAMP and AMPs not being validated through consulting stakeholders (Policy manager 1, 2, 5)

8) Design Verification

Measures are not being verified to the requirements stated in the SAMP or AMPs (Asset manager; Asset specialist 2 about Measure 1, 2). This statement was confirmed through an analysis of all available documents from Measures 1 through 4 (doc. Measure 1-4). The impact of the measures on the requirements stated in the SAMP and AMPs is not mapped objectively (Asset manager; Asset specialist 2). The expected attribution of the measures to the ambitions is implicitly assessed during the measure development (Asset manager; Asset specialist 2; Project leader 1, 2). The absence of measurable indicators for sustainability results in measures that are unable to be verified (Policy manager 5).

9) Design Validation

As with the specification validation, measures are not being validated by consulting stakeholders (Policy manager 2, 5; Asset manager; Asset specialist 2). As previously stated, this is mainly due through the absence of an accountable asset owner who provides input to the process and can be consulted to validate the process. During the design synthesis, the measures are sighted to the ambitions directly as a limited form of validation (Asset manager; Asset specialist 2; Project leader 1, 2 about Measure 1, 2). However, the impact of the measures is not assessed (Asset manager; Asset specialist 2) so no objective link can be made to map the impact on the ambitions.

10) Implementation Testing

Prioritization of inspection is based on the personal interpretation of supervisors and contract managers (Project leader 1; Contract manager 1, 2; Supervisor 1, 2). The prioritization is done is coordination with this team in accordance with project leaders. Maintenance operations which are not executed according to the contract specification is documented and fed back to the contractor. When not resolved, the contractor is penalized (Project leader 1, 2; Contract supervisor 1, 2). This is confirmed by the research through analysing the Mobile Inspection Application used for this purpose (doc. MIA). The supervisors consider the underlying rationale behind the measure (Supervisor 1, 2). However, adherence to contract specifications is paramount for inspection practices because contractors are paid based on execution according to contract specifications (Project leader 1; Contract manager 1, 2; Supervisor 1, 2).

Various tasks require input from asset specialists. They are consulted for their expertise when assistance is needed. They collaborate with supervisors to instruct contractors by setting a quality baseline that must be met. Asset specialists provide context to the contract specifications and establish working guidelines when gaps in the contract specifications are identified (Asset manager; Asset specialist 1, 2; Project leader 1, 2; Contract manager 1, 2; Supervisors 1, 2).

Execution is not always performed according to the initial measure definition due to unforeseen circumstances such as weather conditions or external interests (Asset specialist 2; Project leader 1, 2; Contract manager 1, 2; Supervisor 1, 2; Measure 1). When this is outside the control of the contractor or province, no direct action is taken (Contract manager 1, 2; Supervisor 1, 2). The effect of the deviation from the contract specifications is mostly unknown (Policy manager 1, 5; Asset specialist 2).

11) Performance Testing

The monitoring performed for sustainability serves a general purpose and is not tied to requirements (Policy manager 1, 5; Asset specialist 2). It provides an overview of trends in provincial assets through various indicators. These indicators are not directly linked to predefined goals (Policy manager 1, 5; Asset specialist 2). Monitoring that serves an objective do not primarily serve environmental sustainability ambitions. For this type of monitoring, the effects are monitored based on the goal's indicators (Policy manager 1; Asset manager; Asset specialist 2 about Measure 3, 4). Some measures, as the ERM-measure, are being monitored directly without referring to a goal directly (Asset manager; Asset specialist 2; Project leader 1 about Measure 1).

Monitoring is mainly conducted by third parties who then provide the results to the asset specialists. The monitoring contracts are being coordinated by the project leaders (Asset manager; Asset specialist 1, 2; Project leader 1, 2). The asset specialists aim to use the monitoring results to evaluate the performance of the measures, but they currently do not (Asset specialist 1, 2).

12) System Testing

The province's monitors their system serving a general purpose (Policy manager 1, 5; Asset specialist 2). Monitoring for a general purpose involves collecting data about the system from available sources. This type of monitoring provides a general overview of the status concerning the ambitions. This leads to the system validation step. The province does not clearly divide its monitoring practices (Policy manager 1, 5). The responsibility and coordination are done the same as with stated at the Performance Testing step.

13) Implementation Verification

Inspection results lead to the verification of the contractors' work. The verification is all done by the supervisors and contract managers. When there are disputes between them and the contractors, the project leaders are involved in the process (Project leader 1, 2; Contract manager 1, 2; Supervisor 1, 2).

The process follows the structure specified in the theoretical framework: if the contractors' execution does not meet specification, it must be redone or adjusted to comply (Project leader 1, 2; Contract manager 1, 2; Supervisor 1, 2). However, when this is not feasible, there seems to be limited action taken to adjust the measure or work performance (Asset specialist 2 about Measure 1, 2). This process is minimally documented, making verification of this statement difficult.

Verification is sometimes an issue during the execution phase. Insufficiently considering verification during measure development has rendered measures impractical or unfeasible in execution due to practical impossibility or lack of measurability. This led in measure of the CUWM-measure to the discontinuation as mentioned before.

14) Performance Verification

Verifying the performance of measures on the sustainability requirements and functions is not done (Policy manager 1; Asset manager; Asset specialist 2). The monitoring is not aimed at assessing the requirements and functions as they are minimally defined. Some individual measures, for example the ERM-measure, are partially evaluated on their performance over the years (Asset manager; Asset specialist 2 about Measure 1). The evaluation is conducted through a combination of monitoring data, advise from third parties who monitor the measure, and implicit knowledge gained during the contract period (Asset manager; Asset specialist 2; Project leader 1; Contract manager 1). This evaluation and decision-making process is not systematically documented as observed in the SAMP and AMP documents (doc. SAMP; AMP).

Evaluation of measures is heavily influenced by bottlenecks and practical objections encountered during execution (Asset manager; Asset specialist 1, 2; Project leader 1; Contract manager 1). Practical objections and conflicting interests emerge during the implementation phase. This results in sustainability measures being modified in favour of other interests (Asset manager; Asset specialist 2; Project leader 1). This process is mainly done during the evaluation and the preparation of new contract specifications by the project leader and asset managers (Asset manager; Asset specialist 2; Project leader; Contract manager 1).

15) System Validation

The status of the ambitions is partially being assessed with monitoring results (Policy manager 1, 5; Asset manager). This assessment is done by the policy managers as they aim to assess the status of the ambitions and use that as input to feedback to the Programming departments and Provincial Council (Policy manager 1, 2, 5). This is examined using the Dashboard Asset Core Values (doc. DACV).

Validation of the system is not possible because of the absence of an asset owner as mentioned before. The assessment of the ambitions' status is constrained by the availability of monitoring data and the lack of SMART-defined ambitions (Policy manager 1, 2, 4, 5; Asset manager; Asset specialist 2). The policy managers are primarily responsible for the assessment but are not accountable due to the lack of obligation to meet sustainability ambitions (Policy manager 1, 2). There are no requirements from stakeholders to report the status of ambitions (Policy manager 2).

As a side note, it is observed that the roles regarding sustainability implementation are being fulfilled, but they are not defined. Individuals act on their own initiative, but their specific roles are not designated in for example the process structure specification called the 'Metrokaart' (doc. Metrokaart).

6. Differences and similarities

This chapter answers the following sub-question: *'What are the similarities and differences between Systems Engineering as described in theory and the practices used by the province, and how does the province perceive these?'*. The first section shows the results of matching the theoretical framework from chapter 2 with the empirical pattern observed in the current sustainability implementation process outlined in chapter 5. The second section analyses the differences and similarities between the two pattern and provide substantiation of the match scores. Subsequently, the perception of the management and maintenance department about the differences and similarities is described.

6.1. Pattern matching

The comparison between the theoretical and empirical pattern are summarised in Table 2. The first column contains the process step. The second column lists the conditions of the process steps following the theoretical framework. The third column details the data analysis results of the provincial process. Traceability of the analysed data is ensured through referenced statements. The second to last column contains the match score per condition. The last column concluded the match score between the patterns. The legend of the table containing the abbreviations used is stated in Table 3.

A match between the patterns is identified when 75% or more of the conditions are met, and there are no mismatches. If 50% or more of the conditions are not met, it is considered a mismatch between the patterns. If the results fall between these two thresholds, it is considered a partial match. For this comparison, the RACI conditions are treated as a single criterion. If one RACI condition is not met, the criterion is considered partially met. If more than one RACI conditions are not met, then the RACI conditions are deemed not met.

Table 2 – Comparison theoretical and empirical pattern of sustainability implementation in maintenance operations

Process step	Theoretical pattern*	Empirical pattern**	Derived from	PM1	PM2	PM3	PM4	PM5	AM	AS1	AS2	PL1	PL2	TS	CM1	CM2	SV1	SV2	SAMP	AMP	MYMP	PSM	GO doc	Cond.	Match
1) Requirements Analysis	*Defined from stakeholders' needs*	*Minimally defined from stakeholders' needs*	*Policy managers were unable to specify new policies for sustainability implementation in maintenance operations.*	x	x	x	x	x																o	-
		Stakeholders minimally involved	*Input from Programming departments is limited*	x	x			x																	
			Policy managers experience major challenges in involving Programming departments	x	x			x																	
	SMART	*Not SMART*	*Development of sustainability ambitions into the SAMP is insufficiently done in SMART terms*	x				x	x		x								x					-	
			It is perceived that achieving sustainability goals is challenging because these are not quantifiable	x				x	x		x														
	RBS with referencing system	*No RBS*	*No structured documentation of stakeholders' needs into requirements*																x					-	
			No prioritization has been made among sustainability ambitions	x				x			x														
	V&V plan	*No V&V plan*	*"Verification and validation are not being considered during this phase"*					Quote																-	
			No V&V plan																x						
	RACI roles in place	*Accountability not defined*	*There is no asset owner to refer to*	x	x		x	x	x		x													o	
			No team is directly responsible for achieving sustainability goals with operations of the management and maintenance department	x							x														
2) Functional Analysis & Allocation	*Defined from requirements*	*Minimally developed requirements*	*"I see that asset managers are struggling with making sustainability concrete for their assets"*					Quote	x															o	-
			AMPs are largely copies of the SAMP					x											x	x					
			The AMP and MYMP lack comprehensive information on addressing overarching ambitions	x				x	x																
			The tactical level experiences insufficient support for developing the requirements into functions for sustainability implementation						x	x	x														
	Solution-free	*Not solution-free*	*Functions contain solutions and describe what has been and will be done*																	x	x			-	
	FBS and SBS with referencing system	*No FBS and SBS*	*No structured documentation of development of requirements into functions*																	x				-	
	Allocation to objects	*Minimal object allocation*	*Some functions are allocated to objects*																	x				o	
			Functions are not specified for objects																	x					
	Interfaces analysed	*No interface analysis*	*Impact of measures on other ambitions is implicitly assessed during development process*						x		x	x										x		-	

Process step	**Theoretical pattern***	**Empirical pattern****	**Derived from**	**PM1**	**PM2**	**PM3**	**PM4**	**PM5**	**AM**	**AS1**	**AS2**	**PL1**	**PL2**	**TS**	**CM1**	**CM2**	**SV1**	**SV2**	**SAMP**	**AMP**	**MYMP**	**PSM**	**GO_doc**	**Cond.**	**Match**
3) Design Synthesis	*Developed from functions*	*Originate from individual expertise, stakeholder's needs sighted*	*Measures originate from desire to benefit sustainability*	x					x	x	x	x	x											-	-
			Measures developed for these goals are mainly implemented out of the professional fanaticism and desire to do the right thing	x					x			x													
			The measures stem from opportunities perceived by individuals in the process based on their expertise and knowledge in their field of work						x		x	x	x												
			The aim is to align the measures with the ambitions	x					x	x	x	x	x									x			
	Multiple alternatives	*No alterative development*	*Functions are not the origin of measures. Measures are the starting point.*					x															x	-	
			There was no mention of asset requirements. The discussions focused on proposing measures and deciding on implementing them in the contract specifications																			x			
	Traceable underpinned trade-off	*No objectively substantiated decision-making*	*Unclear goals result in an ad hoc approach to measure development*	M1				M1																-	
			Sustainability goals are not quantifiable, which leads to not weighing measures on impact	x				x	x										x	x					
			The measure's expected effect is not actively weighed based on the sustainability ambitions and conflicting interests						M1,2		M1,2														
			The expected attribution of the measures to the ambitions is implicitly assessed during the measure development								x	x	x												
	Implementation verification plan	*Minimal verification considered*	*Verification methods for verifying contractors' work are perceived to be underdeveloped*									x	x		x		x	x						o	
			Measure is discontinued because of not adequate possibility to verify						M2			M2	M2		M2										
	Decision-making process documented	*Decision-making process is minimally documented*	*The process of decision-making and the final decisions made are not being documented apart from meeting notes and email communications*									x	x	x										o	
4) Requirements	*RBS revised based on developments*	*Requirements assumed to be changes based on process developments*	*The asset managers are consulted by the policy managers during the setting of requirements*	x				x	x															o	o
	Changes to requirements documented with reasoning	*Changes not traceable through documentation*	*There is no documentation of the development of AMPs influencing the SAMP*	x				x	x										x					-	
5) Design Loop	*FBS and SBS revised based on developments*	*Functions revised based on developments*	*Project leaders are involved in setting functions*	x				x	x															+	o
	Changes to functions documented with reasoning	*Changes not traceable through documentation*	*This process step is not documented*						x											x				-	

Process step	Theoretical pattern*	Empirical pattern**	Derived from	PM1	PM2	PM3	PM4	PM5	AM	AS1	AS2	PL1	PL2	TS	CM1	CM2	SV1	SV2	SAMP	AMP	MYMP	PSM	GO_doc	Cond.	Match
6) Specification Verification	*Requirements and functions verified to higher-level requirements and functions; changes to specification documented with reasoning*	*Process step not performed*	*Requirements and functions are not verified to higher level requirements and functions as they do not exist*																				x	-	-
			Expected impact of requirements and functions on ambitions are not mapped	x				x	x		x									x					
7) Specification Validation	*Requirements and functions validated to stakeholder's needs; changes to specification documented with reasoning*	*Process step not performed*	*Expected impact of requirements and functions on ambitions are not mapped****	x				x	x		x									x				-	-
			The SAMP and AMPs are not being validated through consulting stakeholders	x	x			x																	
	RACI roles in place	*Primary stakeholder unable to be consulted*	*There is no asset owner to refer to****	x	x		x	x	x		x													-	
8) Design Verification	*Design verified to requirements; changes to design documented with reasoning*	*Process step not performed*	*The measures' impact is not mapped objectively*						x		x												M1,2,3,4	-	-
			The measures' impact is not verified to the requirements						M1,2														M1,2,3,4		
9) Design Validation	*Design validated to stakeholder's needs*	*Design is implicitly estimated to be in line with stakeholder's needs*	*The measures' impact is not mapped objectively****						M1,2														M1,2,3,4	-	-
			Ambitions are sighted during measure development						M1		M1	M1	M1									x			
			The expected attribution of the measures to the ambitions is implicitly assessed						x		x	x	x												
	RACI roles in place	*Primary stakeholder unable to be consulted*	*There is no asset owner to refer to****	x	x		x	x	x		x													o	
			Measures are not being validated by consulting stakeholders		x			x	x		x														
	Changes to design documented with reasoning	*Not documented*	*No validation of measures found*																				M1,2	-	

Process step	Theoretical pattern*	Empirical pattern**	Derived from	PM1	PM2	PM3	PM4	PM5	AM	AS1	AS2	PL1	PL2	TS	CM1	CM2	SV1	SV2	SAMP	AMP	MYMP	PSM	GO_doc	Cond.	Match
10) Implement	*Testing is conducted based on strategy*	*Testing prioritization done implicitly*	*Prioritization of inspection is based on personal interpretation*									x			x	x	x	x						-	o
	Results are documented	*Results are documented*	*Deficiencies are documented and fed back to the contractor to resolve*									x	x		x	x							MIA	+	
11) Performance Testing	*Performance-based*	*Not performance-based*	*Monitoring is not aimed at verifying goals*	x				x			x													-	-
			Some measures are monitored on their own performance						M1		M1	M1													
			Asset specialists aim to use the monitoring results to evaluate the performance of the measures, but they currently do not							x	x														
	Based on KPIs	*Not based on KPIs*	*The monitoring performed for sustainability serves a general purpose*	x				x			x													-	
	Results are documented	*Results are documented*	*Monitoring is mainly conducted by third parties who then provide the results to the asset specialists*						x	x	x	x	x											+	
12) System Testing	*Goal-based*	*Partially goal-based*	*The monitoring performed for sustainability serves a general purpose****	x				x			x													o	o
	Testing based on KPIs	*Monitoring available data*	*The monitoring performed for sustainability serves a general purpose****	x				x			x													-	
	Results are documented	*Results are documented*	*Monitoring is mainly conducted by third parties who then provide the results to the asset specialists****						x	x	x	x	x											+	
13) Implementation Verification	*Based on testing results*	*Based on testing results*	*Inspection results are the basis for approving contractors' work*									x	x		x	x	x	x						+	+
	Deficiencies are documented and acted upon	*Deficiencies are documented, small deficiencies are acted upon*	*Action is taken if the contractors' work does not meet the specifications*									x	x		x	x	x	x						o	
			When adjustment of the contractors' work is not feasible, limited action is taken to adjust measure						x		M1														
	Changes documented with reasoning	*Changes are documented with reasoning*	*Deficiencies are documented and fed back to the contractor to resolve****									x	x		x	x							MIA	+	
14) Performance Verification	*Based on testing results*	*Minimally based on testing results*	*Measures are not verified on their performance on the requirements*	x					x		x													o	-
			The evaluation is conducted through a combination of monitoring data, advise from third parties who monitor the measure, and implicit knowledge gained during the contract period						x		x	x			x										
	Verified specifications, evaluation of specifications	*Individual measures partially evaluated based on monitoring*	*Some measures are evaluated on their performance over the years*						M1		M1													-	
	Changes to specification documented with reasoning	*Minimally documented without reasoning*	*SAMP and AMP contain minimal performance status of requirements and functions*																x	x				-	

Process step	Theoretical pattern*	Empirical pattern**	Derived from	PM1	PM2	PM3	PM4	PM5	AM	AS1	AS2	PL1	PL2	TS	CM1	CM2	SV1	SV2	SAMP	AMP	MYMP	PSM	GO, doc	Cond.	Match
15) System Validation	*Based on testing results*	*Based on testing results*	*Ambition status is partially assessed with monitoring results*	x				x	x															+	o
	Validated to stakeholder's needs	*Not validated*	*There are no requirements from stakeholders to report the status of ambitions*		x																			-	
	Evaluation of the system	*Partial evaluation of goals*	*There is a lack of monitoring data and SMART-defined ambitions*	x	x		x	x	x		x													-	
			Policy managers aim to assess the status of the ambitions and use that as input to feedback to the Programming departments and Provincial Council	x	x			x																	
	RACI roles in place	*Primary stakeholder unable to be consulted*	*There is no asset owner to refer to****	x	x		x	x	x		x													o	
	Changes to process documented with reasoning	*Minimally documented with reasoning*	*Some ambitions' status is visualized and documented*																				DACV	o	

Table 3 – Legend of Table 2

*	*For all steps of the theoretical pattern, RACI roles are allocated following the structure defined in Table 6, Table 7, and Table 8 in Appendix I.*
**	*When RACI roles are not mentioned, the roles meet the theoretical framework.*
***	*This statement is used multiple times as reference*
PM	*Policy manager*
AM	*Asset manager*
AS	*Asset specialist*
PL	*Project leader*
TS	*Technical specifier*
CM	*Contract manager*
SV	*Supervisor*
SAMP	*Document analysis of strategic asset management plan*
AMP	*Document analysis of asset management plan*
MYMP	*Document analysis of multiyear maintenance plan*
PSM	*Observed during project startup meeting*
GO, doc	*General observation, or analysis by the researcher*
Cond.	*Match score per condition of process step*
Match	*Overall match score of process step*
x	*General statement of interviewee or general observation by the researcher if in column [GO, doc]*
M1,2,3,4,5	*Specific statement of interviewee about measure 1,2,3,4,5 or observed by the researcher in document of measure 1,2,3,4,5 if in column [GO, doc]*
MIA	*Analysis of Mobile Inspection Application*
DACV	*Analysis of Dashboard Asset Core Values*

6.2. Analysis

In this section, the match scores are analysed, and the degree of alignment is substantiated per process step. Additionally, the perception of the management and maintenance department is included to provide insight into whether they recognize these problems.

1) Requirements Analysis

There is a mismatch between the theoretical and empirical pattern for this process step. One condition and the RACI conditions are partially met, and three conditions are not met.

Among all levels of the management and maintenance department, this mismatch is perceived as a problem. The policy managers believe that the inadequate definition of requirements is due to a lack of established accountability and the minimal involvement of stakeholders being the Programming departments. The tactical level, the asset manager and asset specialists find that current requirements are not well defined enough or ambiguous. They aim to contribute to sustainability objectives but lack guidance from the Programming departments on how to achieve these objectives, as well as financial support. The operational level experience the problems due to conflicting interests by not defining priorities at the higher levels. This results in measures that are not well thought out or conflicting with other provincial or third-party interests. As Project leader 2 stated, “From higher up, they always say that we need to do something about sustainability, but when push comes to shove, nothing happens, or we are left to handle it ourselves.”

2) Functional Analysis & Allocation

There is a mismatch between the theoretical and empirical pattern for this process step. The RACI conditions are met, two conditions are partially met, and three conditions are not met.

This mismatch is perceived as a problem among all levels of the management and maintenance department. The problems coincide with the problem perceived with the Requirements Analysis (1). The policy managers observe that the asset managers struggle with constructing a cohesive plan for sustainability implementation. The asset managers and asset specialists aim to develop functions for their assets but experience difficulties due to requirements not being SMART enough and the lack of guidance from Programming departments. The operational level experience conflicts of interest due to the lack of a cohesive plan.

3) Design Synthesis

There is a mismatch between the theoretical and empirical pattern for this process step. The RACI conditions are met, two conditions are partially met, and three conditions are not met.

This mismatch is perceived as a problem by the tactical and operational level of the management and maintenance department. They are both engaged in the development of measures. As mentioned before, they experience a lack of guidance for the implementation of sustainability. This results in them trying to meet the overarching ambitions from the province without a cohesive plan. These measures are not always cohesive with each other or other measures or interest from the province or third parties. This results in problems during the execution phase of the maintenance contract where conflicts arise which could be mitigated beforehand. They feel that these conflicting measures results in measures are not reaching their potential.

The policy managers and asset manager acknowledge that requirements and functions not being the basis of measure development is a problem. They identify two disadvantages: (1) the measures might not align to ambitions and (2) the measures are not supported by funding. Measures stem from individual expertise and motivation, and requirements are sighted during the development of contract specification. This leads to an ad hoc approach to measure development. The effectiveness of the measures is unknown as goals are not defined in SMART terms and how to verify the measures performance is not being concretized during the measurement development. Because of this, they stated that they cannot confirm that the combined impact of the measures overall is in line with the stakeholders’ needs.

When the development of measures is not directly derived from ambitions, funding is limited. The management and maintenance department receives its budget from the Provincial Council based on expected execution cost of maintenance practices to preserve provincial assets. Financiers such as the Programming departments are minimally involved in the process because of the gap between ambition and measure development. When measures originate at the tactical and operational level, the higher organizational levels are not involved in the process thus there is no extra funding for implementation of sustainability measures. This limits the possibilities of the management and maintenance department to attribute to the sustainability ambitions of the province. Sustainability measures that are being implemented currently fit within the maintenance budget as they need minimal additional spending during execution (Asset manager).

4) Requirements Loop

There is a partial match between the theoretical and empirical pattern for this process step. The RACI conditions are met, one condition is partially met, and one condition is not met. The empirical pattern cannot be aligned with the theoretical framework, which states that an RBS should be revised. An RBS is not established in the Requirements Analysis (1), so the empirical pattern refers to requirements instead of an RBS.

The changes not being traceable is not perceived as a problem by the management and maintenance department. The interviewees did not identify this a problem. This may be caused by there being minimal development between the Requirements Analysis (1) and the Functional Analysis & Allocation (2) which in turn leads to minimal changes to the requirements because of function development.

5) Design Loop

There is a partial match between the theoretical and empirical pattern for this process step. The RACI conditions and one condition are met, and one condition is not met.

As with the Requirements Loop (4), the changes not being traceable is not perceived as a problem by the management and maintenance department. The interviewees did not identify this a problem. This may be caused by the Design Synthesis (3) not being developed based on the Functional Analysis & Allocation (2).

6) Specification Verification

There is a mismatch between the theoretical and empirical pattern for this process step. This process step does not exist so not conditions are met. Currently, specification verification is not part of the development process as there is only one process level in place.

The absence of this process step is not perceived to be a problem by the management and maintenance department. Policy manager 1 and 5 recognize the potential benefits of an integrated sustainability implementation plan. Implementing such a plan would require the addition of multiple process levels, as this would include adding stages to allocate sustainability ambitions across departments and assets. Consequently, this process step would have a purpose in this context.

7) Specification Validation

There is a mismatch between the theoretical and empirical pattern for this process step. None of the conditions of the theoretical pattern are met. This mismatch of this process step is a result of stakeholders being minimally involved in the management and maintenance department's operations as stated in the Requirements Analysis (1).

The policy managers, asset manager, and asset specialists see this as a problem because they lack guidance on how to prioritize and give substance to the requirements and functions. They state that involvement from the Mobility Programming and other Programming departments would improve sustainability implementation. The operational level did not comment on validation.

8) Design Verification

There is a mismatch match between the theoretical and empirical pattern for this process step. The RACI conditions are met, and two conditions are not met. This problem is in part due to requirements not being specified SMART and no V&V plan being initiate and developed during the Requirements Analysis (1) and Functional Analysis & Allocation (2).

This mismatch is perceived as a problem by the policy managers and asset manager as they are not able to objectively state that the developed measures result in achieving ambitions. This problem is not able to be solved currently as the Mobility Programming department does not want additional policies to be drafted because it does not fit in their workflow as stated before.

9) Design Validation

There is a mismatch between the theoretical and empirical pattern for this process step. None of the conditions of the theoretical pattern are met. This mismatch of this process step is a result of stakeholders being minimally involved in the management and maintenance department's operations as stated in the Requirements Analysis (1).

The perception of the policy managers, asset manager and asset specialists is the same as with the Specification Validation (7). Additionally, the project leaders believe they should not be taking the lead in implementing sustainability, as they are currently doing. They feel that sustainability measures should be initiated by the asset manager and asset specialists. They believe it is not their responsibility to validate whether the measures align with the province's ambitions.

10) Implementation Testing

There is a partial match between the theoretical and empirical pattern for this process step. The RACI conditions and one condition are met, and one condition is not met.

Policy Managers 1 and 5 view the lack of a strategy for testing as problematic, as it may result in high-impact measures not being verified. They state inspection could be done more efficiently when high impact measures are prioritised during inspection. Project leaders, contract managers and supervisors acknowledge that this is the current way of working but do not perceive it as a problem.

11) Performance Testing

There is a mismatch between the theoretical and empirical pattern for this process step. The RACI conditions and one condition are met, and two conditions are not met.

The policy managers, asset manager, and asset specialists see this as a problem because they are unsure of the impact the measures have on sustainability ambitions. While they believe they are moving in the right direction, they lack certainty. The asset manager and asset specialists feel they could contribute more effectively to sustainability ambitions if they had a clearer understanding of whether these goals are being met. They believe the main issue is the lack of SMART requirements and functions that provide clear targets to work towards.

12) System Testing

There is a partial match between the theoretical and empirical pattern for this process step. The RACI conditions and one conditions are met, one condition is partially met, and one condition is not met.

The policy managers, asset manager and asset specialists consider the lack of requirements-based testing to be a problem. Policy manager 1 stated: "The purpose of testing is to verify the goals that you agree on in advance. Testing for the sake of testing is pointless." They feel KPIs should be adopted to enable testing and verification and validation of requirements.

13) Implementation Verification

There is a match between the theoretical and empirical pattern for this process step. The RACI conditions and two conditions are met, and one condition is partially met.

The management and maintenance department does not perceive there to be a problem with this process step. Contract manager 2 and the supervisors noted that, in recent years, the verification of contractors' work has greatly improved. They claim this is due to the implementation of digital control software and the reassignment of key responsibilities to the contract manager rather than the contractor.

14) Performance Verification

There is a mismatch between the theoretical and empirical pattern for this process step. RACI conditions and one conditions are partially met, and two condition are not met.

The perception is in line with the statement made at Performance Testing (11).

15) System Validation

There is a partial match between the theoretical and empirical pattern for this process step. One condition is met, the RACI conditions and one conditions is partially met, and two conditions are not met.

Policy managers find it astonishing that the Provincial Council does not require updates on the status of sustainability ambitions and fails to take action when these ambitions are not met. They feel that substantial amounts of money are being spent without knowing the results.

When comparing the theoretical and empirical patterns, it can be concluded that the empirical pattern overall is very different to the theoretical pattern and that there is much room for improvement. The pattern matching of the two patterns yielded one complete match, six partial matches and eight mismatches. The ratio of matches to mismatches reflects the perception of the management and maintenance department regarding the implementation of sustainability in its maintenance practices.

7. Validation

This chapter presents the results of validating the empirical pattern. This validation is conducted by discussing twenty-one statements during a focus group meeting. These statements are formulated based on the mismatches between the theoretical and empirical pattern. They cover all process steps and are phrased in terms used by the management and maintenance department. Details of method used are provided in chapter 3.6. The first section presents the initial validation results by having participants provide their feedback through scoring the statements on a 5-point Likert scale. The second section summarizes the subsequent discussion results and revises the statements as necessary.

The validation results have been applied to the empirical pattern described in chapter 5.

7.1. Evaluation of statements

Figure 4 shows the results from the validation session. The validation statements are stated on the left side with the combined feedback of the participants on the right side.

Figure 4 – Results from the focus group validation session.

7.2. Revision of statements

Any statements with disagreements led to discussions aimed at clarifying participants' feedback. The objective of these discussions is to achieve a consensus on each statement. As a result, some statements were redefined.

7.2.1. Statement 1

‘The current strategic documents were collaboratively created by asset managers and policy managers and approved by the Mobility Programming department.’

This statement is not true on two points. Firstly, the current strategic documents were not collaboratively created between policy managers and asset managers. The discussion led to the consensus that the policy managers set up the strategic documents and the asset managers were consulted. Secondly, the Mobility Programming department did not approve the strategic documents. The SAMP is approved by the general management team of the management and maintenance department and the framework for managing provincial infrastructure assets is directly approved by the Provincial Council.

Statement 1 is redefined as: ‘The current strategic documents were created by the policy managers. The asset managers were consulted in this process. The SAMP is approved by the general management team of the management and maintenance department and the framework for managing provincial infrastructure assets is approved by the Provincial Council.’

7.2.2. Statement 4

‘The measures in the AMP and MYMP are not well aligned with the province's overarching ambitions.’

This statement can be interpreted in two ways. The consensus is that the SAMP and AMP do not define how the ambitions should be integrated in the tactical and operational levels. However, the original statement implies that the work of the management and maintenance department does not follow the provincial ambitions. This is not deemed to be the case as during the measure development process ambitions are sighted. However, ambitions are not sufficiently developed to be used in measure development. It is observed that this leaves decision-making of the tactical and operational levels unsupported.

Statement 4 is redefined as: ‘The measures in the AMP and MYMP are not derived from the province's overarching ambitions but are deemed to align with them.’

7.2.3. Statement 9

‘No department is responsible for achieving sustainability ambitions.’

The statement is incorrect, as the consensus is that everyone within the province is responsible for achieving the sustainability ambitions. Accountability of achieving the sustainability ambitions is deemed to be the issue.

Statement 9 is redefined as: ‘Although everyone within the province is responsible for achieving sustainability ambitions, no department is accountable.’

7.2.4. Statement 11

‘The asset manager and asset specialists are leading in the implementation of sustainability measures.’

This statement is incorrect. The consensus is that asset managers and asset specialists are the key players in the implementation of sustainability measures as they are included the entire development and implementation process. However, the project leaders and technical specifiers have an important role in initiation and development of sustainability implementation.

Statement 11 is redefined as: ‘The asset manager and asset specialist are the key players in the development and implementation of sustainability measures.’

7.2.5. Statement 17

'There is limited consideration of how measures can be inspected and monitored during implementation.'

The consensus is that this statement is correct. However, it is noted that some quality assurance instruments cannot be used as intended because they are under the contractors' supervision.

Statement 17 is not redefined.

7.2.6. Statement 18

'There is no consideration of how measures can be monitored for their contribution to biodiversity or climate adaptation during development process.'

The consensus is that this statement is true. The implementation is being monitored. However, monitoring is deemed to not reach its full potential because objectives are not defined SMART and the absence of KPIs. This results in the measures contribution to biodiversity and climate adaptation not being considered during the development process. Currently, monitoring only visualizes the changes over the years.

Statement 18 is not redefined.

7.2.7. Statement 19

'Uncontrollable factors, such as weather conditions or contractor decisions, can lead to deviations from the specifications during implementation.'

This statement is deemed to be true. It is stated that contract specifications allow the contractor to adapt their working methods to these uncontrollable factors. The contractors are penalized for deviating from the contract specifications, but this is done according to principles of reasonableness and fairness. The contractors will not be penalized if the deviations are deemed to be beyond their control.

Statement 19 is not redefined.

7.2.8. Statement 21

'Control tools, such as work plans or forms submitted by the contractor, often provide a distorted picture of the actual situation during implementation.'

This statement was unclear. The consensus is that control tools are used minimally during the implementation process. However, it was noted that these tools do not necessarily present a distorted view of the actual situation, but it is unknown whether the contractors are adhering to their work plans.

Statement 21 is redefined as: 'Control tools, such as work plans or forms submitted by the contractor, are minimally used to check contractors' work during implementation.'

The rest of the statements were deemed to be true by the participants of the focus group meeting. In conclusion, the focus group meeting provided valuable insights into the current process of sustainability implementation in the maintenance process. Through discussions, the participants clarified key issues and refined the findings. Their input ensured that the results accurately reflect the collective perspectives and clarified the collected data. As a result, the validated outcomes are now more robust and aligned with the group's consensus, setting a solid foundation for the analysis in the next chapter.

8. Discussion

This chapter discusses limitations of this research. By doing this, areas of improvement are identified, and the remarks are made about the research results and comparison between the empirical and theoretical pattern.

8.1. Limitations

8.1.1. Scope

The units of analysis within the case were limited to five. The selection was made based on the contract specifications of different maintenance contracts. It is important to acknowledge that contract specification do not contain measures but result from the measures that have been selected. New or adjusting measures might not affect contract specification as it can be implemented within the contractual boundaries, or it does not affect the contractor's work. As the selection was done at the start of the study, these kinds of measures might not have been highlighted. On the contrary, such measures were not found in other documentation and did not came up during the interviews.

The selected measures had no connection to climate adaptation, as mentioned by an interviewee. This is mainly caused by the nature of maintenance operations. Climate adaption often coincides with changing functions of objects which is outside the scope of maintenance operations. This left climate adaptation underemphasized in this study. As mentioned at the problem statement, climate adaption is an underdeveloped ambition topic within the province. Giving insight into the status of climate adaptation measures in infrastructure projects requires the research on how the area development and implementation department handles climate adaptation in their projects. Climate adaptation is included in this research as its implementation encounters similar challenges as biodiversity.

The interviewees for this research consisted of individuals from all levels of the management and maintenance department. Their perception of the sustainability implementation in the maintenance process is examined as part of the research. While this research also touched on stakeholders such as the Provincial Council, the Mobility Programming department, and other Programming departments, their perspectives were not directly explored and were only minimally addressed through the eyes of the policy managers. Including these stakeholders would have enhanced the research by providing insights into how certain strategic processes operate.

8.1.2. Data collection

The primary source of data for this study came from interviews. The interviews were conducted with individuals from the management and maintenance department's division 'Asset Green & Water'. This study aimed to included individuals involved in all levels of the process and successfully did so. However, due to personal circumstances not all individuals involved in the strategic level of the process were able to be part of the study. Their insights and work specifics might have provided a broader understanding of the decision-making in the higher levels of the department and the province. They might have offered further insights into the collaboration between the management and maintenance department, the Programming departments, and the Provincial Council, as these individuals are involved in aligning the perspectives for these three bodies into strategic documents for maintenance operations.

This research focuses on the process of the division 'Asset Green & Water'. Several challenges during the data collection phase were encountered. Firstly, at the strategic and operational levels, the process of this division is heavily intertwined with the division 'Asset Pavements'. Secondly, interviewees often focussed on the practical implications rather than the maintenance process. Thirdly, the interviews often shifted between sustainability ambitions. Due to these challenges, interpretation of collected data was needed for this research. This might have led to a partially subjective analysis because of researcher bias.

When questions were asked about the origin and development of measures, there were inconsistencies regarding the reasons behind certain measures. The lack of documentation of the development process and the measures' alignment with the ambitions or requirements has led to a sense of ambiguity regarding the measures' purpose. Various interpretations of the measures' purpose and contract specifications seem to exist among interviewees. Naturally, not all people within the management and maintenance department need to know specifics of the measure, but combined with the lack of documentation, this resulted in a partially unclear picture of the measures' implementation.

8.1.3. Systems Engineering

The SE methodology is used as point of departure of this study. This methodology has potential for improving the implementation of sustainability within maintenance operations by being able to address key challenges, as stated in chapter 6. However, other methodologies might be better suited for structuring sustainability implementation within maintenance operations. For example, fully implementing the iAMPRO methodology, of which the province is in the process of implementing, and using its potential might lead to a more suited approach. This study's benefit for the province is the analysis of the current process and potential methods to address the challenges observed. The proposed methods from the SE methodology might not be the optimal solution for the province but have proven to be effective in other infrastructure projects.

This research used SE to reflect on the current sustainability implementation process within maintenance operations. The management and maintenance department organizes their process according to the iAMPRO methodology. Adapting the empirical pattern to fit the fifteen-step process outlined in the theoretical framework proved challenging as process steps did not align. This misalignment may have affected the empirical pattern, potentially obscuring a complete understanding of the process.

8.1.4. Generalisability

This thesis focuses on the maintenance operations of the province of Gelderland. The theoretical framework can be applied to other organisations as it is developed independently of this thesis' focus. The conclusions drawn from the comparison between practices of the province and the theoretical framework are not generalizable. Drawing conclusions and specifying recommendations for other organizations requires the analysis of the organization to address its needs.

8.1.5. Researchers' expertise

The experience of the researcher is limited in doing academic research and conducting interviews and focus group meetings. This could have led to lower quality data compared to that collected by a more experienced researcher. This could have impacted the formulation of questions and statements or the interpretation of the collected data.

9. Conclusion & Recommendations

This research answers the main research question: *'To what extent can Systems Engineering help the province structure the process of decomposing high-level sustainability ambitions into project requirements and measures into their maintenance operations?'.*

To answer the main research question, the research was conducted in four phases. The first phase consisted of establishing the theoretical framework by using Systems Engineering to translate stakeholders' needs into a design and its implementation, ensuring that the system meets these needs. The second phase consisted of identifying the current sustainability implementation process through interviews with individuals involved in the process and analysing five measures as exploratory support. The third phase utilized pattern matching to identify differences and similarities between the theoretical and empirical pattern. The results of this comparison were then analysed and validated by presenting them to focus group comprised of the previous interviewees. In this last phase, conclusions are drawn, and recommendations are made based on the analysis and validation the research findings.

The first section covers the conclusion resulting from the analysis phase through identifying challenges faced by the province. The second section covers the actionable recommendations for the province to improve the current process of implementing sustainability into maintenance operations derived from this research. The last section covers the areas for future research.

9.1. Conclusion

Four key conclusions have been drawn from the comparison between the SE methodology and the provincial working methods for implementing sustainability. These highlight critical issues in the province's current approach to sustainability implementation.

9.1.1. Non-existent documentation

Instrumental to a development and implementation process following the SE methodology is ensuring traceability and transparency in the process through structured documentation. Overall, documentation of sustainability development process (elements 1-9) is virtually non-existent, except from the SAMP and AMPS. Most of the decision-making process is done implicitly. Consequently, the development process lacks traceability, and measures are not schematically linked to ambitions. During the interviews it was noted that there was considerable talk around "I think we do it this way" and "we need to figure this out." This led to the conclusion that documentation of sustainability implementation process in maintenance operations is subpar. The connections that are documented are minimally described in the SAMP and AMP. This means that the connection between ambitions, requirements, and measures is generally only understood implicitly by individuals acquainted with the process.

Limited documentation of the development process has its effects during the implementation process (elements 10-15) as this enable the verification and evaluation of the measures' performance on the prescribed goals. The current documentation for the implementation process is comprised of contract inspection reports, serving as confirmation of contractors' performance, and monitoring reports. When external parties are not involved, documentation is limited. As inspection and monitoring reports has no direct connection to the performance evaluation, evaluation is mostly done on implicit knowledge. This limits the possibilities for substantiated evaluation of measures.

9.1.2. Ill-defined ambitions

Sustainability development in maintenance operations lacks a solid foundation in ambitions because of the shortfall in ensure the achievement of sustainability ambitions and the absence of measurable indicators for tracking development process.

This issue can be traced back to the undefined accountability for achieving ambitions. The Mobility Programming department has all characteristics of an asset owner but has not assumed accountability for the sustainability implementation within the maintenance process. According to Costello (2012), without a designated party being accountable, there is no performance accountability. This issue is observed to manifest in three main areas of the process. Firstly, when setting sustainability requirements, there is limited input on the goals the management and maintenance department needs to achieve concerning sustainability ambitions. Secondly, during the development phase, validation is not possible due to the absence of a primary stakeholder to refer to for validating requirements, functions and measures. Thirdly, in the implementation phase, the system's performance cannot be properly validated. These three key areas are directly impacted by the absence of main accountability, and it is observed that this issue influences the entire sustainability implementation process due to the lack of support and reference for implementing ambitions.

9.1.3. Inadequate requirements and functions development

Another key issue identified is that measurement development is directly based on abstract ambitions without assessing its effect on the ambitions. This creates a challenging development process, as the ambitions are not defined in sufficient detail to effectively guide the development of measures. Furthermore, there is insufficient insight into how each measure contributes to achieving these ambitions and the potential side effects of the measures.

9.1.4. Individual-driven approach to sustainability

In general, the roles are not structurally assigned but individuals take their roles. Roles for sustainability implementation in maintenance operations are not specified, in for example the process structure specification called the 'Metrokaart'. This renders the process highly implicit, relying on individuals' motivation to integrate sustainability into their operations. Consequently, this may lead to minimal progress in sustainability implementation as continuity of sustainability implementation is not ensured. One example of this happening was the period of the change of asset manager 'Green & Water'. The period between the last long-standing asset manager and the current asset manager resulted in minimal implementation of sustainability within the division 'Asset Green & Water'. It is concluded that there is a heavy reliance on individuals' commitment to achieve sustainability goals.

In the inspection process, although roles are implemented and the process is well-structured, it is highly reliant on performance of individuals. Supervisors and contractor managers can make decisions what to inspect based on their expertise, but the impact of their decisions remains unclear.

9.2. Recommendations

This section aims to answer the sub-question *'What should the province do to improve the current situation?'*. This last sub-question gives answer to the last part and enables concluding the main research question. This section summarizes the key insights into six main recommendations for the province of Gelderland. The recommendations are arrange based on their relevance to improve the current process of the province.

9.2.1. Process documentation

It is recommended to use structured documentation practises as this has several advantaged. Firstly, documenting decision-making improves traceability and prevents ambiguities because the measures' relation to the requirements and ambitions is known. Documentation enables referring to and mapping of the decisions made so they can be verified and validated at later stages. Secondly, implementing measures with conflicting objectives can be prevented. Through documentation, conflicting objectives can be identified early in the process. When conflicts emerge in the latter part of the development phase or implementation phase, solving these conflicting interests can be harder.

Improving documentation of the process has the highest priority as structured documentation is of key importance when applying SE practices.

9.2.2. Ambition concretization

It is recommended that the asset owner should be defined, as the current lack of accountability for sustainability implementation in maintenance operations effectively means that there is no obligation to integrate sustainability into the maintenance process. Although the Provincial Council considers contributing to sustainability ambitions part of the standard working practices of the organization, it results from not specifying how and what ambitions should be incorporated into the process. It is crucial to identify and reference a primary stakeholder accountable for defining these goals to ensure that sustainability is effectively integrated into the maintenance process.

This recommendation has the second highest priority because this challenge currently causes the most problems throughout the sustainability implementation process.

9.2.3. Requirements and functions development

It is recommended to integrate multiple process steps to develop abstract sustainability ambitions into concrete measures that serve those ambitions. The theoretical framework defines two intermediate process steps before measure development, being defining SMART requirements and developing functions that are allocated to different objects. Implementing these process steps into the practices of the management and maintenance department offers four main benefits:

1. Using ambitions as the basis for measure development ensures that measures are effectively aligned with goals. By developing ambitions, conflicting requirements and functions are identified, allowing for trade-offs to be made to ensure the system effectively meets all the ambitions. This approach enables development based on objectives rather than the current measure-based development. In the proposed method, requirements drive the achievement of ambitions, and measures serve as tools to reach those ambitions, rather than measures being the primary focus for achieving the ambitions.
2. Full integration of ambitions enables the creation of more effective sustainability measures. Developing measures from functions is more effective because major trade-offs are addressed before this step. This approach narrows the focus to concrete functions rather than abstract ambitions. Additionally, it ensures coherence among measures, as functions derive from all combined ambitions and are based on achieving the most effective outcomes.
3. Sustainability measures become a more integral part of the maintenance process. Supporting sustainability measures with concrete objectives such as requirements and functions, rather than abstract ambitions, strengthens their integration into the maintenance process. This approach ensures that trade-offs made during the implementation phase are balanced with other interests and provincial goals.
4. It allows for determining whether the ambitions are being met. SMART requirements and functions facilitate their verification during both the development and implementation phases. First, during the development phase, requirements, functions, and measures can be cross verified to ensure alignment among them. Second, monitoring can be conducted on the KPIs defined in the requirements and functions to assess whether the estimated impact of the measures on the ambitions is being achieved.

This recommendation is seen as the third step for improving the sustainability implementation process as, after ambitions are concretized, requirement and function development are the basis of a system that achieves stakeholders' needs.

9.2.4. Assessing roles and responsibilities

It is recommended that the management and maintenance department should establishing clearly defined roles. This ensures accountability and reduces the reliance on the motivation and commitment of individuals. This in turn strengthens the sustainability process by assuring process steps are assigned clearly to individuals can be held accountable for their role.

When assessing the roles and responsibilities, the department could benefit from seeking guidance from sustainability specialists within the province or external parties. Currently the maintenance and management department is inward-focused and largely depends on its own expertise for addressing sustainability implementation. The department encounters difficulties in integrating sustainability measures into its practices. Consulting these 'outside' experts could improve the implementation process and enhance the effectiveness of measures in achieving the province's sustainability goals.

Implementing this recommendation is not considered crucial for enhancing the sustainability implementation process, as the roles are generally defined according to the RACI methodology. Nevertheless, clarifying these roles would strengthen the process and reduce the impact of individual influences on its proper execution.

9.2.5. Risk-based inspection approach

Adopting a structured, risk-based approach to inspections would enhance control over measure implementation by eliminating the need for individuals prioritizing what to inspect. Instead, inspection routines should be predefined through an impact assessment of deviating from the contract. A risk-based inspection routine supports the system's implementation by evaluating risks associated with contract deviations and their impact on ambitions, leading to a more effective inspection strategy where measures are evaluated based on their impact on achieving goals.

This recommendation is likely to yield the least improvement compared to the others, as the current inspection routines are already well established. However, adopting a risk-based inspection approach could enhance the alignment between measure development and execution.

9.2.6. Integral sustainability implementation

This study focused solely on the division 'Asset Green & Water'. During the interviews, ideas were proposed for an integrated approach to sustainability implementation across all infrastructure practices. SE can play a broader role in achieving a more integrated approach. SE practices can serve in defining a holistic strategy that prioritizes contributions from each operation and asset. Resources can be used more effective when an impact analysis is conducted. This approach allows prioritization of efforts based on each asset's impact on the ambitions. The province is already piloting such an integral approach to asset management. Including aspects of SE results allows for a more structured and objective approach to sustainability implementation.

This would require multiple process levels; this process is visualized in Figure 5. The first process level would be the general infrastructure objective of the province. The ambitions that affect infrastructure assets would be divided into objects corresponding to the different infrastructure departments within the province. The second level would be integral requirements per department. The third and last level would be specific requirements for each asset separately. Further research is needed to explore the exact implementation details and needs for higher levels.

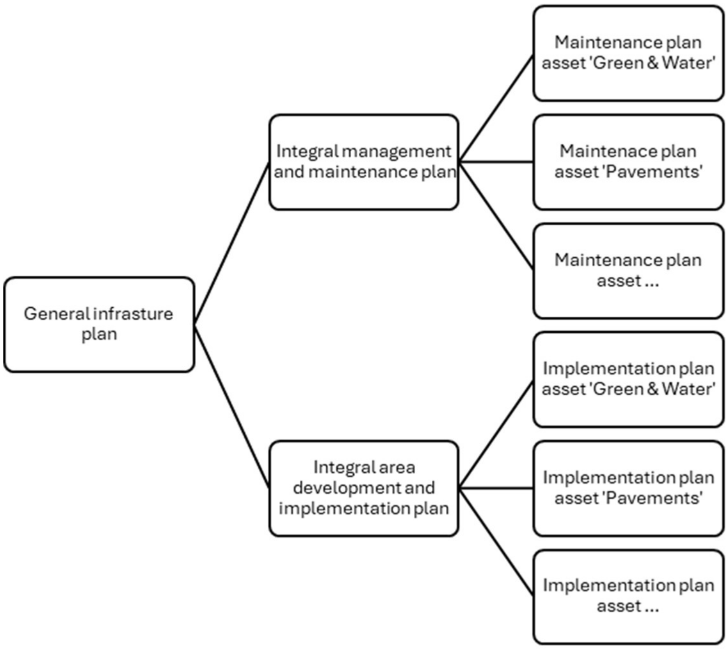

Figure 5 – Proposed structure for the infrastructure objective.

This study has focused on the environmental aspect of sustainability. However, organisations have a broader view of sustainability which also includes the economic and social aspects of sustainability. This study describes conflicts between environmental sustainability and social sustainability with biodiversity and traffic safety respectively. To address these conflicts, the province should define how these aspects relate to each other and address their priorities.

This recommendation is considered experimental and would necessitate the most extensive structural changes within the entire provincial infrastructure organization. While it could have a substantial impact on achieving sustainability goals, it would also demand the greatest effort.

In conclusion, challenges have been identified that can be addressed by applying the SE methodology, as revealed through a comparison between the SE theoretical framework and current sustainability practices. Six recommendations have been formulated to enhance the translation of high-level sustainability ambitions into concrete measures and application of those measures in maintenance operations of the Province of Gelderland.

It can also be concluded that the SE methodology possesses attributes that can enhance the implementation of sustainability in maintenance operations. As implementation of the SE framework has not yet been carried out, the specific benefits of applying in practice remain to be fully determined. However, it can be stated that using a systems approach to sustainability development and implementation can streamline the process. By structuring the process and clearly identifying conflicts of interest, SE can provide a more traceable and transparent framework for developing and achieving sustainability ambitions.

9.3. Future research

This section discusses areas for future research that emerged during the analysis of the results and discussion of this research.

9.3.1. Implementation

This study compares the empirical pattern of the province with the theoretical pattern of SE. However, the management and maintenance department does not aim to work in accordance with the SE methodology. This resulted in the decision not to address the SE tools such as requirements and functional breakdown structures as, in principle, they have not adopted the use of the tools. This resulted in a superficial analysis of SE where the details of the SE tools are not addressed. When deciding on implementing SE in the practices of the management and maintenance department, care should be taken to setup an implementation plan. This plan should be adapted to cover the needs of the development and implementation process of all maintenance operations and contain the tools that are essential for SE.

Implementing SE in the management and maintenance department and creating an integrated approach needs different personal traits because of the changing process structure. The criteria which these personal traits must meet have not been investigated. Operating more integrally requires different knowledge and skills (Chester & Allenby, 2019). Future research should identify what knowledge and skills are needed for implementing sustainability following an integral approach.

As is observed during this research, implementation is complex and difficult to manage in practice despite theoretical expectations. This research shows potential benefits of using SE in the maintenance operations but application in practice and testing is needed to affirm these potential benefits for the organisation. The success of the province's implementation of SE in its maintenance operations hinges on its approach, given that the construction industry is primarily a "people-oriented business and profession." (Clough et al., 2015).

9.3.2. Inspection methods

In the conclusion, using a risk-based inspection approach was proposed enhance the effectiveness of contract inspection. In future research, the effects of using a structured inspection method could be analysed. The current approach is heavily based on personal expertise and focus of supervisors (Project leader 1, 2; Contract manager 1). Surveillance registration mainly consists of supervisors register anomalies from specification (Supervisor 1, 2). This leads to untransparent inspection practices which minimally consider the overall impact on provincial ambitions. Implementing a structured inspection method could provide more insight could be provided into the maintenance works adherence to contract specification.

9.3.3. Integrated approach

This research focused on sustainability implementation into the practices of the management and maintenance department. The focus for the measures were on the division 'Asset Green & Water'. The conclusion proposed an integrated approach to sustainability implementation for all operations surrounding infrastructure construction and maintenance. The other assets and departments mentioned in the proposed structure are not investigated. Before implementing the proposed integral approach, the specific needs and challenges should be investigated so the new approach could be catered to address these.

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Appendices

Appendix I - Province characteristics

This appendix goes into adapting the province characteristics that influence sustainability implementation in maintenance operation of the province. First, the current provincial maintenance process structure is mapped out and explained. Following this, the characteristics of implementing sustainability in the province's maintenance operations are identified, and strategies for addressing these characteristics are specified. Finally, the current roles within the management and maintenance department are identified and allocated for sustainability implementation according to the RACI methodology.

A. Provincial maintenance process structure

The department of management and maintenance is structed as Figure 6. The department is in the process of implementing the iAMPRO model for their management practices, which is based on the asset management theory and the Plan-Do-Check-Act cycle (CROW Essit, 2023). The asset management theory can be understood by examining the role of three entities: (1) asset owner, (2) asset manager and (3) service provider. The asset owner is responsible for the strategy of the asset by setting objectives. The asset manager implements the strategy by making key decisions, providing necessary expertise, and coordinating the activities. Lastly, the service provider is responsible for the execution of the operational maintenance tasks. The PDCA cycle is a four-step method, aimed at continuous improvement. ‘Plan’ stands for goal setting and plan development. ‘Do’ stands for the implementation of the plan. ‘Check’ stands for evaluation of the implementation against the expectation. Lastly, ‘Act’ stands for determining if the plan is successful or if adjustment of the plan is needed and the cycle is repeated.

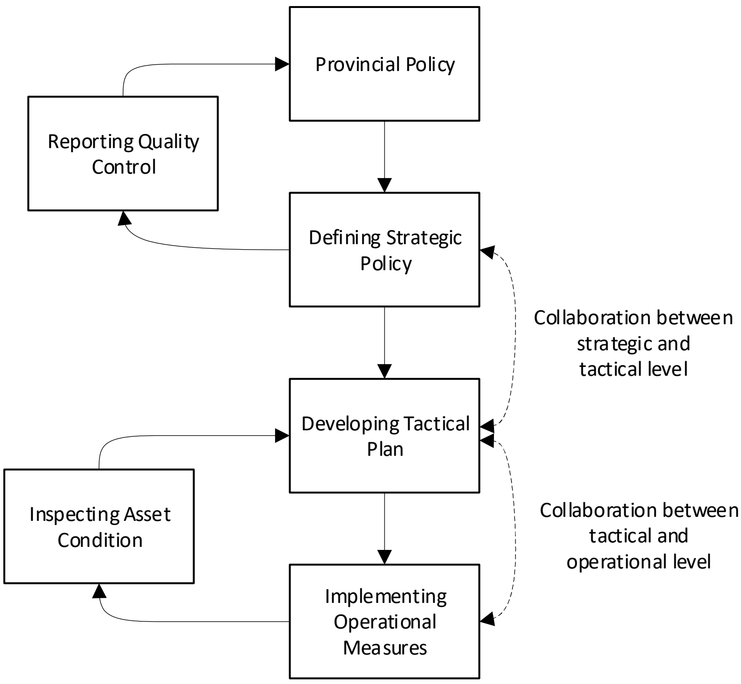

Figure 6 – Structure of department of management and maintenance.

Below, the structure of the management and maintenance department is elaborated upon.

Defining strategic policy

Two documents are the basis of the management and maintenance department, (1) the framework for managing provincial infrastructure assets and (2) the strategic asset management plan, called the SAMP. The framework for managing provincial infrastructure assets includes two main elements, (1) a desired quality level of the maintenance operations for the provincial infrastructure assets and (2) upcoming large maintenance operations that are due. This framework is the basis for the yearly budget for the management and maintenance department and is directly approved by the Provincial Council. The SAMP is a statement about how the province's policies affect the provincial infrastructure assets. It is an administrative document, so it did not require approval from the Provincial Council (Policy manager 2). However, this document has been shared with the Provincial Council to provide insight into how the department handles policy (Policy manager 2). During the definition of the strategic policy, asset managers are involved and can give input (Policy manager 5).

Developing tactical plan

Based on these documents, asset management plans (AMPs) per asset and a multiyear maintenance plan (MYMP) are developed by the asset managers. They serve as a guideline for the maintenance operations of their asset. Policy managers are involved in this process to assist asset managers in the development process. Objectives stated in these plans are operationalized through maintenance contracts. Two types of contracts can be distinguished, integral maintenance contracts and asset-specific maintenance contracts. The integral contracts transcendent assets and include general inter-asset maintenance operations such as cleaning and mowing. Asset-specific contracts are issued for more specialized and asset-specific operations. The contracts that have been analysed for this research, contracts for pruning trees, dredging watercourses, or replanting trees. These contracts are the division 'Asset Green & Water' specific. These contracts are developed in collaboration between the tactical and operational level.

Implementing operational measures

The maintenance division, consisting of project leaders, contract managers and supervisors, are responsible for the maintenance operations being executed by the contractor. They oversee and collaborate with the contractors to perform the maintenance according to the contractual specifications. The province uses a standardized work specification system, for their contracts, known in the Netherlands as the 'RAW-systematiek'. This contract type results in the contractor only being responsible for the execution of the contract specifications. Through daily surveillance by supervisors and weekly meetings, the work is coordinated with the contractor. The contractor is paid when executed operations are performed following specifications and approved by the contract manager and supervisor. During operations, asset specialists are involved in important matters for expert input. The maintenance division and asset specialists communicate directly about the practical implications in the field. Since the asset specialists and asset managers holds ultimate responsibility for their asset, they have the final say on matters at hand.

Inspecting asset condition

The status of the assets is monitored through condition inspections. These inspections serve as input for the maintenance operations. Additionally, maintenance inspections are issued to determine the overall condition of the assets. These inspections aid in determining the future strategy for scheduling major overhauls of the assets. Both types of inspections are drafted by the asset specialists and coordinated by the project leaders. Results from these inspections serve as input for the asset specialists to act upon.

Reporting quality control

Planning and control documents are being used to give feedback to the Provincial Council about the budget needed and quality of the provincial infrastructure assets. The Provincial Council demands these documents to determine the status of the provincial infrastructure and to attain an understanding of the allocation of financial resources. The policy managers are responsible for this document.

Determining the provincial maintenance process sets the baseline for adapting the theoretical framework to this process. The next section addresses the specific characteristics of the provincial maintenance process that impact the application of the theoretical framework for sustainability implementation.

B. Sustainability implementation in provincial maintenance process

This section addresses applying the theoretical SE model to the process of sustainability implementation in maintenance operations of the province. Firstly, the process characteristics and terminology are identified and their impact on the application of the theoretical framework is addressed. Secondly, the RACI roles are assigned following theory to the involved parties of the maintenance operations.

Characteristics of province's maintenance process

To apply Systems Engineering (SE) in the maintenance process of the province, several key points need to be addressed. The SE development and integration model is designed for product or project development (Walden et al., 2015). However, the maintenance process differs in three significant ways:

1. Abstract ambitions: Part of the input of the development process are abstract sustainability ambitions set by the Provincial Council. Due to this and the subjective nature of sustainability development (Brown et al., 1987; Kemp & Martens, 2007), this results in broadly defined stakeholders' needs as input for the development process.
2. Undefined products: Unlike product or project development, where the end result is clearly defined, the maintenance process does not involve a strictly defined product. In maintenance operations, methods and practices, referred to as measures, are defined to achieve objectives. These measures are less detailed compared to the final designs in construction projects.
3. Complex system boundaries: System boundaries for biodiversity and climate adaptation are complex. For instance, a provincial road passing through a nature reserve complicate that assessment of biodiversity improvement measures because natural systems do not adhere to defined system boundaries and are heavily influenced by outside factors.
4. Limitedly assessable: Maintenance operations are time bounded which leads to contractors employing multiple teams to perform maintenance activities at the same time. Consequently, it is impossible for the supervisors to attend every maintenance activity and assess all contract specifications.

These differences lead to the following implications:

1. Verification & validation: Increased attention is needed during the verification and validation stages because abstract and policy-dependent ambitions are complicated to validate, and less defined products leave room for interpretation. Sustainability implementation involves setting goals and requirements using KPIs. KPIs are to be chosen carefully to adhere to the objectives (Addison et al., 2020).
2. Impact assessment: More effort is required to assess the impact of measures before and after implementation. The impact on the entire system is limited and heavily influenced by external circumstances, making it difficult to quantify the success of the measures (Stevenson et al., 2021). Managing expectations during the development phase results in realistic objectives and provides insight into the complexity of sustainability implementation.
3. Prioritized inspection: Inspection practices should be prioritized to get the most complete picture of maintenance activities performed by the contractors. An inspection strategy should be drawn up to effectively assess the contractors' work, ensuring that the execution conforms to contract specification and that the measures are implemented as intended.

Client-contractor dynamics in province's maintenance process

The execution of the maintenance operations is done by a contractor instead of the province. This introduces a client and contractor relationship which has its influence on the process. The output of the development process are the contract specifications containing the operational maintenance operations for the contractor to execute. The transfer point of responsibilities from client to contractor is an important aspect of infrastructure projects (Prorail et al., 2013). The province using a standardized work specification system for their contracts results in the management and maintenance department being responsible for the entire development phase. After development, a contract is established containing the work to be executed by the contractors. Consequently, any adjustments made after tendering may not be possible or may result in increased costs, as they are not included in the contract. This underscores the importance of the development phase and the need to assess the performance of measures before implementation. Verifying and validating the measures before tendering is of key importance for meeting the stakeholders' needs (Walden et al., 2015).

The contractors' responsibility is to carry out maintenance operations according to the contract specifications. The contractor states quantities of the performed work and gets paid accordingly when approved by the supervisors and contract managers. Implementation Testing and Verification (elements 10,13) is aimed at evaluating the contractor's work. The subsequent monitoring, verification, and validation of the measures and system are evaluating the department's own development work. Once the contractor has implemented the measures according to the contract specifications, the contractor is no longer involved in the process, and responsibility for the performance of the measures shifts to the province.

As a result, there is a strong emphasis on the verification and validation of the measures, given that their execution is not under the province's control. To ensure the contractor works according to contract specifications, the work is guided and inspected by the operational level of the management and maintenance department. Additionally, control elements that assess the contractor's performance must be clearly defined in the contract, providing the operational department with tools to guide the contractor as needed to ensure the maintenance operations meet expectations.

Lastly, quality assurance processes serve as the input for the evaluation of the maintenance process. The rigid nature of the standardized work specification system limits adjustments during the integration phase due to contractual constraints. However, maintenance operations are cyclic, with maintenance contracts spanning two to four years. With each cycle, the process can be adjusted based on the system's performance and evolving stakeholder needs. Making the process traceable and documenting results is key for the ability to evaluate the impact of the implementation on the goals set (Chofreh & Goni, 2017; Epstein & Buhovac, 2010).

C. Roles and responsibilities for sustainability implementation

Decision-making for sustainability implementation`

The decision-making process for sustainability implementation consists of three-levels, strategic, tactical, and operational (Chofreh & Goni, 2017; Loorbach et al., 2010; Montana & Charnov, 2008). Decisions at these levels should be made on the corresponding top, mid and supervisory levels of the organization respectively (Chofreh & Goni, 2017; Montana & Charnov, 2008). The province uses the terminology of asset management with an asset owner for strategic decision-making, an asset manager for tactical decision-making, and a service provider for the operational decision-making (CROW Essit, 2023). The connections are shown in Table 4.

Table 4 – Level alignment decision-making, organizational, and asset management

Decision-making level	Organizational level	Asset management level
Strategic	*Top*	*Asset owner*
Tactical	*Mid*	*Asset manager*
Operational	*Supervisory*	*Service provider*

Below, the levels are detailed to define the needs for each one:

1. Strategic level: At this level, the sustainability vision and goals are defined (Loorbach et al., 2010). This phase is aligned with the stakeholders' input and Requirements Analysis (1), where the fundamental requirements and objectives are established. Consequently, strategic decision-making is pivotal at this level, as it lays the foundation for all subsequent actions and initiatives. Feedback from lower levels aids the strategic level redefining or adjusting goals set to ensure the stakeholders' needs are met.
2. Tactical level: At this level, plans are developed to achieve the targets set by the strategic level (Loorbach et al., 2010). This stage corresponds to the Requirements Analysis (1) and Functional Analysis & Allocation (2), where requirements and specific functions are analysed, and resources are allocated. Decision-making at this level aims at translating strategic goals into actionable plans and ensuring that necessary resources and processes are in place. Feedback from the operational level and monitoring feedback enables the tactical level to adjust plans to be more efficient and to recalibrate plans to ensure they meet goals set by the strategic level.
3. Operational level: At this level, implementations are drawn up and implemented following the plans made by the tactical level (Loorbach et al., 2010). As this stage, concrete actions are developed, and measures are implemented. Operational decision-making ensures that the tactical plans are carried out and sustainability objectives are achieved. Feedback within the operational level ensures that measures are executed according to specification. This level is associated with the Design Synthesis (3), Implementation Testing (10) and Implementation Verification (13).

Role allocation for sustainability implementation in province's maintenance process

This section outlines the RACI roles for sustainability implementation in maintenance operations within the province's management and maintenance department. Before detailing these roles, it is necessary to identify the existing roles within the department. Table 5 outlines the existing roles and their tasks within the maintenance process.

Table 5 – Provincial roles involved in sustainability implementation in maintenance operations that are part of or directly affecting the management and maintenance department.

Provincial role	Descriptions
Provincial Council	*The Provincial Council provides the main funds directly to the management and maintenance department for infrastructure maintenance. The department provide the Provincial Council with a budget plan for them to approve. This plan contains the quality level for maintenance operations and the upcoming mayor maintenance operations and reconstructions. The Provincial Council allocated the provincial of the province to the various Programming departments*
Mobility Programming department	*This department is responsible for all mobility aspects within the province of Gelderland. There are multiple Programming departments, each tasked with achieving provincial ambitions. They can choose to utilize the provincial infrastructure to achieve these ambitions among other strategies. As the Mobility Programming department is part of the top level of the province, this department is accountable for setting system requirements. This department collaborates with other departments to align their various ambitions to implement them in infrastructure assets. Additionally, the Programming departments are consulted for acting on ambitions they are responsible for and are kept informed about the status of the ambition.*
Policy managers	*Policy managers have various diverging roles. They have in common that they all provide the connection between the department of management and maintenance and the higher level of the province such as the Provincial Council and the Programming departments. They are the intermediate between the strategical and tactical level of the process. They are translating the ambitions for use in maintenance operations, and they provide the top level with feedback on activities regarding their responsibilities.*
Asset managers	*Asset managers are the central figure in the management and maintenance departments. They are accountable for their specific assets. Their main accountability lies in the tactical level. Additionally, they are consulted and informed throughout the whole process.*
Asset specialists	*Specialists provide expertise on parts of one asset. They are mainly accountable during the development and execution of measures and monitoring and evaluating the assets performance. During the integration phase, they are consulted to provide expertise.*

Provincial role	Descriptions
Project leaders	*Project leaders are accountable for the maintenance operations performed by the contractor. They provide the main connection between the tactical and operational level of the process. They are responsible for the developing the design and providing operational knowledge in the development process. They orchestrate all work executed by contractors.*
Technical specifiers	*Technical specifiers assist the department in setting up contract specifications determining the contractor's work. They work primarily with the project leader to establish the contract.*
Contract managers	*Contract managers oversee the contractor during the contract period. They are responsible for the administrative operations surrounding maintenance operations. They are co-responsible for the inspection and verification of executed work. Additionally, they provide administrative knowledge during the development of the contract.*
Supervisors	*Supervisors work with and oversee the contractor during the contract period. They are responsible for the daily supervision of maintenance operations. They are co-responsible for the inspection and verification of executed work. Additionally, they provide operational knowledge during the development of the contract.*

In the tables below, the RACI roles are defined for the existing roles in the maintenance process in accordance with the theory from 2.3. The process is divided into the strategic, tactical, and operational levels. These tables only contain roles that are currently in-place in the management and maintenance department.

Table 6 – Strategic RACI roles definition for sustainability implementation in maintenance operations of the province.

SE process step	Responsible	Accountable	Consulted	Informed
1. Requirements Analysis	*Mobility Programming department, Policy managers*	*Mobility Programming department*	*Asset managers*	*Provincial Council*
6a. Specification Verification, strategic	*Policy managers*	*Policy managers*	-	*Asset managers*
7a. Specification Validation, strategic	*Policy managers*	*Policy managers*	*Mobility Programming department*	*Asset managers*
12. System Testing	*Policy managers, Asset specialists*	*Policy managers*	-	*Asset managers*
15. System Validation	*Policy managers*	*Policy managers*	*Mobility Programming department*	*Provincial Council, Asset managers, Asset specialists*

Table 7 – Tactical RACI roles definition for sustainability implementation in maintenance operations of the province.

SE process step	Responsible	Accountable	Consulted	Informed
2. Functions Analysis & Allocation	*Asset managers, Asset specialists*	*Asset managers*	*Policy managers*	*Project leaders*
4. Requirements Loop	*Asset managers, Asset specialists*	*Asset managers*	*Policy managers*	-
6b. Specification Verification, tactical	*Asset managers, Asset specialists*	*Asset managers*	*Policy managers*	-
7b. Specification Validation, tactical	*Asset managers, Asset specialists*	*Asset managers*	*Policy managers, Mobility Programming department*	-
11. Performance Testing	*Asset specialists*	*Asset specialists*	*Policy managers*	*Project leaders*
14. Performance Verification	*Asset managers, Asset specialists*	*Asset managers*	*Policy managers*	*Project leaders*

Table 8 – Operational RACI roles definition for sustainability implementation in maintenance operations of the province.

SE process step	Responsible	Accountable	Consulted	Informed
3. Design Synthesis	*Project leaders, Technical specifiers, Asset specialists*	*Project leaders*	*Contact managers, Supervisors, Asset managers*	-
5. Design Loop	*Project leaders, Asset specialists*	*Project leaders*	*Asset managers*	*Technical specifiers*
8. Design Verification	*Asset managers, Asset specialists*	*Asset manager*	*Policy managers*	*Project leaders, Technical specifiers*
9. Design Validation	*Asset managers, Asset specialists*	*Asset manager*	*Policy managers, Mobility Programming department*	*Project leaders, Technical specifiers*
10. Implementation Testing	*Contract managers, Supervisors*	*Contract managers*	*Project leaders, Asset specialists*	*Asset managers*
13. Implementation Verification	*Project leaders, Contract managers, Supervisors*	*Project leaders*	*Asset specialists*	*Asset managers*

By following these defined RACI roles, tasks are assigned to the appropriate roles within the management and maintenance department. Defining the roles in this way aligns the role conception, role expectation and role behaviour. Additionally, the RACI roles follow the logical structure within the management and maintenance department. This role structure facilitates the translation of ambitions into measures and ensures their implementation.

Overall, adapting the fifteen SE process steps together with the allocated RACI roles to the existing roles creates the framework for applying sustainability measures in maintenance operations of the province of Gelderland. By using this framework, measures are derived from and can be traced back to sustainability ambitions. By using this holistic approach, the resources can be used more efficiently by determining the effect on all ambitions combined. This eliminates unforeseen negative side effects on the other ambitions and allows for weighted decision-making that results in optimal ambition implementation. This is ensured by feedback loops between development levels. Additionally, real-world feedback is integrated into the development process, allowing for the optimization of measures and adjustments based on monitoring. Defining and adhering to the RACI roles ensures the process is executed correctly and by the appropriate individuals and departments. Finally, this process can adjust to evolving ambitions since measures can be traced back, and their effects on the ambitions are documented and mapped.

Appendix II – Interview Protocol

Interview Explanation

Points to clarify:

- Purpose of the Interviews: How does the process transition from abstract sustainability ambitions and policies to concrete measures and implementation?
    - Focus is on the themes of biodiversity and climate adaptation within the Green & Water assets.
- Contracts Investigated:
    - Integrated maintenance contracts, green component
    - Pruning specifications
    - Dredging specifications
    - Planting specifications
- Tracing the Process:
    - Using measures from the specified contracts
    - Trace the process from measure to origin.

Point for myself:

- Keep the sub-research question in mind during the interview
- Assess based on SE elements.
- Reason from measure back to ambition and policy.

Sign the 'Informed Consent' Form

Opening Question

1. Can you briefly describe your role and what you do?
    a. Can you indicate where you are involved in the process? (Referencing the management and maintenance departments' process diagram)

Specific Questions About a Measure

- I would like to trace the process from abstract requirements to concrete implementation using a few specific measures. The following measures are taken from the specifications:
    A. Measures for ecological roadside management (ERM)
    B. MEAT scheme for circular use of waste materials (CUWM)
    C. Choice of biological or mechanical method for oak processionary caterpillar control (OPCC)
    D. Choice of tree species to be replanted
    E. Maximum soil compaction in road verges

2. Which measures can you provide more details about?
    a. Have you been involved in developing the measure?
    b. Are you involved in the implementation of the measure?
    c. Have you dealt with this measure?
        - #If multiple measures are associated, select two measures in order, choosing 'a' over 'b'.

A. What is the origin of the measures for ERM-measure?
    - #Measures from specifications: sowing with flower mix, applying nutrient-poor soil, sinus mowing, removing mowed material, working according to 'Kleurkeur' standards
   a. Are these isolated measures or are they coordinated with each other?
   b. What role does a guideline play in taking these measures?
      - #'Kleurkeur' standards
   c. How is the decision made to apply or not apply certain measures from the guideline?
   d. How is the decision made between sustainability ambitions and, in this case, road safety?
      - #Flower-rich grass mowed once a year vs. first 0.5 meters from the road mowed several times a year
   e. How is this measure monitored?

B. What is the origin of the CUWM-measure?
   a. How is this measure coordinated with other measures?
      - #Possibly in conflict with shredding and leaving hedge trimmings

C. What is the origin of the OPCC-measure?
   a. How is it determined where biological or mechanical control methods are applied?
      - #Use of nest boxes, experimenting with promoting natural predators

D. What is the origin of the choice of tree species to be replanted?
    - #Ambition states to plant a maximum of 20% of the same species

E. What is the origin of the measure for maximum soil compaction?
   a. How does an adjustment of such a measure occur?
      - #Earlier specifications set a maximum compaction of 50mm in road verges during work, later specifications set a maximum of 30mm

General Questions

#Use the following questions in the context of the above measures:

3. Do these measures stem from ambitions?
   a. If yes, which ambitions and where is it lacking?
   b. If no, what is the origin?
   c. If no, are they in line with the ambitions?
4. Is it known which ambition is affected by this measure?
   a. If yes, is it known what the combined effect of the measures is on the ambitions?
   b. If yes, how is this reflected?
   c. If no, why not?
5. Do these measures originate from requirements?
   a. If yes, how are the requirements determined? And in which phase?
   b. If yes, does the province manage requirements?
   c. If yes, who determines these requirements?
6. Is a decision made between different measures when determining them?
   a. If yes, how are these different measures determined?
   b. If yes, how is this decision made? And in which phase?
   c. Who makes this decision? Who is involved in this decision?
   d. Is the decision clearly documented?
7. Is external expertise, such as guidelines, standards, or consulting firms, used in defining measures?

    a. If yes, why is this done?
    b. If no, why not?
8. Are the measures checked for compliance with contract specifications?
    a. If yes, how is this evident?
    b. If no, why not?
9. Is the measure monitored aimed at evaluating it performance on ambition during implementation?
    a. If yes, how is the measure monitored?
    b. Is it clear whether the measure meets the ambitions or requirements?
10. Are the measures evaluated for achieving the desired effect after implementation?
    a. If yes, how is it evaluated?
    b. If yes, how is the evaluation incorporated into the next maintenance contract?
    c. If yes, where is this evident?
    d. If no, why not?
11. Who is involved in the process of measure development?
    a. Is the role distribution in this process appropriate, or should more or fewer people be involved?
    b. Why do you think so?
12. Who is involved in implementing the measure?
    a. Same as question 11
    b. Same as question 11

Opinion Questions

13. Where in the process do you think the most progress can be made to better meet sustainability themes in the B&O process?
    a. Why do you think so?

Closure

14. Do you have any additional comments on this topic or any other remarks about this research?
15. Are there other individuals within the province whom I could interview as a follow-up to this research?

#Next Points to Mention:

- Send a copy of the interview report
- Offer the opportunity to review the interview
- Possibly approach for focus group discussions
- Ask if there is interest in receiving the final research report
- Thank them for participating in the research