ESSAYS ON INFRASTRUCTURE ASSET MANAGEMENT

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INFRASTRUCTURE ASSET MANAGEMENT

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DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF BUSINESS ECONOMICS: BUSINESS ENGINEERING FROM THE
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“The man who removes a mountain begins by carrying away small stones.”

-

Confucius

FOREWORD

In the last decades, infrastructure has proven to be one of the significant drivers of our economy. ORI, as the sector organization for engineering and consulting firms in Belgium, acknowledges this importance. The infrastructure sector in Belgium is one of the largest of the Belgian economy and infrastructure makes up a large part of Belgian's public investments.

Public infrastructure will face many challenges from different fields in the future. Economic, social and environmental aspects will all influence its management. As a result, public authorities will have to act accordingly. Although demands are increasing, at the supply side more effort is required. Additional investments and sound project management, together with a more integrated network approach and improved stakeholder collaboration will form the basis of these actions. We are already on the right track, however further guidance is still needed. Therefore, we – as ORI but also as a sector as a whole – welcome research on infrastructure management with high enthusiasm.

The PhD research of Laura Molinari is the result of the Chair Infrastructure Asset Management. This Chair is a collaboration between the major engineering firms; Antea Group Belgium, Arcadis, Sweco Belgium and Tractebel, supported by ORI.

Laura Molinari's research is of high relevance as it addresses these aforementioned challenges for infrastructure. The analyses and results of this book will assist public decision makers by improving their public infrastructure management processes and in making their network future-proof. Throughout the book, many clear suggestions are made on better long-term infrastructure planning and customized corresponding strategies, which will be quick wins for any government which implements them. In addition, the research emphasizes a strong request for more attention to better relationships within the sector, as well as with all the stakeholders outside the sector. On that last note, we can confirm as active organization in the infrastructure sector, that the entire sector is willing to cooperate. Our common goal is to provide public infrastructure that meets the current and future needs of our society.

Let us take this research as a start of a new way towards a more collaborative and integrated infrastructure management and a guide to future- and climate-proof infrastructure projects.

Jan Parys

President ORI and CEO Antea Belgium

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Finishing a PhD challenges you as a person and pushes you in some aspects to your limits. Fortunately, I was guided by different persons and organizations throughout this exciting yet demanding experience. On these first pages of my dissertation, I would like to take the opportunity to thank these persons and organizations for their support.

First, I would like to thank the Vrije Universiteit Brussel. Up to this month, September 2023, I have spent nine incredible years at this university, as a first-year student, as a graduating business engineer, as a starting PhD student and finally as a doctor. Who would have thought I would make it this far? I certainly did not. Thank you VUB and Solvay Business School for making me the person I am. Thank you for giving me the freedom to discover the person I was at the time and to form me into the woman I am today. A strong and passionate woman with a critical mind and lots of energy to contribute to society.

Undeniably part of the added value the VUB has given to me, is my promotor, guiding hand and personal mentor, prof. dr. Elvira Haezendonck. We found each other through a mutual passion: infrastructure, but after four years, we both know that that list of mutual interests is way longer. Elvira, it is almost unwritable what you have taught me on a professional and even more on a personal level. You taught me how to balance life, how to work for clients, how to give presentations and deliver high quality work, how to build up a network and so much more. This dissertation is not only the end product of my work, but it is the outcome of a successful collaboration over more than four years. There are no words for how grateful I am for having had the opportunity to pursue my PhD under your supervision.

I also would like to thank the Université Libre de Bruxelles and my co-promotor prof. dr. Vincent Mabillard. Vincent, what a journey has it been. You stepped into this story during my second year as a PhD candidate. You only had arrived shortly in Belgium after your academic career in Switzerland. Thank you for joining us back then. You have taught me the foundations of public management and how to grow as a young academic. Thank you for being so approachable and for answering the questions that must have been seem obvious for you. I was your first PhD student and I will highly recommend you as a supervisor for the next ones. They will be in great hands.

Of course, this dissertation would not have existed without the support of the Chair Infrastructure Asset Management and Lifecycle Planning and its partners Antea Belgium, Arcadis, Sweco Belgium, Tractebel and ORI. I would like to specifically express my deepest gratitude to the, current and former, representatives of the partners in the Steering Committee, Mrs. Lieve Neiyrinck (Arcadis), Mr. Jan Parys (Antea Belgium and ORI), Mr. Carl Verelst (Sweco Belgium), Mr. Jan Groeninckx (Tractebel), Mr. Christophe Hautier (former ORI) and Mr. Bram Vandenboom (former Tractebel). I am so grateful that you gave me the opportunity to pursue my PhD in which I could combine two of my greatest interests, management and infrastructure. We had eight STEERCOs of on average two hours and a half, resulting in spending 20 hours together. Twenty hours of interesting and valuable discussions, twenty hours of sharing our thoughts and twenty hours of combining our passions. Thank you all for your input, not only on the topic, but also on a personal and professional level. You contributed to making me a real infrastructure professional.

Next to the guidance from a practioner's point of view, I was also fortunate to be guided by a strong academic advisory committee and PhD jury. Prof. dr. Caroline Buts, prof. dr. Larissa Van der Lugt, prof. dr. Yvan Verbakel and prof. dr. Samia Ben Rajeb, thank you for being part of my jury. Prof. dr. Diane Breesch and prof. dr. Philip Vergauwen, thank you for being a member of advisory committee. A special thank you also to prof. dr. Caroline Buts for taking on the responsibility of being the president of my PhD jury and to prof. dr. Diane Breesch for being the president of the advisory committee. Your work was highly appreciated. Jury, thank you for reading and evaluating my dissertation, and for the valuable and constructive comments and questions. Advisory committee, thank you for providing me with interesting feedback throughout the entire process. Your diverse backgrounds ranging from a technical and engineering perspective to transport economics and finance added an immense value to this dissertation.

I would also like to show my deepest appreciation for two other members of our VUB team on transport and infrastructure, prof. dr. Michael Dooms and prof. dr. Alain Verbeke.

Prof. dr. Michael Dooms, Michael, our story started in 2018 when I became president of Initiatiefgroep Solvay and when we organized the trade mission together. After the trade mission we had a talk on a potential PhD journey with Elvira. You gave me the opportunity to join two of my best professional experiences of all time: the trade mission in Colombia in 2019

and my PhD, and I am very grateful for that. Elvira and you are a team, both complementary in your personalities and ways of working, of which every organization could dream of, and I was honored to be part of it. What Elvira taught me was always supplemented by your expertise and wise advice. We have been through different challenges, mostly abroad on trade mission, but we always had a good time. We travelled to Colombia, Morocco, Spain, Greece and the United States together and it was a pleasure to be your travelling partner during these trips. Thank you for showing me how to work in and with a team, and the skills of a real people manager!

Prof. dr. Alain Verbeke, the academic mentor of us all. You started this department with a focus on transport economics and I am grateful that I also had the opportunity to gain some of this knowledge from you. You have guided me through the basics (and not so basics) of academic theories and for teaching me how to bring academic papers to a higher level. It was a pleasure working with you.

Besides individuals, there are also some organizations to which I want to express my gratitude to. Thank you De Vlaamse Waterweg, Agentschap Wegen & Verkeer, SPW Infrastructures & Mobilité, Infrabel and Tucrail for providing me with data and information based on which I could perform my research. Thank you De Vlaamse Waterweg in specific for trusting the team with the development of SEMI. Thank you ADEB-VBA and its members for your support in the research on cost overruns and causes of cost overruns and for spending time with me during the interviews. The hours of STEERCO and board presentations brought in both cases a lot of added value to this dissertation. Furthermore, I would like to thank all other respondents in the survey of causes of cost overruns for spending their valuable time on completing the survey.

Colleagues and friends, thank you for being there for me at all times. Fanny, Fiona, Lynn, Magali, Ellen and Katrien, thank you for the enjoyable and happy moments in the office. For the many hours we were talking and laughing rather than working and for the way-to-many online coffee breaks and aperitivo's. Spending time at the office with all of you was never boring for sure. Katrien, a special thanks to you for travelling to the other side of the world with me and for discovering all nice bars and restaurants during conferences. I was not aware that other persons existed who scoured so many websites to find the best spots in town like I do. Friends, thank you for supporting me through this time. I am sure it must have been annoying listening to me while I was complaining about data collection and publication processes. I am thankful that you were always there for me during a nice evening with good food and drinks.

In the last part, I would like to thank some special persons in my life to whom I attribute my success of today.

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With much gratitude,

Laura Molinari

August 10, 2023

On my way to my happy place Italy to take some well-deserved rest

PUBLICATIONS AND PAPERS UNDER REVIEW

Chapter 2

Molinari, L., Haezendonck, E., & Hensmans, M. (2022). A Strategic Asset Management Framework for Improving Transport Infrastructure: Analysis for Belgian Land Transport Modes. *In Pinto, J.O.P., Kimpara, M.L.M., Reis, R.R., Seecharan, T., Upadhyaya, B.R., Amadi-Echendu, J. (eds) 15th WCEAM Proceedings. WCEAM 2021. Lecture Notes in Mechanical Engineering.* Springer, Cham. https://doi.org/10.1007/978-3-030-96794-9_4

Chapter 3

Molinari, L., Haezendonck, E., Dooms, M., Merckx, J., Verbeke, A., and Mabillard V., and Dooms, M. (2023). Social Economic Monitoring Instrument (SEMI): Making the right project investment decisions at the right moment.
Presented at the International Association of Maritime Economists Conference, September 5-8, 2023, Long Beach, California, United States.

Chapter 4

Molinari, L., Haezendonck, E., & Mabillard, V. (2023). Cost overruns of Belgian transport infrastructure projects: Analyzing variations over three land transport modes and two project phases. *Transport Policy, 134,* 167–179.

Chapter 5

Molinari, L., Haezendonck, E., Van Rompay, K., Mabillard V., and Dooms, M. (2023). Relational issues as causes of persisting cost overruns in public infrastructure projects. *Under review for publication in Public Money and Management.*

SUMMARY

Infrastructure is one of the most important cornerstones of our society. It enables international trade and thereby contributes to the overall economic growth of a country or region. Yet the contribution of infrastructure is not just limited to the economic aspect of society. At the social level, it brings value by providing education and care and facilitating the movement of people. Infrastructure, in its horizontal and vertical forms, has in fact become an integral part of the daily lives of both families and businesses.

To achieve the defined goals and satisfy the needs of users, the management of the infrastructure network must be carried out in a sound manner. Despite the importance of the network, there exists a mismatch between the demand for infrastructure and its supply. Expectations from users have changed and increased under influence of several macroeconomic factors. An example of this is a change in the demographic composition of a country, such as an ageing population. This will cause the pressure on healthcare to increase, creating more demand for healthcare infrastructure. A second example is climate change. Climate change requires resilience of our infrastructure network so that it can adapt to changing conditions and cope with extreme natural phenomena. For example, coastlines will need to be strengthened to withstand rising water levels.

Fulfilling demand is complicated by constraints on the supply side. Government budgets for public infrastructure are limited and the current infrastructure network is nearing the end of its service life. Investments in both new infrastructure and maintenance are falling short, while significant investments are required.

This dissertation investigates where potential efficiencies are located in the current management of public infrastructure, with the aim of better responding to the demands without needing to allocate additional resources. For this purpose, the initiation phase, the planning phase, the development phase and the realization phase were analyzed and a proposal for optimization was made for each phase.

With the aim of optimizing the overall management of infrastructure and setting clear goals, eight critical success factors required to create and implement a sound strategic infrastructure management plan (SIAM) were identified. Next, a decision tool called SEMI (for *social economic monitoring instrument*) was developed that can help public organizations in making

the right investment decisions at the right time. As a third option for increased efficiency, project costs were examined. Cost overruns in project realization must be kept below 5% so that the public administration can realize its full investment plan within the same budget. Finally, recommendations are made on how to reduce these cost overruns, namely by focusing on relational problems during the development phase, and not just technical problems. For instance, good collaboration and stakeholder management with the parties involved can reduce cost overruns. Applying these four recommendations allows public organizations, responsible for providing public infrastructure in a country, to manage their infrastructure portfolio in a more efficient way. This enables them to better meet the increasing and changing demands of society without having to allocate additional financial resources.

SAMENVATTING

Infrastructuur is één van de belangrijkste fundamenten van onze samenleving. Het maakt internationale handel mogelijk en draagt hiermee bij aan de algemene economische groei van een land of regio. Maar de bijdrage van infrastructuur beperkt zich niet enkel tot het economische aspect van de maatschappij. Op sociaal vlak brengt het waarde door onderwijs en zorgverlening aan te bieden en verplaatsingen van personen te faciliteren. Infrastructuur, in zijn horizontale en verticale vorm, is immers niet meer weg te denken in het dagelijkse leven van zowel families als bedrijven.

Om de gestelde doelen te bereiken en aan de noden van de gebruikers te kunnen voldoen, moet het beheer van het infrastructuurnetwerk op een degelijke manier worden uitgevoerd. Ondanks het belang van het netwerk, bestaat er een mismatch tussen de vraag naar infrastructuur en het aanbod ervan. De verwachtingen van de gebruikers zijn veranderd en gestegen. Verschillende macroeconomische factoren hebben hier een invloed op. Een verandering in de demografische samenstelling van een land, i.e. de huidige vergrijzing van de bevolking, is hier een voorbeeld van. Dit zal er voor zorgen dat de druk op de zorg zal verhogen, waardoor er meer vraag naar zorginfrastructuur zal zijn. Een tweede voorbeeld is de klimaatverandering. Klimaatverandering vereist veerkrachtigheid van ons infrastructuurnetwerk opdat het zich kan aanpassen aan de wijzigende omstandigheden en kan omgaan met extreme natuurfenomenen. Zo zullen kustlijnen moeten worden versterkt om de stijging van het waterpeil te kunnen tegenhouden.

Het voldoen aan de vraag worden bemoeilijkt door beperkingen aan de aanbodszijde. Budgetten van overheden voor publieke infrastructuur zijn gelimiteerd en het huidige infrastructuurnetwerk nadert het einde van de levensduur. Investeringen in zowel nieuwe infrastructuur als onderhoud schieten te kort, terwijl significante investeringen noodzakelijk zijn.

Dit proefschrift onderzoekt waar mogelijke efficiënties zich bevinden in het huidige beheer van publieke infrastructuur, met als doel beter aan de vraag te kunnen voldoen zonder extra middelen te moeten aanwenden. Hiervoor werd de initiatiefase, de planningsfase, de ontwikkelingsfase en de realisatie fase geanalyseerd en werd voor elke fase een voorstel tot optimalisatie gedaan.

Om het algemeen beheer van infrastructuur te optimaliseren en de doelen scherp te stellen, werden als acht key-succesfactoren geïdentificeerd die noodzakelijk zijn om goed strategisch beheersplan (SIAM) op te stellen en uit te voeren. Vervolgens werd een beslissingstool ontwikkeld genaamd SEMI (voor *social economic monitoring instrument*), die publieke organisaties kan helpen met het maken van de juiste investeringsbeslissingen op het juiste moment. Als derde mogelijkheid voor hogere efficiëntie werden de projectkosten onder de loep genomen. Kostenoverschrijdingen bij de realisatie van projecten moeten onder de 5% worden gehouden opdat de publieke administratie haar volledig investeringsplan kan realiseren binnen hetzelfde budget. Tenslotte worden aanbevelingen gedaan over hoe deze kostenoverschrijdingen te beperken, namelijk door te focussen op relationele problemen tijdens de ontwikkelingen, en niet enkel op technische problemen. Zo kan een goede samenwerking en goed stakeholdermanagement met de betrokken partijen de kostenoverschrijdingen beperken. Het toepassen van deze vier aanbevelingen zou publieke organisaties, verantwoordelijk voor het aanbieden van publieke infrastructuur in een land, toelaten om hun infrastructuurportfolio efficiënter te beheren. Dit laat hen toe beter te kunnen voldoen aan de stijgende en veranderende vraag van de samenleving, zonder extra financiële middelen te moeten aanwenden.

SYNTHÈSE

Les infrastructures ont une importance majeure pour nos sociétés. Elles permettent le développement du commerce international, contribuant ainsi à la croissance économique d'un pays ou d'une région. Mais la contribution des infrastructures ne se limite pas à l'aspect économique de la société. Au niveau social, elle apporte une valeur ajoutée en offrant des services d'éducation et de soins et en facilitant la circulation des personnes. En effet, les infrastructures, sous leur forme horizontale et verticale, font désormais partie intégrante de la vie quotidienne des familles et des entreprises.

Afin de réaliser les objectifs définis et de répondre aux besoins des utilisateurs, la gestion du réseau d'infrastructures doit être effectuée de manière rigoureuse. Malgré l'importance du réseau, il existe souvent un décalage entre la demande et l'offre d'infrastructures. Les demandes des utilisateurs ont changé et augmenté. Plusieurs facteurs macroéconomiques influencent cette situation. Un changement dans la composition démographique d'un pays, c'est-à-dire le vieillissement actuel de la population, en est un exemple. La tension sur les soins de santé augmentera, ce qui se traduira par une croissance de la demande d'infrastructures de soins de santé. Un deuxième exemple est le changement climatique. Ce dernier impose la résilience de notre réseau d'infrastructures, afin qu'il puisse s'adapter à des conditions changeantes et résister à des phénomènes naturels extrêmes. Par exemple, les digues situées près des côtes devront être renforcées pour pouvoir faire face à la montée des eaux.

Répondre à la demande est complexifié par des contraintes du côté de l'offre. Les budgets gouvernementaux consacrés aux infrastructures publiques sont généralement limités et le réseau d'infrastructures actuel approche sa fin de vie. Les investissements dans les nouvelles infrastructures et dans leur entretien sont encore insuffisants, tandis que des investissements importants sont plus que jamais nécessaires.

Cette thèse de doctorat se penche sur la notion d'efficacité dans la gestion actuelle des infrastructures publiques. Autrement dit, comment mieux répondre à la demande sans avoir à attribuer des moyens supplémentaires? Dans cette optique, la phase d'initiative, la phase de planification, la phase de développement et la phase de réalisation ont été analysées et une proposition d'optimisation a été faite pour chacune de ces phases.

Afin d'optimiser la gestion globale des infrastructures et de préciser les objectifs, huit facteurs clés de succès ont été identifiés comme nécessaires à la création et à la réalisation d'un plan de gestion stratégique adéquat. Un outil de décision a ensuite été développé, appelé SEMI (pour *social economic monitoring instrument*), qui peut aider les autorités publiques à prendre les bonnes décisions d'investissement au bon moment. Les coûts des projets ont été examinés en détail, ce qui constitue une troisième option pour améliorer l'efficacité. Les dépassements de coûts dans la réalisation des projets doivent être maintenus en dessous de 5 % pour que l'administration publique puisse réaliser l'intégralité de son plan d'investissement avec le même budget. Enfin, des recommandations sont formulées sur la manière de réduire ces dépassements de coûts, notamment en se concentrant sur les problèmes relationnels au cours des développements, et pas seulement sur les problèmes techniques. Ainsi, une bonne collaboration et une bonne gestion des parties concernées peuvent réduire les dépassements de coûts. L'application de ces quatre recommandations permettrait aux organisations publiques, responsables de la mise à disposition d'infrastructures publiques dans un pays, de gérer leur portefeuille d'infrastructures de manière plus efficace. Celles-ci pourraient ainsi mieux répondre aux demandes croissantes et changeantes de la société sans avoir à allouer de ressources financières supplémentaires.

ACRONYMS

IAM	Infrastructure Asset Management
SIAM	Strategic Infrastructure Asset Management
PA	Public Administration
NPM	New Public Management
NPG	New Public Governance
MOW	Mobiliteit en Openbare Werken
SPW	Service Public de Wallonie Mobilité et Infrastructures
GPS	Gestion des Projets routiers
PMS	Pavement Management System
SEMI	Social Economic Monitoring Instrument
CBA	Cost-Benefit Analysis
SCBA	Social Cost-Benefit Analysis
NPV	Net Present Value
ROT	Real Options Thinking
ADEB-VBA	L'association des Entrepreneurs Belges de Grands Travaux - Vereniging der Belgische Aannemers van Grote Bouwwerken
PPP	Public-Private-Partnership
DB	Design & Build
DBF	Design, Build & Finance
DBM	Design, Build & Maintenance
DBFM	Design, Build, Finance & Maintenance
DBFMO	Design, Build, Finance, Maintenance & Operate

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CHAPTER 1

GENERAL INTRODUCTION

Laura Molinari

CHAPTER 1

GENERAL INTRODUCTION

Roads allow you to travel from home to your family;

trains get you from your house to work;

ships transport goods from one place to another;

people are healed in hospitals;

children are taught in schools;

and justice is served in court houses.

1. The concept of infrastructure

Our society and economy are backboned by infrastructure. Infrastructure is a broad concept and although in general everyone knows what is understood by it, it has been proven that creating a general definition for the concept is challenging (see amongst others Buhr, 2003; Baldwin & Dixon, 2008; Marshall, 2012; Uddin, Hudson & Haas, 2013). Infrastructure finds its roots in the Latin language, stemming from *"infra"*, translated as *"below"*. As a consequence, *"infra-structure"* can be defined as *"foundation"* (Buhr, 2003). The Organisation for Economic Cooperation and Development (OECD) (2007, p. 13) defines infrastructure as *"means for ensuring the delivery of goods and services that promote prosperity and growth and contribute to quality of life, including the social well-being, health and safety of citizens, and the quality of their environments"*. Instead of attempting to define infrastructure in a general way, Fourie (2006) states it is also possible to describe the term based on the elements included in the definition, being assets for transportation and service delivery in the case of the OECD (2007). Because of its importance to the general public and its potential for nation-wide value creation, this dissertation focuses solely on public infrastructure or infrastructure with a public goal.

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*We define **public infrastructure** as "…all these combined facilities that provide essential public services of energy, transportation, roads, airports, water supply, solid waste disposal, parklands, sports and athletic fields, recreational facilities, and housing. Infrastructure also provides the physical systems used to provide other services to the public through economic and social actions. These infrastructure facilities and services are provided by both public* *agencies and private enterprises.", like Uddin, Hudson and Haas (2013, p. 10) did (see also Chapter 2).*

This definition of public infrastructure can be linked with infrastructure as defined by the OECD (2007), mentioning transportation and other services as well. The differentiation between infrastructure in general and public infrastructure can be made in the fact that public infrastructure is supplied, i.e. tendered, (co-)financed and provided to citizens, by the public authorities (and in some cases by (semi-)privatized companies, for example energy supply in Belgium). We can further categorize public infrastructure into economic and social infrastructure. Economic infrastructure, as defined by the Council of Europe Development Bank (CEB) (2017, p. 8), "*comprises of fixed assets that primarily serve as common inputs used to produce goods and services by industry. … This category includes transportation related services, utilities and telecommunications*". Social infrastructure on the other hand is "*categorized as public investments that serve public necessities such as education, health and community services*" (CEB, 2017, p. 8). Others describe these categories as respectively hard and soft infrastructure (Fourie, 2006). The difference between economic and social infrastructure lies in its nature. Whereas economic infrastructure consists of physical assets, connecting point A to point B and facilitating the delivery of goods and persons, social infrastructure consists of public buildings facilitating the delivery of services.

In this dissertation, the following types of public infrastructure are examined: road infrastructure, rail infrastructure and waterways infrastructure (including surrounding infrastructure such as locks, quays, etc.), as well as education, recreation and social housing, public buildings and hospitals and residential care facilities. The first group called horizontal infrastructure, include types of transport infrastructure. The second group called vertical infrastructure, include buildings, which are hosting services provided to the public. Table 1-1 gives an overview of the infrastructure types discussed in this dissertation. In Chapter 2 and Chapter 4 only transport infrastructure (called horizontal infrastructure in Table 1-1) is covered, whereas in all other chapters horizontal as well as vertical infrastructure are discussed.

Table 1-1 Discussed categories of infrastructure

Public infrastructure	
Horizontal infrastructure	Vertical infrastructure
• Road infrastructure • Rail infrastructure • Water infrastructure (maritime and inland waterways)	• Education, recreation and social housing (e.g. schools, swimming pools, sport infrastructure, museums, student housing,...) • Public buildings (e.g. prisons, courthouses and administrative buildings) • Hospitals and residential care facilities

2. The importance of infrastructure

Infrastructure is considered to be essential to the economic and social development of a country (Schraven et al., 2011; Kasper, 2015; Meersman & Nazemzadeh, 2017). For example, investments in transport infrastructure make transporting goods within and outside a country less expensive. As a consequence, trade levels increase which has a positive impact on economic growth (European External Action Service (EEAS), 2021; Redding, 2022). Another example, in the case of Belgium, is that investments in the transport infrastructure network not only create additional employment, but also make Belgium more attractive as a country for foreign investors (Meersman & Nazemzadeh, 2017). In general, the European Investment Bank (2019) confirms the positive correlation between the quality of infrastructure and a growing GDP. More on the social side, improving road infrastructure leading to an easier and faster access of other cities and places, increases the ability for citizens to find work further away from home. In addition, there is more time for leisure activities, resulting in a greater quality of life (CEB, 2017). Besides the positive impact of horizontal infrastructure, vertical infrastructure also contributes to the economic and social state of a country. Access to schools and education improves the skills of citizens, which is also beneficial for companies, while hospitals contribute to better health conditions (CEB, 2017).

The necessity for a sound infrastructure network was also acknowledged by Michael Porter (1990), who includes infrastructure as a factor condition in his diamond of national advantages. According to him, factor conditions (e.g. infrastructure) are required to sustain the competitiveness of a country vis-à-vis others. A better infrastructure network facilitates, for example, access to markets for companies (for sourcing inputs and transporting products). An easier access reduces production and shipping costs and thereby creates a competitive advantage over other companies. Governments should provide these infrastructure networks in order to support the companies active in their country and to be more attractive to new investments (Porter, 2008). Although many European countries already possess an extensive infrastructure network, maintaining and (at the appropriate time) upgrading that network is important to keep that competitive advantage. Infrastructure assets are ageing and no longer keep up with users' demands (see section 4 Demand side of infrastructure for more detail on the changing demands). Challenges such as the twin transitions (green and digital transition) are putting additional pressure on the management of our infrastructure network. As a result, to respond to the demand and maintain the region's competitiveness, basic maintenance alone is not sufficient. Considerable investments will be required to adapt and upgrade the network to comply with current and future demands (Muench et al., 2022). An example in the case of transport infrastructure is the increasing need for charging infrastructure for electric vehicles.

In the ongoing time of crises (economic, health, social, etc.), the ability to rely on a solid infrastructure system is even more important. Depending on the nature of the crisis, the need for a certain type of infrastructure will rise. For instance, the Covid-19 crisis called for an increased capacity of our healthcare systems and network. In this case, countries relied heavily on their existing network of hospitals and care facilities. A clear advantage was found when sufficient infrastructure was already available (Winkelmann et al., 2022).

Notwithstanding the importance of a sound infrastructure network, infrastructure alone cannot deliver value. It only facilitates value creation. For example, value created for a customer by receiving its package on time is not delivered by the train system itself, but having a good train system can be seen as an intermediate output to deliver the package and to eventually create value (Hartmann & Ling, 2016).

3. Infrastructure Asset Management

Based on the above arguments and examples, infrastructure seems to be a key cornerstone of a nation's economic system and welfare creation. Moreover, managing an infrastructure network is a continuous process because changes in competitiveness, crises and transitions are inherent to economic dynamics. In Chapter 2, the definition of Infrastructure Asset Management (IAM) is extensively discussed. We conclude here that IAM should comprise the management of all activities in the lifecycle of infrastructure, ranging from assessing the needs to the end-of-life phase. But it is also recognized that for an effective IAM, the focus should lie on ***Strategic Infrastructure Asset Management (SIAM)***. Other than IAM, SIAM does not only focus on the technical side, for example by introducing new ways to measure the state of bridges, but it also considers the strategic aspect. SIAM differs from IAM in the degree of the attention that is given to the alignment of the strategy (or policy) with the general organizational (or societal) objectives.

4. Demand side of infrastructure

Managing a large complex network of infrastructure comes with challenges, especially considering the changing and increasing demands of users (Schraven et al., 2011; Van der Velde et al., 2013). For example, the rising trade levels request a larger capacity of transport infrastructure (UNCTAD, 2022). In Chapter 2 we refer to expectations on quality, reliability and service. Multiple macro-economic factors are influencing these three potential objectives of SIAM. Some of them are discussed as examples in the following section.

Global trade levels are rising. Following our arguments set out more in detail in Chapter 3, global trade will continue to increase in the future (UNCTAD, 2022), even though more and more voices raise the importance of degrowth and changing trade patterns and volumes because of the circular economy transition (Raworth, 2017; Yamaguchi, 2018). As a result, increased availability and better quality of infrastructure is needed to transport larger amounts of and more differentiated goods, and to decrease transportation costs while reducing the environmental impact thereof. The need for infrastructure suited to handle the increasing demand for capacity was made clear by the obstruction of the Suez Canal by the containership Ever Given on March 23, 2021. As a consequence, trade worth USD 9 billion was blocked every day the obstruction lasted, resulting in significant time overruns for deliveries (Notteboom et al., 2023).

Besides that, infrastructure supports a country's competitiveness and productivity as Porter (2008). The degree of a country's competitiveness is a significant factor for the private sector when deciding whether or not to invest in a specific region. As a consequence, providing a reliable infrastructure network to the business environment is crucial given that it contributes to that competitiveness score. The European Union's competitiveness score has declined in the last two decades (European Investment Bank (EIB), 2016). According to the European Investment Bank (EIB) (2016), this was due to a lag of productivity growth in the EU compared to the US and other regions and a misallocation of investments. The EIB (2016) argues that additional attention to infrastructure is required to restore that decrease in competitiveness, as they find the current infrastructure network unsuitable. In line with Porter's theory (2008), the EIB also identifies poor infrastructure as a barrier for companies to increase investments in the region (EIB, 2021).

Digital advances are also posing a challenge for infrastructure. Various new technologies are in stage of development and ready to be implemented in our daily life. However, our infrastructure network needs to be upgraded to make it suitable for these new techniques, which requires additional investments (EIB, 2019). Some examples of new technologies include self-regulating streetlights and autonomous metro's in the field of transport and sensors for patient data collection in healthcare (EIB, 2019).

Additionally, the demographic age distribution is changing. Figures indicate that the older population (over 65 years old) will increase with 50% by 2030 compared with 2005. This change will increase the demand for hospitals and residential care facilities (CEB, 2017; European Parliamentary Research Service (EPRS), 2018). In addition, the recent health crisis of Covid-19 and globalization causing an increased possibility for other pandemics, already did put extra pressure on our healthcare infrastructure.

Next to health, the increased provision of high-level education influences the demand for infrastructure. More students going to school requires an upgrade and expansion of the current school infrastructure. Providing good education to all citizens creates opportunities to reduce social inequality and improves the quality of life. Continuing on closing the social inequality gap, social housing could also benefit from an infrastructure upgrade (CEB, 2017). These challenges can also be linked with some of the defined UN Sustainable Development Goals (SDGs), such as good education, reduced inequalities and good health and well-being (United Nations Development Programme, 2023).

Climate change related challenges are a final example of macroeconomic influences on the changing demand of infrastructure. These challenges are now at the top of the agenda of policymakers and companies and these will require changes to our infrastructure system. The transition to more sustainable mobility options will require an adaptation of the existing network and the construction of new parts (for example vehicle charging infrastructure (EIB, 2021)). Besides mobility, the existing state of our public buildings is also extensively debated. Next to periodic maintenance, we will have to put additional effort into upgrading existing public buildings in order to make them more energy efficient (CEB, 2017). In addition, we need to improve the resilience of our network to climate change. Extra investments will be required to make our infrastructure assets as *'climate-impact'*-proof as possible. While as stated by the OECD (2018), creating a network of fully *'climate-impact'*-proof infrastructure will not be achievable, we should be able to reduce a part of the risks if sufficient investments are made. For example, investments could be made in the construction of coastal defense structures to protect countries from rising sea levels as much as possible but the risk of floods cannot be fully eliminated (OECD, 2018).

5. Supply side of infrastructure

Reviewing the challenges related to the demand side of public infrastructure, raises the question on the adequacy of efforts on the supply side to respond to these high demands.

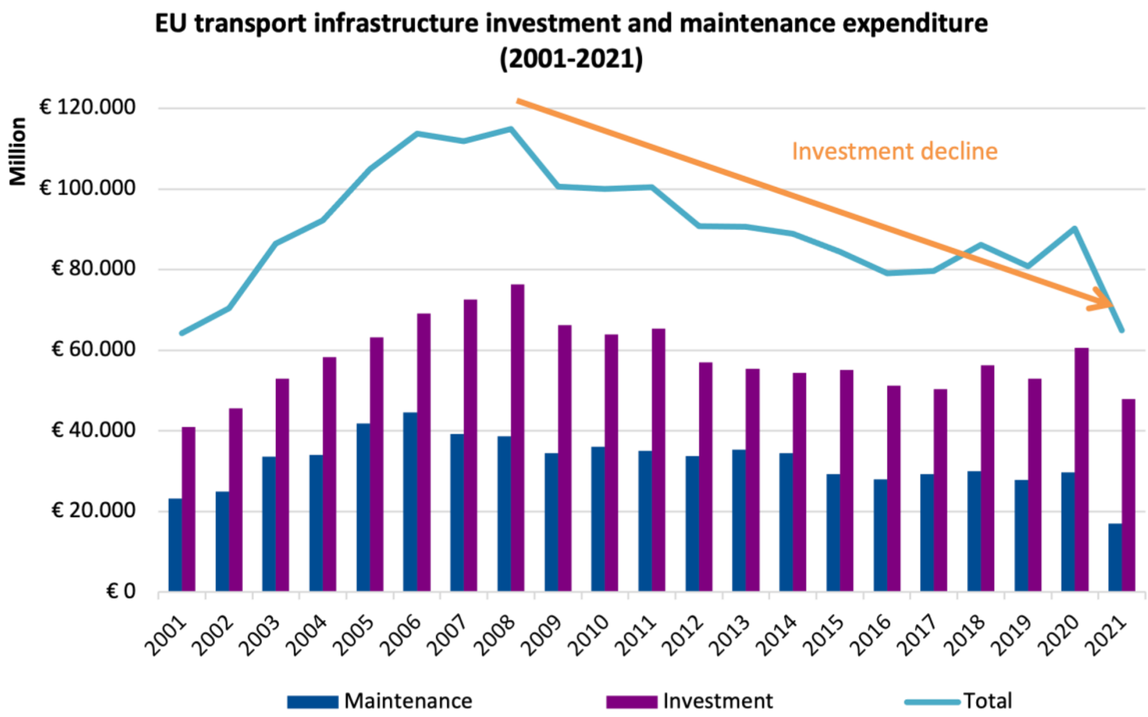
Public infrastructure is essential to a country and is therefore an important part of public policies. Public organizations exist to implement these policies and ensure that services are delivered. To support these, resources are assigned. The concept of public management (PM) can therefore be explained as the way public authorities are working and organized to manage these resources and to achieve the state's goal (Lynn, 2006).

This subsection on the supply side of infrastructure focuses on two parts: (1) the resources to implement policies and (2) how these resources are managed.

Public government budgets, used for funding public infrastructure, are restricted (Van der Velde et al., 2013). Combined with the previous and ongoing crises in the fields of health, immigration, energy and economy, the already limited resources available are even more constrained. In addition, existing public infrastructure, in Europe in particular because of many post-WWII investments, is ageing and reaching the end of its lifespan (EIB, 2016). As discussed in Chapter 2, many infrastructure assets date back from the post-World War II period, now almost 80 years ago. Considering an average lifespan of 30 years for transportation assets, some expiration dates have passed a long time ago (World Economic Forum, 2014). Considerable investments are required to compensate the backlog of investments in new infrastructure and maintenance, which have been neglected for years. Reasons for this decline in investments include restricted government budgets in general and a shift in spending to other domains than infrastructure (EIB, 2019).

Figure 1-1 shows an overview of the EU expenditure on new transport infrastructure investments and maintenance over the last two decades (2001-2021). As can be seen from the graph, total investment levels in the period 2009-2017 were low. The European Investment Bank (2019) mentions a decline in investments of 15% between 2009 and 2017. Additionally, they also argue that a shift has taken place from upgrading assets and new construction towards more basic maintenance. Data indicates a total investment of 1.6% of the GDP in 2017 for countries of the European Union (EU), while according to a study from 2016, annual investments of 4.7% of the GDP would be required, identifying a significant investment gap (EIB, 2016; 2019; Centre for Economic Policy Research (CEPR), 2018).

Figure 1-1 EU transport infrastructure investment and maintenance expenditure (2001-2021)



Source: OECD (2023a; 2023b)[1][2]

Recently, more positive news was announced as the amount of total infrastructure investments in the EU rose again as of 2018 (EIB, 2022), however this was only the case for

[1] Due to data restrictions, no information is included for the following EU countries: Cyprus, Germany, Greece, Hungary and Spain.

[2] Transport infrastructure includes road, rail, inland waterways and sea

Southern, Central and Eastern Europe. For Northern and Western Europe, total investment levels remained constant (EIB, 2022). During the first year of the Covid-19 crisis (2020-2021), investment in infrastructure as percentage of GDP increased for the EU. Nonetheless, this was caused by a larger decrease of the GDP compared to the decrease of investments (EIB, 2022). Some argue that investment amounts in new infrastructure remaining stable is a good thing, as they state a saturation level of infrastructure is reached and that all facilities are now available (CEPR, 2018; EPRS, 2018). Notwithstanding the above, the renewal of ageing infrastructure and its upgrades to meet current demands for transition, climate change resistance, etc. (see supra) cannot be forgotten, which also requires considerable investments (CEPR, 2018; EPRS, 2018).

As a response to the impact of the Covid-19 crisis, the European Commission launched recently NextGenerationEU, a plan consisting of multibillion euro investments to help the recovery of the EU in addition to the EU's general budget. In this plan, about 12 billion euros is reserved until 2027 for investments in transport infrastructure, which will be realized through the Connecting Europe Facility plan (European Commission, 2021). But, although the unprecedented large budget reserved for infrastructure, a one-time large investment will not be sufficient to fill the investment gap. What we need is a structural solution to infrastructure investments, in order to fulfil its users' demands.

Besides the budget spent on infrastructure, the way these resources are managed is also impacting the quality of the infrastructure supplied. Perspectives, below also called paradigms, on PM changed significantly over time. Three paradigms are worthwhile mentioning: public administration (PA), new public management (NPM) and new public governance (NPG)[3] (Hood, 1991; Osborne, 2010; Pyper, 2015; Lynn, 2016). The emergence of one paradigm however does not equate to the disappearance of another (Christensen, 2013; Pyper, 2015). A paradigm rather amplifies a specific part of the way of managing public organizations, without getting rid of all elements that were central in other paradigms. For example, while NPM is usually characterized by more flexibility and autonomy of certain government units (agencies), they are still bound to rules that are specific to public bodies.

[3] We picked these three perspectives as they are central in most contributions on the subject. But we are aware that NPG is only one way to conceptualize public governance, and that other post-NPM trends exist (e.g., whole-of-government).

Public administration is by academics seen as the starting point of PM evolution. The main focus of PA was a strong hierarchical and rules-based organization. Resulting in structuring the activities of implementing public policy and delivering public services in a vertical and bureaucratic way (Weber, 1947). The PA perspective on PM was also known to have a more closed approach, i.e., having limited influence from outside government organizations (Osborne, 2010; Pyper, 2015). As a consequence of some impactful trends such as internationalization, privatization, the intermingling of the public and private sector, automation of processes and a decline of government growth (in terms of personnel and resources), there was an increased need for a flexible public structure with more attention to the changing outside dynamics. Processes were improved and practices from the private business sector were implemented. Some examples of this were improved resource management, increased output control, implementation of performance measures and the creation of larger departments to achieve economies of scale. Third-party agencies were founded to facilitate the implementation of these measures. This described perspective of optimizing intraorganizational processes with the goal of managing resources more efficiently (i.e. mostly financial resources), was called new public management (NPM) and emerged in the last decades of the 20th century (Hood, 1991; Pyper, 2015).

In subsequent years, the significance of networks and interaction with other parties gained importance. This resulted in the emergence of critiques on the NPM perspective and the current structure encountered its limits. As a consequence of the disaggregation in NPM, problems arose with coordination and accountability distribution between departments. More collaboration and better arrangements with foreign organizations (e.g., World Bank), private enterprises and other non-governmental parties (i.e., citizens) were required (Pyper, 2015).

In reaction to this, new public governance (NPG) brought another perspective to PM. A perspective in which service users are seen as customers with demands (Pyper, 2015). Osborne (2010) described NPG as a more plural and pluralistic approach to PM, meaning that multiple organizations are collaborating for public service delivery, with participation from other non-governmental actors. Compared to NPM, NPG is more about creating value for society through policy implementation, instead of optimizing the use of available resources and executing as much as possible with (mostly financial) constraints. The focus here lies on interorganizational processes (between organizations), rather than intraorganizational processes (within one organization) which is the case with NPM (Osborne, 2010).

Important to stress again is that perspectives are co-existing with each other, but that the main focus of PM changes per perspective (Christensen, 2013; Pyper, 2015). Rules regarding the political structure will always exist (referring to PA), practices implemented to improve resource efficiency will remain relevant (referring to NPM), but with NPG, wishes and opinions from outside stakeholders are essential, and so is collaboration through more active networks and partnerships.

The insights given by the literature indicate that not only the assigned resources matter to infrastructure management, but also how this budget is managed. It is clear that a sound perspective on PM is required in order to assure good resource management and, together with an appropriate budget, the realization of an infrastructure policy that corresponds to the needs of society. Researching the PM processes applied for infrastructure will gain deeper insights in the characteristics this PM perspective should have and how this influences the formation of the infrastructure policy.

6. General problem statement and research questions

Considering the discussed challenges regarding the demands for our infrastructure system and the current supply in terms of the physical state, investments and management practices, a mismatch between both can be noticed. While demands are only increasing, investments are remaining stable or even decreasing and the state of the network is deteriorating. At the same time, the importance of infrastructure to a nation’s economy and society is clear, as infrastructure is key to creating or supporting welfare. Proper infrastructure management asks for higher investments or at least more efficient spending to realize more infrastructure or upgrades with the same budget. The definition of Strategic Infrastructure Asset Management (SIAM) refers to the optimization of resources allocation over the entire infrastructure life cycle (Too, Betts & Kumar, 2006). This dissertation responds to the need for better efficient spending of the limited resources available, by researching different parts of the infrastructure life cycle more in depth. Figure 1-2 shows the life cycle of infrastructure, starting with the project initiation phase and continuing until the end-of-life phase. Besides the maintenance and end-of-life phase, all phases of the life cycle are covered by one or more chapters in this dissertation.

The general problem statement translates in the following main research question considered: ***How can a country improve the efficiency of its infrastructure asset management over the whole life cycle, considering the challenges on the demand and supply side?*** Financial resources are limited and increasing the infrastructure budget is not always straightforward. During the last decade, it is at least in a very strong budget competition with other investment domains such as health, defense, education and energy provision. Therefore, in this dissertation, we look for possible options to improve the efficiency of infrastructure management, without compromising on the rising demands and taking into account the constraints on the supply side. For each of the phases of the life cycle, a research question on the potential efficiencies is identified (see Figure 1-3 for a summary). Each research sub-question also relates to one of the chapters in the dissertation. In the following paragraph, we discuss the different phases of the life cycle, together with their corresponding research sub-questions.

Figure 1-2 Structure of the dissertation linked to the infrastructure life cycle

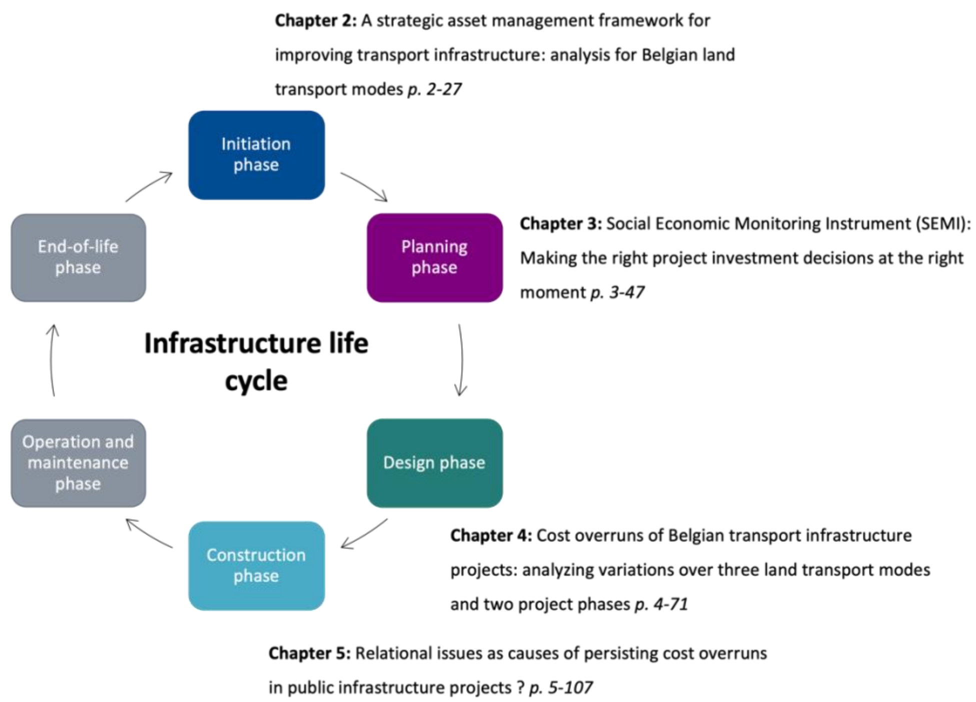
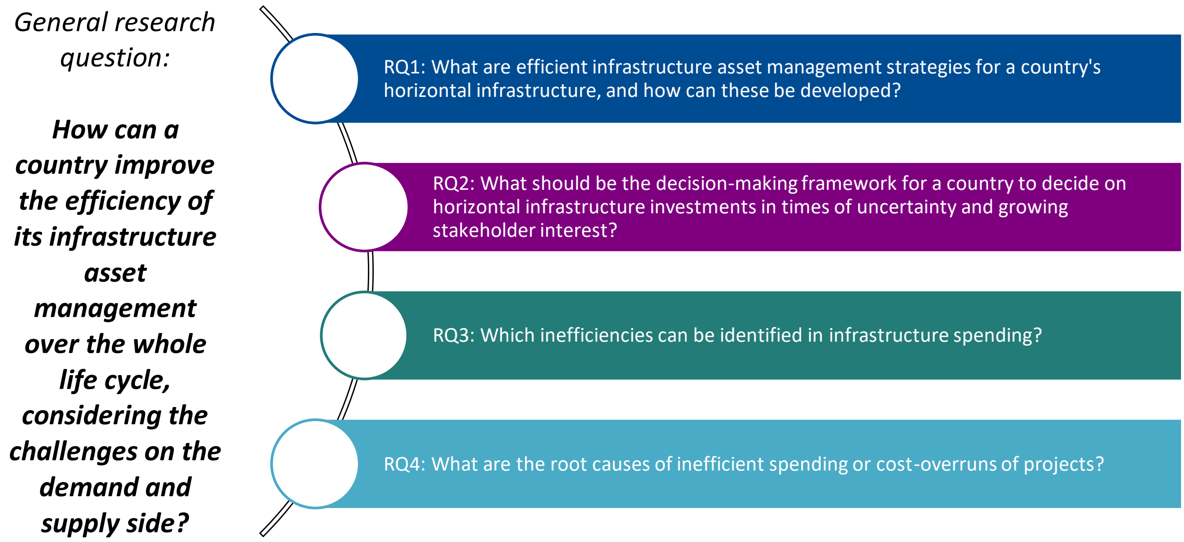


Figure 1-3 Research questions



Public infrastructure development is to be seen as a policy process. A general policy process consists of four stages: (1) agenda setting, (2) policy formulation and decision making, (3) implementation and (4) evaluation (Jann & Wegrich, 2007, p. 43-62).

First in the agenda setting-phase, social problems are identified and recognized and put on the agenda by the government. The problem identification and recognition can be done by different actors. In some cases by the government itself, but also by other state-actors (such as governments from other political levels) and non-state actors (for example companies, sector associations,..). Depending on where the responsibility for the specific problem lies, other government levels are included in the other state-actors. For instance, in the case of public infrastructure in Belgium, responsibility lies with the regional governments and federal and local governments might influence the agenda as other state-actors. When an issue makes it to the agenda, it means that the government acknowledges the need to take action. Specificaly for public infrastructure, we are now in **the initiation phase**. A societal problem is identified (either only by the government or with influence of other actors) and the idea to solve that problem is initiated. For example, a mobility issue to cross a river at an important place is pointed out and the government decided to put this problem on the agenda (Jann & Wegrich, 2007, p. 43-62).

In the second phase, specific policy actions are formulated and decisions are made. Issues that made it to the agenda are now translated into government actions. For public infrastructure development this is **the planning phase,** in which infrastructure works are identified as a solution to the problem and possible interventions are proposed. Following the same example of the river crossing, several options such as the construction of a bridge or a tunnel are proposed and a final decision on the preferred option is made. The process of going from a set of options to the final choice is complex and influenced by different stakeholders and their interests. For instance, group A may have its reasons for favoring the bridge (ex. maintaining the water eco-system), while group B may have its arguments for preferring a tunnel (ex. noise reduction). As a consequence, the beliefs of the government or the minister can influence the final decision by prioritizing the wishes of one group above the others (e.g. when the government is more oriented to environmental sustainability) (Jann & Wegrich, 2007, p. 43-62).

After deciding on the preferred option, implementation can start. Public agencies are now requested to realize the solution. In the case of public infrastructure development, we can distinguish four different phases during implementation: the design, construction, operation and maintenance and end-of-life phase. In **the design phase**, the chosen option is developed more in-depth. The tendering agency decides on the initial budget, timing, technical specifications and drawings, type of procurement contract, etc. Subsequently, the infrastructure asset is constructed and delivered during **the construction phase**. When users are allowed to start using the asset, **the operation and maintenance phase** starts. During this phase, the asset needs to be maintained in order for it to be able to continuously fulfil its function at the initial goals put forward. After a specific period of time, in **the end-of-life phase**, the public agency can decide to decommission the asset (Jann & Wegrich, 2007, p. 43-62).

The final stage of the policy process is initiated simultaneously with the last phases of the implementation stage (operation and maintenance and end-of-life phase). Governments now evaluate the decisions made and actions realized against the initial identified problem and decide on further actions (Jann & Wegrich, 2007, p. 43-62).

In this dissertation, phase 1 until 4 of the infrastructure life cycle (initiation, planning, design and construction) are covered by the different chapters (see also Table 1-2 for more information on the chapters and main contributions). **Chapter 2** focuses on the development of a strategic infrastructure asset management plan for a country or an organization, considering the goals and requests from users. In order to efficiently manage infrastructure assets, the existence of a sound long-term strategy is required. Therefore, **Chapter 2** attempts to answer the following research sub-question: ***What are efficient infrastructure asset management strategies for a country's horizontal infrastructure and how can these be developed?*** This question is answered by defining eight key success factors for efficient strategic infrastructure asset management. By applying such an infrastructure plan, based on the eight key success factors, the focus is laid on the right issues to solve and a holistic and long-term view is applied. **Chapter 3** helps with applying that holistic and long-term view by searching for potential efficiencies in the way projects are evaluated. The following research sub-question is asked: ***What should be the decision-making framework for a country to decide on horizontal infrastructure investments in times of uncertainty and growing stakeholder interest?*** In **Chapter 3** an improved project evaluation tool called Social Economic Monitoring Instrument (SEMI) is developed. This tool can support responsible authorities in the planning phase to evaluate several options for solving an infrastructural need, often comprising more than a single infrastructure project. Besides guidance in selecting the optimal scenario (or project configuration), while considering the changing demands from users and the thereby following uncertainty, SEMI also helps with defining the optimal timing for the individual project investments within a configuration. **Chapter 4 and Chapter 5** consider both the design and construction phase. Together, this realization phase - from the first initial design of the project until the asset being ready for use - is analyzed in more detail in these chapters. The focus here is put on proper cost management and efficient project execution, and the following research sub-questions are researched: ***Which inefficiencies can be defined in infrastructure spending?*** and ***What are the root causes of inefficient spending through increasing costs of projects?*** In **Chapter 4**, initial costs at the design phase were compared to final costs at the end of the construction phase for different projects or so-called *cost overruns* were calculated and variations over different determinants such as project type, project size, project phase, etc. were researched. Combined with the causes of cost overruns researched in **Chapter 5**, inefficiencies in project realization were identified. At the end of each chapter, recommendations are given that could be applied to optimize each phase of the infrastructure life cycle. To finish the dissertation, Chapter 6 draws conclusions from the entire research and provides recommendations for the public as well as the private sector engaged in infrastructure. At the end, possible options for further research are discussed.

In this dissertation, all research questions were applied to Belgium, as this country is home to the researcher and the research chair. Section 3.1 in Chapter 2 argues some key reasons for a Belgian case. In short, besides a decrease in the quality of infrastructure, Belgian investments are low compared to neighboring countries. From an institutional and governance viewpoint, different political challenges exist. The short government terms are at odds with the ability to develop a long-term plan for infrastructure. Additionally, responsibilities for different horizontal infrastructure types lie within numerous governmental agencies, while infrastructure assets are clearly a network and cannot be seen as stand-alone structures. Silo-mentality and limited communication between government agencies could therefore be a major barrier for infrastructure development. Although the research was conducted in the Belgian context, all conclusions and recommendations can be applied worldwide in small open economies with a similar governmental organization for infrastructure decisions and spending.

Table 1-2 summarizes the different research chapters, type of research and the main contribution to academia and practice.

Table 1-2 Structure of the dissertation by the different chapters

Dissertation chapter	Research design	Main contribution
Chapter 2: **A strategic asset management framework for improving transport infrastructure: analysis for Belgian land transport modes**	*Experimental*	*Eight key-success factors proposed for Strategic Infrastructure Asset Management and applied to transport infrastructure in Belgium.*
Chapter 3: **Social Economic Monitoring Instrument (SEMI): Making the right project investment decisions at the right moment**	*Conceptual and experimental*	*Proposal of a new tool to evaluate infrastructure investments, with more attention to uncertainty, stakeholder involvement and interdependence of the network.*
Chapter 4: **Cost overruns of Belgian transport infrastructure projects: analyzing variations over three land transport modes and two project phases**	*Experimental*	*Analysis of cost overruns for 36 Belgian transport infrastructure projects and results obtained on variations over different determinants.*
Chapter 5: **Relational issues as causes of persisting cost overruns in public infrastructure projects ?**	*Review and experimental*	*Identified ten most frequently occurred causes of cost overruns for the Belgian and global context.*

This research was conducted in the context of the Chair on Infrastructure Asset Management and Life-Cycle Planning, established by the Vrije Universiteit Brussel and Université Libre de Bruxelles, in collaboration with ORI vzw/asbl and sponsored by Antea Group, Arcadis Belgium, Sweco Belgium and Tractebel. Interactions between the research team and the Chair partners contributed significantly to the feedback on research questions and data, practical value of the findings of this research, and were therefore of great added value. The Chair partners acted as an initial focus group during which discussions were held on interesting research topics and next steps, but also on data collections, analyses and reflection on the results. Their contribution was not only general by putting the research into context from a practical perspective and generating research ideas relevant to practice, but also by direct involvement and providing support and data access throughout the analyses. More specific, the Chair partners provided input in the conceptual phase of Chapter 2, supported the search for data and respondents with their network in Chapter 2, Chapter 4 and Chapter 5, and contributed directly as respondents to Chapter 4 and Chapter 5.

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CHAPTER 2

A STRATEGIC ASSET MANAGEMENT FRAMEWORK FOR IMPROVING TRANSPORT INFRASTRUCTURE: ANALYSIS FOR BELGIAN LAND TRANSPORT MODES

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CHAPTER 2

A STRATEGIC ASSET MANAGEMENT FRAMEWORK FOR IMPROVING TRANSPORT INFRASTRUCTURE: ANALYSIS FOR BELGIAN LAND TRANSPORT MODES

Laura Molinari, Elvira Haezendonck and Manuel Hensmans

Abstract In today's society, infrastructure asset management is a priority for multiple policymakers as it is key to guarantee high-quality transport infrastructure. While the relative quality of transport infrastructure in a number of Western European countries is deteriorating, the volumes of freight and passengers, as well as the expected service levels of all modes of transport for citizens and businesses, are increasing sharply. In response, infrastructure asset managers have developed and integrated technical and management system innovations. While short-term cost and damage control is taken better care of, a long-term asset vision and strategic principles supporting a strong future transport infrastructure network are still largely missing in many EU countries. In this paper, we analyze the strategic infrastructure asset management (SIAM) for Belgian road transport, rail and inland waterways through a cross-case analysis. Our literature study identifies strategic asset management principles, potential barriers and solutions for transport infrastructure assets in general, as well as for the different transport modes in particular. Through in-depth interviews with Belgian top administrators, the principles and SIAM frameworks for different types of mainland infrastructure are analyzed. We find, based on the studied Belgian cases, that 'one SIAM-model does not fit all', and that a variety of models, adapted to transport modes and the regional context, could better suit the strategic goals of different policies.

1. Introduction

Infrastructure, in Europe in particular, is ageing and is reaching the end of its lifespan (OECD, 2012; Parlikad & Jafari, 2016; van Breugel, 2017). Many of these assets date from the 1950s until the 1970s as a result of the post-World War II Marshall plan and are desperately in need of new investments (World Economic Forum, 2014; Parlikad & Jafari, 2016). Contrary to the aforementioned need, expenditure in the EU has remained stable in 2016, the year that it reached its lowest point in 20 years. This while expectations from users and stakeholders regarding quality, reliability, and service are continuously increasing (Shah et al., 2017; Wijnia & Herder, 2017; Directorate-General for Mobility and Transport of the European Commission, 2019). Expectations of infrastructure remain unanswered as long as investments are not forthcoming (Parlikad & Jafari, 2016). This is also the case beyond the EU, on a global scale. A report from McKinsey Global Institute indicates a yearly investment need in transport, utility and telecom infrastructure of $3.7 trillion until 2035 to be able to support the global economy (Woetzel et al., 2017). The Global Infrastructure Outlook's report (Global Infrastructure Hub; 2017) extends the investment time range until 2040 instead of 2035 with a necessary investment of $4.6 trillion by 2040. Global spending on infrastructure by 2040 is estimated at $3.8 trillion, which leads to a gap of $800 billion (Global Infrastructure Hub; 2017). This gap is estimated at $93.4 billion by 2040 for European transport infrastructure assets, including ports, airports, roads and railway infrastructure (Global Infrastructure Hub; 2017). Even though many EU-countries have recently taken steps to increase the infrastructure investments, cf. recent Eurostat figures, the huge gap between the current assets state and the service level demands in a competitive Europe will continue to exist or even sharpen again, if in the long run the assets are not managed strategically. Porter (1990) defines infrastructure, in his "Diamond of national advantage" – a seminal framework to understand competitiveness of business clusters and regions, as one of the most salient factor conditions when determining and supporting regional competitiveness. Making sure infrastructure does not become a competitive disadvantage in times of crises or serious budgetary restrictions, requires tight control as well as a long-term plan and vision. Both are at the core of asset management objectives. Sound asset management matches user's demands with infrastructure's supplies by setting a strategic direction and supports decision-makers with taking the right decisions at the right time when executing this strategy. Principles and possible frameworks for good asset management are discussed in the next section, and when looking at the evolution of insights on this matter, the focus of management of long-life assets evolves from a technical approach to a strategic matter (Too et al., 2006; Too & Too, 2010; Arif & Bayraktar, 2018). Yet, while (case-based) research contributions on the operational approach continue to grow, insights on what a strategic approach to transport infrastructure asset management should entail, are largely absent (Laue et al., 2014; El-Akruti et al., 2013). This paper defines eight key factors for a sound SIAM for managing land transportation assets by public organizations and analyzes for three modes and three regions in Belgium how their SIAM can potentially be improved to ensure a better asset quality and service level in the long run.

2. Infrastructure assets of a region and their management

Infrastructure assets refer to assets with a physical rather than a financial nature. Uddin, Hudson and Haas (2013, p. 10) add the 'public' aspect and define them as *"…all these combined facilities that provide essential public services of energy, transportation, roads, airports,… Infrastructure also provides the physical systems used to provide other services to the public through economic and social actions. These infrastructure facilities and services are provided by both public agencies and private enterprises."*. This paper researches the aspects related to public infrastructure for transport or with 'transportation' as main function, based on the research of Baldwin and Dixon (2008). Roads, inland waterways, railways, bridges and tunnels are particularly considered as these assets seem to have suffered heavily from underinvestment during the last decades and are still the main transport vectors in society today. According to the Global Infrastructure Hub (Global Infrastructure Hub; 2017), the greatest investment gap is supposed to be in road infrastructure, where the gap between spending following the current trends and investment needs will be around 31%. Policymakers are therefore under pressure and consequently, it is important to advise them on their strategies in maintaining and if possible, improving these particular assets, beyond countering basic infrastructure concerns such as safety and availability.

Infrastructure Asset Management (IAM) may range from managing maintenance activities only in a narrow focus (Shewen & Kovacs, 1995), to managing all activities related to the lifecycle (Weninger-Vycudil et al., 2015). The asset's life cycle consists of the following activities: (1) needs assessment & goals identification, (2) infrastructure planning, (3) infrastructure design, (4) infrastructure construction, (5) infrastructure operations, (6) infrastructure monitoring and inspection, (7) infrastructure preservation and (8) end of life (Sinha et al., 2017). Within preservation, the following subsections can be distinguished: regular maintenance, rehabilitation, replacement and upgrade. This can range from a small-scale maintenance intervention to the replacement of the asset by a more sustainable option (Zoeteman, 2001; Uddin et al., 2013). The International Organization for Standardization (2014) states that IAM can be seen as all the activities that create value from an asset. But, since the demand for infrastructure assets can be viewed as a derived demand for transport or movements, assets do not express value on themselves. They can contribute to the value-creation for its users by enabling them to travel more rapidly or easily (Hartmann & Ling; 2016). Better road infrastructure for example can increase this contribution (Hartmann & Ling; 2016). Many variations of IAM definitions and objectives exist, resulting in the fragmentation of the concept (Schraven et al., 2011). Definitions of IAM of roads are focusing mainly on cost effectiveness, while the objectives for rail and inland navigation infrastructure are respectively safety and reliability and service and availability (Zoeteman, 2001; Bittner & Rosen; 2004; Yin et al., 2009; Sen et al., 2010; Rama & Andrews, 2016; Sinha et al., 2017). As a consequence of this variety, the management of infrastructure can be compared with the iron triangle in project management, consisting of time, performance and cost. An asset manager should always consider the trade-off between cost-effectiveness, safety and reliability and service and availability. Only one objective can be constrained, a second one needs to be optimized and a certain level of the third needs to be accepted. Based on the literature it can be stated that road IAM constrains cost-effectiveness and that inland navigation and rail IAM are constraining respectively service and availability and safety and reliability. The other strategies will be defined accordingly to the organization's objectives. The different objectives may be rooted in current stakeholder expectations regarding a transport mode, and reflected through political priorities, but this is not the focus of our research and therefore this is taken as a basic assumption. The variance in objectives leads to the question if IAM principles and processes should be equal for each public body and each transport mode.

2.1 Developing a Strategic Infrastructure Asset Management (SIAM) framework for transport infrastructure

Several frameworks have been developed to guide decision-makers with the process and implementation of IAM, mainly focusing on the technical side and optimization of IAM systems. Chen and Bai (2019) analyzed 337 academic articles on optimization techniques for asset management and found that the number of articles on this subject only increased during the last years. Some do point at the lack of the strategic aspect and the connection with organizational objectives (Laue et al., 2014; El-Akruti et al., 2013), but few have addressed it from this lens. Some that have (Tranfield et al., 2004; Too et al., 2006; Too, 2010; Brown et al., 2012; Laue et al., 2014; International Organization for Standardization, 2014), defined SIAM as *"A strategic and systematic process of optimizing decision-making in resources allocation with the goal of achieving planned alignment of infrastructure asset with service demand throughout its lifecycle"* by Too, Betts & Kumar (2006, p. 5). After analyzing five main frameworks for SIAM (Tranfield et al., 2004; Too et al., 2006; Too, 2010; Brown et al., 2012; Laue et al., 2014), eight key factors for a sound SIAM were defined: (1) the accountability of context factors' influences on the government policy, (2) the translation of the policy into organizational objectives, (3) the possibility of non-asset solutions, (4) the development of transport mode specific goals, (5) the alignment between the government strategy and asset strategy, (6) the optimization of options, (7) the introduction of feedback loops and (8) organizational and knowledge management. First, to define a governmental policy responding to the needs of a country's economy and society, context factors (for example user's needs and environmental factors) need to be considered (1). Next, the defined policy should be translated into specific organizational strategic management objectives and a corresponding strategy needs to be developed (2). After that, in a stage of strategic planning, the gap between the objectives and the current supply needs to be analyzed, which can consequently be solved with asset or non-asset solutions (3). Including non-asset solutions in the SIAM framework is essential as it offers the possibility to solve existing problems without large asset interventions. Furthermore, different solutions must be translated into goals for each transport mode (4), and asset solutions consequently into asset management goals and plans on acquisition, operation, maintenance and disposal (5). The particular transport mode goals are included as silo-mentality forms one of the greatest issues in managing infrastructure at this moment (Parlikad & Jafari, 2016). The development of strategic goals for each mode can facilitate the collaboration between departments. Thereafter, the possible options need to be optimized based on the defined objectives as cost, time, risk and quality (6). Finally, feedback loops and a constant organizational and information management is required to ensure a continuous optimal service (7)(8).

Applying these factors as management principles when managing infrastructure can contribute to a better IAM and thus, to a better service and a more cost-effective policy. These factors should be included in each SIAM framework, regardless of the mode and the objectives handled by the organization. Considering the different objectives, the focus lies on the translation of organizational objectives into asset objectives and optimization of options. In these two principles, the objective chosen to be constrained should be well incorporated as it is the key aspect that needs to be considered when deciding on an investment or a range of investments.

3. Methodology, Case Selection and Data Collection

3.1 Cross-Case Study of Land Transport Modes Managed by Belgian Regional Administrations

To identify the current and desirable future practices of transport IAM in Belgium, a case study method is used. Schramm (1971, in Yin, 2003, p. 12) argues that *"the essence of a case study, the central tendency among all types of case study, is that it tries to illuminate a decision or a set of decisions: why they were taken, how they were implemented, and with what result"*. In that way the reason and the history behind principles used in the organizations can be discovered. More in detail, the study opted for a multiple case method and investigates the IAM principles of land transport modes, rail, road and inland navigation, managed by Belgian federal and regional administrations. The goal is to give an as extensive as possible overview of the current and future desirable situation, without comparison to other modes or countries. The literature review already suggested that different modes can have different objectives, and therefore also need different frameworks and principles. The characteristics of modes, regions and countries can be various which would make a comparison inappropriate. As different organizations and transport modes are included in this research, the exact research method can be called a holistic multiple case method (Yin, 2003). Belgium was chosen as country to perform the case study. First, the researchers and research chair are based in Brussels, Belgium, which leads to an extensive network of public and private contacts. Next to that, a study by Meersman and Nazamzadeh (2017) states that the network of roads, rail and ports are main indicators to drive the Belgian economy. But despite its importance, it is clear that Belgium needs help with their infrastructure management, especially in the case of transport infrastructure. Comparing 2008 with 2019, the position of Belgium in the Global Competitiveness Report for the road quality index decreased, this while The Netherlands improved their position and the world's median increased (World Economic Forum, 2008; 2019). Furthermore, expenses on maintenance and new investments as % of GDP have been the lowest in Belgium compared to peer-countries[4] from 2007 until 2017. Belgium spent on average 0.6% of their GDP on transport infrastructure investment and maintenance between 2010 and 2017 (OECD, 2021a; 2021b; World Bank, 2021). This is lower than the advised 1% of GDP by the European Conference of Ministers of Transport (2003). Between 2010 and 2017, 75% of the expenditure can be related to new investments and 25% to maintenance (OECD, 2021a; 2021b). Finally, according to Mr. Debrun, senior advisor at the research department of the National Bank of Belgium, the need for public investment in infrastructure in Belgium must be recognized (Trandafir, 2020). Although the need is clear, political obstacles are holding back investments and improvements of the transport network. Belgium forms the perfect example to indicate these potential political obstacles, given the complexity of decision making and the short duration of government terms. The country is managed by six official organizations and four different policy leaders and the duration of a government term is five years. The democratic mandate, and the changing leaders and public opinion, creates a tension field between the political leaders and the top administrators. As a consequence of the regionalization of the ministry of public works in 1989, mobility and infrastructure became regional authorities, meaning that the responsibility of transport infrastructure lies with the regions, except for rail which stayed a federal authority. Belgium is divided into three regions, Brussels, Flanders and Wallonia. The federal government includes one minister of mobility to manage the railways and to keep an overview, and each regional government includes one minister of mobility and public works responsible for roads and inland waterways. Under the responsibility of a minister, there are administrative organizations led by a chief administrator. Six different organizations are mandated with the management of transport infrastructure over the country's three regions, Brussels, Flanders and Wallonia (see Table 2-1).

[4] France, Italy, Luxembourg, The Netherlands, Finland and Austria. There was no complete data available for other countries.

Organizations in Flanders are managed by another overarching organization called Mobiliteit en Openbare Werken (MOW). The federal and regional governments form their own budget, based on their own incomes and expenses. Next to that, the federal government provides the regional governments with additional financial resources. Besides other motives, this complexity, and by consequence possible silo mentality, shows the research interest for a Belgian case study.

Table 2-1 Organizations mandated with the management of transport infrastructure in Belgium (Authors, 2022)

Region	Road	Inland Waterways	Rail
Brussels	Bruxelles Mobilité / Brussel Mobiliteit	Port of Brussels	Infrabel
Flanders	Agentschap Wegen & Verkeer	De Vlaamse Waterweg	
Wallonia	Service Public de Wallonie Mobilité et Infrastructures (& SOFICO)		

3.2 Data Collection Methods

Scientific literature, desktop secondary data in the form of reports from organizations in the same field and policy documents, in-depth face-to-face interviews with top administrators and a focus group with top administrators and experts were used as data collection methods. The interviews covered nearly all regions and all transport modes in Belgium (except for the Port of Brussels). In total seven interviews took place. Based on scientific literature and our developed framework, a semi-structured qualitative survey, including some open-ended questions, was drawn up. After executing seven intensive two-hour interviews in the period October 2019 - November 2020, remaining questions, confirmation of the preliminary findings and potential solutions or ways ahead were discussed in the format of a focus group with all six top administrators responsible for the IAM at their regional level. After carrying out the interviews and gathering the data, the method for cross-case analysis of qualitative data described by Miles and Huberman (2014) was followed. The information was first reduced and synthesized, then it was displayed using visuals in the form of matrices and finally, based on these matrices, relevant conclusions were drawn and validated (Miles and Huberman, 2014).

4. Results

In this section, results of the cross-case study will be discussed per transport mode. For each Belgian organization mandated with the management of road, rail or inland navigation infrastructure, their management is compared against the identified key success factors of the framework for SIAM.

4.1 Road Infrastructure

At this moment, Brussels and Wallonia are considering user's needs before drawing up a long-term vision plan, using workshops or user surveys. Brussels followed this method for the first time during this government term, while Wallonia repeats it regularly. Flanders, on the other side, does not yet include methods to define the demand for infrastructure. Each organization uses their long-term vision plan to translate policy objectives into organizational objectives. However, while focusing on infrastructure to solve the needs identified from the gap between supply and demand, non-asset solutions are not yet considered in the regions. In Wallonia, policy objectives are introduced in the Gestion des Projets routierS (GPS) system, which automatically results in candidate asset projects. Brussels and Flanders translate policy objectives into asset objectives. All regions set transport mode specific goals, in Flanders this is done under the supervision of MOW. SPW in Wallonia also manages inland waterways next to roads, in Brussels only roads are managed by Brussels Mobility. Depending on the scope of activities of each organization in Brussels, general policy goals are being implemented as transport mode specific goals. Railroads are never part of it as this is the responsibility of another organization named Infrabel. Whereas Flanders and Wallonia are already implementing organizational and information processes dedicated to IAM, Brussels is still setting up an asset management direction and collecting information and creating a database. Based on the available information, only Flanders (Pavement Management System - PMS) and Wallonia (GPS) are trying to optimize their interventions. Since road agencies have budget as their main constraint, a strongly embedded budget optimization would be expected in their IAM practices. In contradiction, budget optimization is only done for highways in Flanders. It can be noticed that none of the regions uses feedback loops (Table 2-2).

Table 2-2 Application of the key-success factors of IAM for road infrastructure in Belgium (Authors, 2022)

	Brussels	Flanders	Wallonia
(1) the accountability of context factors' influences on the government policy	●		●
(2) the translation of the policy into organizational objectives	●	●	●
(3) the possibility of non-asset solutions			
(4) the development of transport mode specific goals	●	●	●
(5) the alignment between the government strategy and asset strategy	●	●	●
(6) the optimization of options		●	●
(7) the introduction of feedback loops			
(8) organizational and knowledge management		●	●

4.2 Inland Navigation Infrastructure

Focusing on inland navigation infrastructure, both Flanders and Wallonia are considering context factors and user's needs by having regular conversations with the users of the waterways. Using their long-term vision plans, they attempt to translate policy objectives resulting from the input on these context factors into organizational objectives, and eventually into asset objectives. For the same reason as for road infrastructure, common transport mode goals are defined by the overarching organizations. Both regions already have a system in place to collect inspection data from bridges and to link quality indicators to it. While Flanders already has a database of their other assets, Wallonia is still creating one. The organizations are focusing on the development of an extensive database of all their assets to define the assets that are the most critical in delivering an optimal service and that need an intervention. The optimization of options is not yet done in Flanders, nor in Wallonia and an integration of budget is still work in progress. Equal to road infrastructure, the possibility of non-asset solutions and the introduction of feedback loops are also missing in the SIAM frameworks of inland navigation infrastructure (Table 2-3).

Table 2-3 Application of the key-success factors of IAM for inland navigation infrastructure in Belgium (Authors, 2022)

	Brussels	Flanders	Wallonia
(1) the accountability of context factors' influences on the government policy	No data	●	●
(2) the translation of the policy into organizational objectives		●	●
(3) the possibility of non-asset solutions			
(4) the development of transport mode specific goals		●	●
(5) the alignment between the government strategy and asset strategy		●	●
(6) the optimization of options			
(7) the introduction of feedback loops			
(8) organizational and knowledge management		●	(●)

4.3 Rail Infrastructure

In collaboration with the Belgian railways, responsible for delivering rail service in Belgium, Infrabel defines the user's needs, to draw up the document 'Strategy GO' and to define its objectives. Afterwards, these specific objectives are being translated into asset objectives. Years ago, Infrabel implemented an information system. But, while a large quantity of data is available, the quality of the data is still lacking. Together with the optimization of options, the possibility of non-asset solutions and feedback loops are at this moment non-existing (Table 2-4).

Table 2-4 Application of the key-success factors of IAM for rail infrastructure in Belgium (Authors, 2022)

	Federal
(1) the accountability of context factors' influences on the government policy	●
(2) the translation of the policy into organizational objectives	●
(3) the possibility of non-asset solutions	
(4) the development of transport mode specific goals	●
(5) the alignment between the government strategy and asset strategy	●
(6) the optimization of options	
(7) the introduction of feedback loops	
(8) organizational and knowledge management	●

5. Conclusion

Based on the results and the findings of this study it can be concluded that each transport mode and each region have its own objectives, good practices and challenges. A variety of asset management principles and processes exists, is possible and is potentially even required based on the differences. A ‘one fits all strategy’ implementation does not exist, nor in theory, nor in practice. The framework provides general guidelines, retrieved from best practices abroad and scientific literature, that can be applied on each mode and each region and that can help policy makers and top administrators with the introduction and development of their custom asset management process. In this way, tension fields between policy makers and top administrators resulting from the short government terms can be reduced or even solved as clear principles are available. It is however necessary to include all these principles to achieve a sound SIAM. None of the studied organizations are considering non-asset options as possible solutions and are introducing feedback loops. Moreover, while option optimization and supporting databases should be well developed to focus on the chosen objective, this is only the case in respectively two and three out of the six organizations included in the research. Given the raising complexity in launching, budgeting and executing infrastructure assets, a strategic, and following operational asset management (including data management), would provide more resilient asset management and thus, a more stable and stronger infrastructure factor for competitiveness in a centrally located country in the European Union.

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<u>CHAPTER 3</u>

SOCIAL ECONOMIC MONITORING INSTRUMENT (SEMI): MAKING THE RIGHT PROJECT INVESTMENT DECISIONS AT THE RIGHT MOMENT

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SOCIAL ECONOMIC MONITORING INSTRUMENT (SEMI): MAKING THE RIGHT PROJECT INVESTMENT DECISIONS AT THE RIGHT MOMENT

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Abstract As the volume of goods transported globally continues to rise, public infrastructure owners and operators must find ways to expand capacity and at the same time cope with limited financial resources. Is it possible to have a sustainable transport infrastructure network that is efficient in both economic and societal terms? We contend that current ways of evaluating public project investments, most notably Cost-Benefit Analysis (CBA), are not able to meet the needs of decision-makers for the capital investments required. We propose a new tool that can handle the dynamic nature, international dimension, and interdependence of infrastructure projects. We refer to this tool as 'Socio Economic Monitoring Instrument or SEMI'. SEMI is based on CBA and on the Real Options philosophy. It can be used by decision-makers to identify the investments with the highest economic and societal benefits, and to help them in making the right decisions at the right time, in framing future options, and in presenting decisions made to stakeholders. We show how SEMI can be applied through a case study of the hinterland connections of the Port of Zeebrugge.

1. Introduction

The cost of trade-related, public infrastructure megaprojects has been rising rapidly in recent decades (Jones et al., 2014). At this stage, global trade has surpassed its pre-Covid-19 levels and it continues upward, the value of goods reaching some $28.5 trillion in 2021 and forecast to be even higher in 2022 (UNCTAD, 2022). Additional investments will be required, both to make the most of new trading opportunities in the proximate future and to comply with the need of sustainable transition, which requires considerable infrastructure investments to increase the capacity of eco-friendly modes of transport. Governments and public agencies need to find a way to complete an additional $12 trillion investment (new investments and maintenance) in transport infrastructure (road, rail, air and sea) by 2040, over and above what was originally expected. More than half of this will need to be completed in the US and Europe (Global Infrastructure Hub, 2021). What was already a daunting challenge before the worldwide economic crisis took root in 2022 has been made more difficult by ever stricter budgetary constraints.

To use financial resources as efficiently as possible, it is essential that decision-makers adopt a sound and transparent infrastructure projects evaluation method. An increase in the number and size of complex projects and their national and international economic impact has elevated even further the importance of judicious project selection and resource allocation (Dimitriou et al., 2016). Efficient usage of public resources, i.e., realizing the greatest possible economic and societal value, is high on the agenda of policy makers (Notteboom and Winkelmans in Haezendonck, 2007). Jones et al. (2014) underscore the need for improvement in large-scale project evaluation in order to achieve optimal efficiency, since choosing the right investments can generate more value. Uncertainty also plays an important role in project selection.

We introduce a new tool for evaluating public transport infrastructure projects over the long term. It addresses the dynamic nature of infrastructure and the interdependency of projects, facilitates stakeholder involvement, and builds in flexibility. That tool, which we have named Socio Economic Monitoring Instrument (SEMI), incorporates elements of Real Options Thinking (ROT). We will show that it is an improvement over the widely used Cost-Benefit Analysis (CBA) because it responds better to the need for more complete and more dynamic tools for project evaluation. Building upon factual evidence, it can guide decision-makers in weighing investment possibilities to uncover the ones with highest value. We do not suggest that SEMI be substituted for political decision-making, but that it can be helpful in making better informed decisions (Haezendonck, 2007).

In the following sections we will discuss the characteristics and aims of CBA, and then provide arguments for augmenting it. We will then give an example of how SEMI is now being applied by assessing plans for the hinterland connection of the Port of Zeebrugge (Port of Antwerp-Bruges) in Flanders.

2. Evaluating public infrastructure projects

Taking place directly after deciding on the need of adapting existing or building new infrastructure, project evaluation is one of first stages of a project's life cycle. The advantages and disadvantages of a project under consideration are weighed in an effort to determine feasibility and some form of profitability. The way in which project evaluations are carried out has been modified over time, CBA being the most widely used method at present. The European Union requires member countries applying for EU funding for projects of $75 million or more to perform a CBA, and some countries, including Belgium and the Netherlands, require such analysis for all major projects (Haezendonck, 2007; Beukers et al., 2012; European Commission, 2015; Mouter, 2017). Below, we briefly review the extant literature on CBA and discuss challenges to its use to assess public infrastructure projects.

CBA assesses the positive and the negative impacts of a project, as well as those of alternatives—including a null alternative, i.e. not investing–in an effort to determine project viability (Welde et al., 2013). Economic and societal costs and benefits are considered in order to provide a holistic view of project impacts, both locally and more broadly in terms of geographic scope.

Although CBA has become the primary tool for project evaluation, it is not without critics. The main criticism is of two types. Critics have questioned the standard methodologies used in some countries as well as the technical details of CBA calculations, for example the discounting of monetary values and the monetarization of costs and benefits (Mouter et al., 2013; Jones et al., 2014; Marcelo et al., 2016). The second type of criticism calls into question the usefulness of CBA as justification for major infrastructure projects based on projected economic and societal benefits. The importance of a correct calculation methodology is undoubtedly important, but we focus instead on the goal of CBA and its added value when making project decisions, that is, on process-related issues, aligned with Beukers et al. (2012).

A review of the literature shows that CBA falls short because of (1) a lack of attention to the dynamics of infrastructure development and thus an absence of adaptability of this evaluation tool, (2) fragmentation, meaning the absence of a holistic overview of a network of sub-projects; and (3) insufficient stakeholder interaction (See Table 3-1).

Table 3-1 Grounds on which CBA has been challenged (Authors, 2023)

Criticism	References
Too static (not dynamic) and therefore not adaptable for the long-term	Mackie, 2010; OECD, 2011; Beukers et al., 2012; Dimitriou et al., 2016; Machiels et al., 2020
Too fragmented (not holistic)	OECD, 2011; Beukers et al., 2012; Eliasson and Lundberg 2012; Dimitriou et al., 2016
Limited interaction with stakeholders	Haezendonck, 2007; Beukers et al., 2012; Machiels et al., 2020

CBA is viewed as insufficiently adaptable to cope with rapidly changing infrastructure needs (Mackie, 2010; OECD, 2011; Beukers et al., 2012; Dimitriou et al., 2016; Machiels et al., 2020). CBA can evaluate the feasibility of a specific project with a specific configuration at a specific time. What is needed, however, is a tool with which to evaluate large-scale infrastructure projects that can also respond to the long-term needs of stakeholders in an uncertain environment (Dimitriou et al., 2016). In practice, a CBA is typically carried out long before construction starts, and because infrastructure projects have a long life, the results of this initial analysis lose value with the passage of time and changing conditions. The long pre-contractual throughput times with high transaction costs of megaprojects (De Schepper et al., 2015), and the severity of budgetary constraints both need to be addressed. What is needed is a judicious use of resources spent on the right evaluation techniques at the right time and based on the latest information. Thus, it is crucial that there be a means of evaluating infrastructure projects that is dynamic and adaptable, that is, one that allows for re-evaluation as time goes on.

CBA is used to evaluate well-defined single projects but does not take into account the broader context. This is shown in a European Court of Auditors (2020) report on eight cross-border European Commission-funded megaprojects, referred to collectively as *Transport Flagship Infrastructures* (TFIs). TFIs are part of the Trans-European Transport Network initiative, the purpose of which is to deepen physical connections throughout Europe. The EU auditors assessed the quality of various CBAs of the TFIs. Assisted by an outside expert from the Free University of Brussels, the auditors found that there had been no overall high-level CBA conducted, rather only CBAs on sub-projects. As pointed out in the report, the impact of large-scale infrastructure projects is wide-reaching, and their value realized as part of a broad network of projects. Changes in such networks, positive or negative, can directly or indirectly influence the costs and benefits of specific projects (European Court of Auditors, 2020). Dimitriou et al. (2016) highlight the importance of interdependencies between large infrastructure projects and the span of their influence in the areas in which they operate, which sometimes involves more than one country. The literature recognizes that CBA does not provide a holistic view, but rather a fragmented one (OECD, 2011; Eliasson and Lundberg 2012; Dimitriou, et al., 2016).

Transport infrastructure projects must serve many users and contribute to the national economy as well (Haezendonck, 2007). Users (among other affected parties) can have a significant economic stake in projects, and hence exert significant influence. They are therefore important stakeholders. Yet, academics looking at infrastructure CBAs have found limited stakeholder involvement in project planning and evaluation and have identified little effort to communicate with them afterward (Haezendonck, 2007; Beukers et al., 2012; Machiels et al., 2020). Stakeholders might have been able to contribute valuable data at the analysis stage, for example on traffic flows or on alternative project configurations. In addition to overlooking the possibility of stakeholder contributions in the evaluation process, it does not appear that CBA is sufficiently transparent in communicating with stakeholders at later stages (Notteboom and Winkelmans, 2007; Machiels et al., 2020). This underscores the importance of including stakeholders early in the process, and of rapidly communicating with them when decisions are made as well as when uncertainties arise along the way. It has also been suggested that some decision-makers do not use CBA as a decision support tool, but rather as a means of bolstering their case against competing projects (Mouter, 2017).

3. Combining CBA with ROT: The SEMI tool

There is a need for a project evaluation tool that is more dynamic and flexible than CBA. Such a tool should incorporate stakeholder input and foster transparent communication. SEMI attempts to respond to these needs by combining the best of CBA and ROT.

3.1 CBA and ROT: The perfect match?

As discussed above, CBA is not dynamic, does not focus on the long-term, is not holistic, and does not involve stakeholders in the decision process or meet the need to communicate transparently with them afterwards. ROT might help here.

ROT has five characteristics (Triantis, 2005 in Martins et al., 2015):

- It highlights the value of flexibility.
- It stresses the need to respond to new information over time.
- It affects both present and future decisions.
- It increases the effectiveness of investment planning and operating strategies.
- It stresses the need to be more reactive and proactive.

These characteristics complement CBA. ROT sees sub-projects as real options, that is, decision-makers can exercise the option of implementing them, but they are not obliged to do so (Balliauw, 2020). This allows for real flexibility in that additional sub-projects can be undertaken at various points in the future, as actionable information becomes available (Garvin and Ford, 2012; Martins et al., 2015). It must be noted, however, that executing one option may preclude executing another one (for example, constructing a new lock could imply not executing the option of upgrading the existing one).

3.2 Reasons for a new tool

Because transport infrastructure projects are dynamic, a more adaptive approach to project evaluation is needed (Musso et al., 2007). Notteboom and Winkelmans (2007) have suggested an iterative model for transport evaluation that can be adapted as new information comes to light. Infrastructure projects are becoming much more complex. No sub-project should be treated as a stand-alone investment. Sub-projects should be evaluated within an overall network of linked investments. Vickerman (2017) argues that more research is needed on carrying out the assessment of smaller projects as a group. Balliauw (2020) suggests a phased approach to re-evaluate the benefits of sub-projects before proceeding to the next phase of an overall project. Equally important is the need to involve stakeholders in the decision-making process (Haezendonck, 2007; Notteboom and Winkelmans, 2007). This is difficult to do with CBA. Haass and Guzman (2019) note that the societal aspect of projects, often put forth by stakeholders, is typically neglected, yet stakeholder involvement improves project performance. They advocate for a more adaptive methodology and a higher level of stakeholder involvement. We have developed SEMI in response to these unmet needs. SEMI complements the best features of CBA with insights from ROT.

3.3 Explanation of SEMI

SEMI is intended to facilitate making the right decisions at the right time. We list the eight main features of SEMI, and follow this with details and examples. The main features are:

1. Transparent calculations based on supply and demand data reflecting a range of scenarios.
2. Input from outside experts and stakeholders to estimate traffic volumes.
3. Calculation of social costs and benefits of projects based on investment decisions and long-term traffic forecasts.
4. Possibility of adapting to new traffic forecasts.
5. Possibility of taking into account traffic volumes generated by the implementation of new sub-projects.
6. Involvement of stakeholders to tap into their knowledge and to create goodwill.
7. Sequential implementation of sub-projects.
8. Periodic re-evaluation.

Given the above, the following comments should be made. First, SEMI is a transparent calculation model. Projects under consideration are not seen as individual stand-alone ones, but as components of a transportation system. Given that the impact of infrastructure projects can be far-reaching, a project in one locale may engender a change in transport demand in a number of other venues. Thus, project evaluation needs to take into consideration a broader geographic area. The model makes it possible to analyze different supply and demand scenarios on that basis.

Second, a better informed range of scenarios can be made by including outside experts and stakeholders in the process. One example of a stakeholder is a company doing business in a particular geographic location who uses or might use current and future infrastructure.

Third, SEMI compares capacity and investment costs on the supply side and traffic forecasts on the demand side, resulting in a social net-benefit evaluation for action α given traffic β. Action α can be seen as a scenario on the supply side, including investments that might be made. Traffic situation β represents the long-term traffic forecast for a specific scenario. The confrontation of supply and demand shows when there is likely to be overcapacity or congestion. An estimation of when this may occur, together with construction time, is required to define the right investment path. Social costs and benefits, both direct ones and indirect ones—the impact on employment for instance—are used in economic evaluation.

Fourth, SEMI addresses What if? Many scenarios need to be taken into account. For example, what if container traffic triples in the coming five years? This would be the starting point for attempting to devise potential courses of action should the supposed event or situation actually occur. In other words, decision-makers would weigh how to respond and when. SEMI is flexible and allows for simple simulations, especially on the demand side. Those simulations have a direct influence on the expected net benefits of an investment under consideration.

Fifth, SEMI takes into account the possibility of an increase in demand resulting from new infrastructure investment or from existing infrastructure improvement. For example, SEMI could be used to gauge an increase in port traffic following investment in better hinterland waterway connections. Again, input from outside experts and stakeholders is essential.

Sixth, interaction between decision-makers and outside experts, stakeholders, and data sellers is of major importance. SEMI requires input from all these actors. For example, if stakeholders are not consulted, projects can hit a wall of "not-in-my-backyard", indeed "not-in-anyone's-backyard" opposition.

Seventh, SEMI considers sequential investments: each investment creates a real option to execute a subsequent one. This being the case, it is not possible to decide upon and implement a project slated for one stage without also considering and evaluating projects to be undertaken at other stages. Evaluating a project separately from the other ones would undermine the possibility of an option value for subsequent profitable investments.

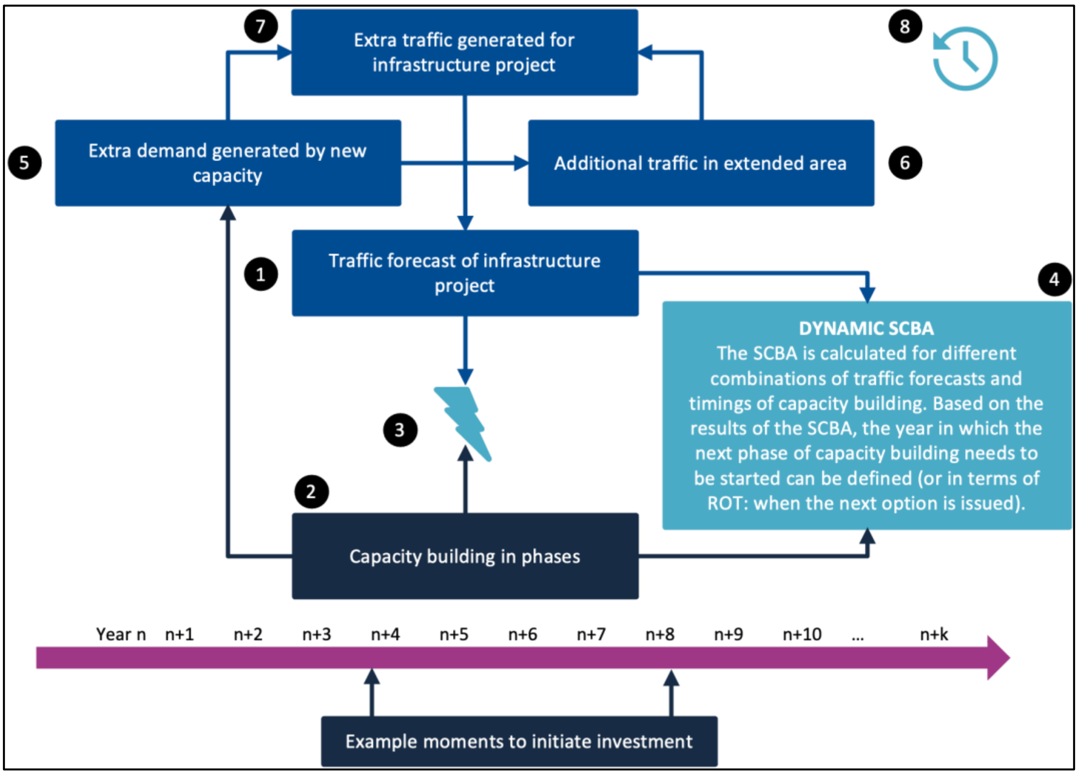
Finally, as new information comes to light—both on the demand and supply side—SEMI outcomes need to be recalculated. Decision-makers, in consultation with outside experts and stakeholders, need to set a reasonable length of time between reviews. For example, it might be agreed to undertake a review two times during a government term, perhaps at the beginning and at mid-point.

Having introduced SEMI, we now compare it to CBA. SEMI is undertaken to help decision-makers determine the right moment to invest in a project or a series of projects. CBA, on the other hand, can help determine the feasibility of projects and their social return, as measured by their net present value (NPV), internal rate of return (IRR) or profit ratio (PR). Another difference is that SEMI generates an investment timeline, while CBA evaluates feasibility at a given point in time. SEMI is more dynamic than CBA. SEMI outcomes are re-calculated periodically based on new information, and this could potentially lead to a new investment timeline.

3.4 Step-by-step guide for SEMI

In this section we provide a step-by-step guide to SEMI (see Figure 3-1). Note that SEMI uses both quantitative and qualitative data.

Figure 3-1 SEMI framework (Authors, 2023)



3.4.1 Step 1: Traffic forecasts for an infrastructure project

The first step is to forecast traffic at a given point in time, taking into account information from market players and outside experts, as well as the volume of additional traffic stemming from previous investment, whether new traffic or traffic shifted from other infrastructure. A null scenario, that of taking no action, is then compared to an investment scenario. The null scenario is the basis for introducing ROT as it shows potential traffic loss. A low, medium, and high scenario for the null alternative is created, with the range between low and high representing uncertainty. The difference in NPV between low and high investment could also be used as a proxy for the valuation of the option of postponing the investment. Although they cannot be fully reliable, traffic forecasts should be made for different points over the life of the project, sometimes for as long as 20 to 30 years. The results of those estimates should be recalculated periodically and adapted to current and future situations, including unforeseeable ones.

3.4.2 Step 2: Capacity building in phases

SEMI looks at capacity expansion executed in phases. Step 2 of the process delivers inputs to the following steps. First, existing and planned capacity is compared to the forecasted traffic. If capacity is less than traffic, forecasted traffic needs to be decreased in the CBA calculation, resulting in lower project benefits. In the case of sufficient capacity, traffic forecasts can be realized. When capacity is larger than estimated traffic, existing capacity will be under-utilized and hence CBA will show a less beneficial outcome. Construction and operating costs also need to be taken into account. Since investments are sequential, some can only be undertaken after other ones have been made. Not undertaking an investment can imply a reduction of the net benefits and NPV of a larger project, to the extent that it precludes subsequent sub-investments. The net benefits and NPV of these follow-up projects will be eliminated because the option to expand and to grow is lost if the initial investment is not undertaken. If no investments are made, then the optimal time to invest is when the sum of the two loss components is the largest. One can draw decision trees with various scenarios and project components with comparisons of capacity and forecasted traffic.

3.4.3 Step 3: Comparing capacity and traffic forecasts

It is possible to compare capacity and forecasted traffic and to identify when points of full capacity utilization will be reached. It will then also be necessary to determine when one should increase capacity to meet demand, given the time needed to build capacity. Increasing capacity too early will result in excess capacity, and hence in lower social benefits and a smaller rate of return. Doing it too late will lead to longer waiting times, the loss of users, and a lower rate of return.

3.4.4 Step 4: CBA Calculation

In step 4, a CBA is made following national or regional guidelines for infrastructure projects—the *Standaardmethodiek* in Flanders—and based on traffic forecasts, external costs, maintenance costs, waiting times, indirect effects, and so forth.

3.4.5 Step 5, 6 and 7: Consequences of additional capacity

Additional capacity can directly and indirectly increase traffic. New infrastructure is likely to generate higher traffic directly but may also do so indirectly as it makes the area more attractive to users, hence generating additional demand. An indirect increase in traffic will raise the net social benefit of a project. Thus, SEMI makes it possible to build scenarios incorporating various costs and traffic forecasts, and to use updated information to recalculate the net social benefits of a project.

3.4.6 Step 8: Timeline

SEMI pays particular attention to simulations over time. The timing of investment over the life of the project, which is based on traffic forecasts, will affect the results of the CBA. That timing may change as new information becomes available (see timeline in framework, year n until year n+k).

3.5 Conclusion and investment roadmap

In contrast to CBA, SEMI keeps investment options open, which means that plans can be changed based on new information. Figure 3-2 shows the investment roadmap based on NPV and on project uncertainty and volatility. NPV is positioned on the horizontal axis. Sub-projects should be undertaken when the NPV is positive. The vertical axis shows the level of uncertainty and volatility of sub-projects. It represents the difference between low and high traffic scenarios. When this difference is low–in an extreme case equal to zero–decisions as to whether to make an investment or not should be based on the project's NPV. SEMI can be used as a tool to guide decisions, but it is up to policymakers to decide on the minimum acceptable NPV, and their decision also depends on the level of uncertainty and volatility they find acceptable when making a decision.

Figure 3-3 shows a change in position of a sub-project between two periods as a consequence of a reduction in uncertainty and a higher NPV threshold. Sub-projects can also be added to or removed from the investment roadmap where relevant. Decision-makers can use the investment roadmap to communicate long-term plans to stakeholders. This assumes that decision-makers have a long-term infrastructure strategy, which is not always the case, for instance because politicians may have only a short term in office.

Figure 3-2 SEMI investment roadmap (Authors, 2023)

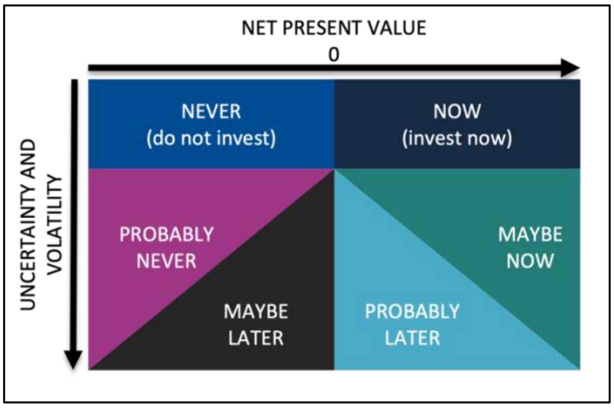
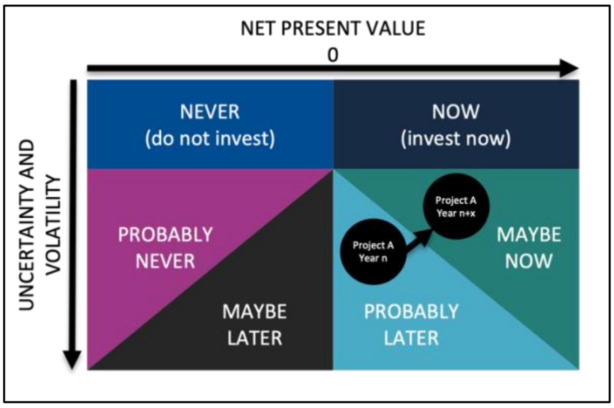


Figure 3-3 SEMI investment roadmap - example project A (Authors, 2023)



4. SEMI in practice: hinterland connection of the port of Zeebrugge

SEMI was first used in a study undertaken for De Vlaamse Waterweg[5] which is a Flemish public agency responsible for the management of waterways in Flanders, including infrastructure construction (bridges, locks, quay walls, etc.). As part of the European Union Trans-European Transport Network, an EU plan promoting territorial cohesion, the EU is providing half of the funding for a canal project that will facilitate French-Belgian-Dutch navigation. This project includes building a canal between the Seine and Scheldt (Escaut) rivers. It is a joint project of Voies Navigables de France (VNF) and Société du Canal Seine-Nord Europe (SCSNE) on the French side, and De Vlaamse Waterweg NV and SPW Mobilité et Infrastructures on the Belgian

[5] For more information on De Vlaamse Waterweg please visit: https://www.vlaamsewaterweg.be.

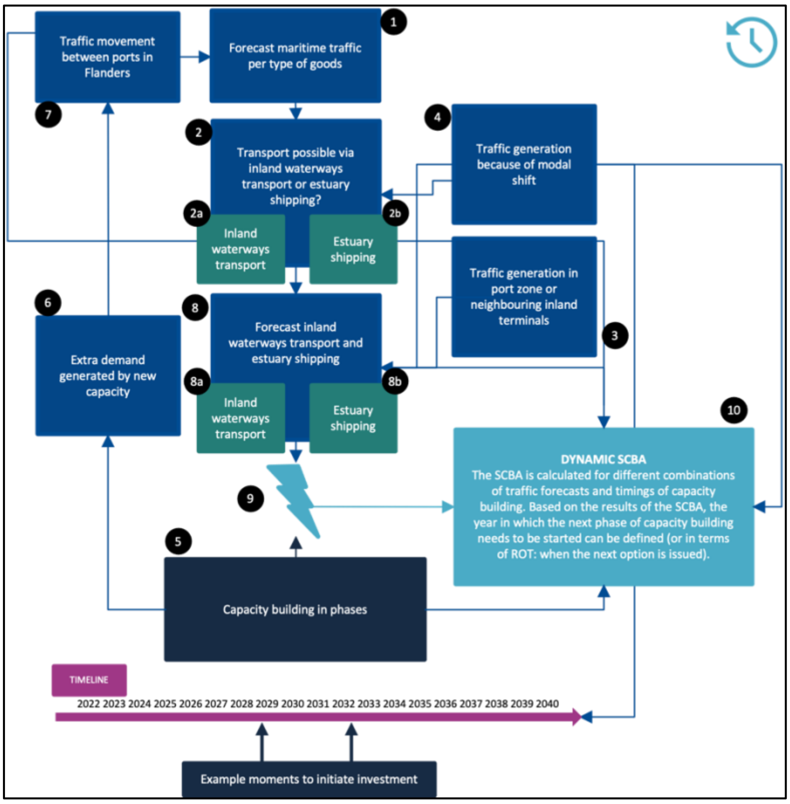
side. It is co-financed by the Connecting Europe Facility of the European Union (EEIG Seine-Scheldt, 2022). Over the years, the project has been extended to include the development of inland waterways in France and Belgium (European Court of Auditors, 2020). The project spans both the Flemish and Walloon regions of Belgium (see Figure 3-4) The Seine-Scheldt project is a complex and expensive one calling for considerable cross-country collaboration. One of its many components is the development of the hinterland connection of the port of Zeebrugge, located on the Belgian North Sea coast. A tool was required to determine the optimal configuration and timing of investments to increase Zeebrugge's hinterland port capacity.

Figure 3-4 Map of the Seine Scheldt project (Dejonckheere, 2020, adapted to document colors)

Five strategies were defined. (1) Strategy 1: maintain the existing infrastructure; (2) Strategy 2: adapt the existing infrastructure; (3) Strategy 3: use ways of increasing existing capacity; (4) Strategy 4: construct new infrastructure, and finally (5) Strategy 5: implement previously defined strategies in stages, starting with 1, followed by 2, then 3, then 4. For Strategy 5, a tool was required to determine the right investment decisions at the right time. SEMI was developed for this purpose. Strategy 1 can be seen as the null alternative against which the results of the CBA are compared. Strategies 2 and 4 could be viewed as building new capacity and 3 as increasing capacity, not by constructing new infrastructure but by stimulating estuary shipping (i.e., shipping from Zeebrugge to Antwerp and beyond via smaller vessels than the large ocean carriers arriving in Zeebrugge).

Figure 3-5 shows the steps of the SEMI framework that we followed in our analysis. First, we conducted forecasts (steps 1, 2 and 8); second, we contemplated phased capacity building (step 5); third, we made capacity and traffic forecast comparisons (step 9); fourth, we conducted a dynamic CBA (step 10); and finally we calculated the impact of new capacity on traffic (steps 4, 6 and 7). We placed a clock at the top right of the scheme to indicate that SEMI calculations need to be periodically redone; in this case decision-makers opted for every two years. Considering the influence of new capacity created on the traffic is important as this might influence the results of the CBA again. Therefore, aside from the periodic repeating, the CBA is called dynamic. Stakeholder involvement is facilitated in two ways. First, stakeholders are approached to deliver input data to calculate traffic forecasts. Second, stakeholders are engaged by presenting them the investment roadmap after each recalculation of SEMI (see Figure 3-2 and Figure 3-3 as examples for the investment roadmap). Stakeholders might see the project in which they have a high interest moving on the map. This does not only communicate transparently to the different actor groups, but also provides perspective for their projects.

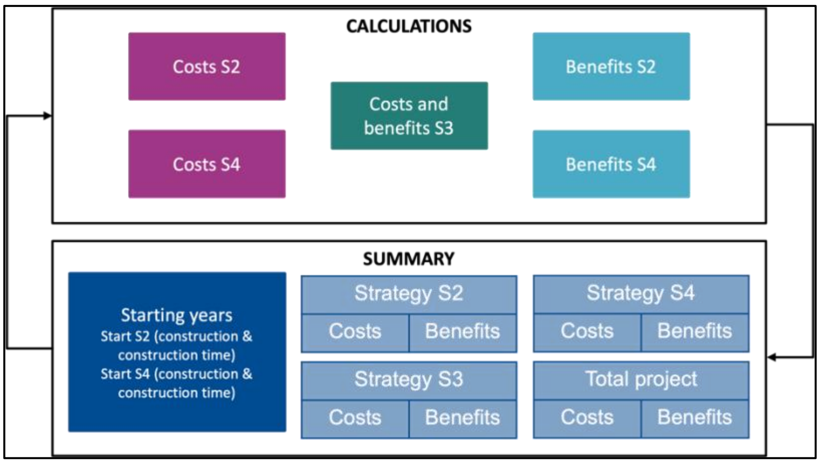
Figure 3-5 Framework for the application of SEMI to the hinterland connection of the Port of Zeebrugge (Authors, 2023)



The upper part of Figure 3-6 shows the five calculations that need to be made in one period. No new calculations are needed for Strategy 1, as they have already been made, nor for Strategy 3, because the costs and benefits of this strategy depend on traffic forecasts. But this is not the case for Strategies 2 and 4. In the lower part of the scheme we have listed the types of data needed to start the simulation. The starting year of construction and the time needed to complete it are inputs, and the results of the CBAs for Strategies 2, 3 and 4, separately and together, are outputs. Inputs and outputs affect each other, insofar as a change in construction start date and/or in construction time affects the results of the CBA analyses and hence call for their updating. One can run simulations with various construction starting times and durations to identify the optimal points in time to start construction. Besides these, Figure 3-5 already showed the possibility to change traffic forecasts based on possible scenarios of the future. Both features of the SEMI tool prove its adaptability to uncertainty and flexibility.

Based on these calculations, and assuming a discount rate of 3% and costs calculated on a perpetual basis, we found that the highest potential social benefit for Strategy 4 was obtained if construction would begin in 2052 so as to be operational by 2064. A CBA yields positive results even if construction is started earlier, for example in 2040, and is operational in 2052. Strategy 3, which entails increasing capacity by developing estuary shipping, can be a temporary solution until Strategy 4 is implemented. Some estuary shipping firms might be interested in this, even without additional government subsidies, as long as a sufficient period of operation is guaranteed. In that case the costs of Strategy 3 will be zero. We have also found that increasing the level of subsidies does not necessary cause a significant impact on the outcome. Strategy 4 requires substantial financial resources but only yields limited short-term benefits, and this is likely to make its net social benefit negative. However, this changes if combined with Strategy 2 (adapting the existing infrastructure) and Strategy 3 (increasing existing capacity by simply adding new vessels). This is where our approach differs from ROT. ROT outcomes depend on changes in traffic forecasts (Balliauw, 2020). With SEMI, we keep the option open to invest in the future through current investments, as investing in a sub-project now means retaining the ability to invest in other ones later: the benefits derived from building the first sub-project can affect the subsequent benefits of future sub-projects. This can mean making an investment with a negative net social benefit now, for example Strategy 2, because undertaking investment this can positively influence the net social benefit of the entire project, including Strategy 4, in the long term.

Figure 3-6 Summary table SEMI calculation (Authors, 2023)



The port of Zeebrugge case study shows the wide applicability of SEMI and the difference in outcome between analyzing a network of linked projects rather than a single project. This is a distinct contribution of SEMI. SEMI focuses on the main long-term goal, in this the improvement of the hinterland connections of the port of Zeebrugge and makes the evaluation of each sub-project dependent on all the other ones. SEMI can also be re-calculated when new data become available and when events suggest replacing existing strategies and adding new ones. SEMI allows in this way as well to be adapted for future uncertainties and to be more proactive towards these. The dynamic nature of the tool permits making periodic recalculations based on the latest information and involving stakeholders, something that we encourage.

5. Conclusion

Projects are increasingly large and complex, and more attention than before is given to their overall social benefits as compared to their economic ones alone. In addition, stakeholders are becoming more involved. Projects are also more vulnerable to uncertainty and unforeseen events than ever before. Academics and practitioners have long been asked to develop a new methodology for infrastructure project evaluation that can meet those challenges.

SEMI provides an answer. It is a new methodology that includes CBA but is complemented with a ROT approach. Unlike a conventional CBA, SEMI evaluates the feasibility and the timeline not of single projects, but of a network of linked sub-projects. It aims to define the optimal moment to invest, but also the best configuration of various sub-projects. It emphasizes the dynamic nature of infrastructure projects and takes a holistic view in acknowledging the interdependency of sub-projects. Furthermore, it underscores the need to involve stakeholders throughout the process by asking their input at different moments in time. SEMI was developed to guide decision-makers in planning and evaluating long-term infrastructure projects. Its goal is to provide a transparent and rational way to come to decisions.

For the application of SEMI to succeed, decision-makers (public agencies and political actors) need the willingness to follow a long-term plan. As already mentioned, this is unfortunately not always the case. In most countries, politicians only stay in office for a fixed period of time and prefer to realize projects according to their action plan. This might hamper the ability to follow a long-term strategy. However, SEMI attempts to increase this ability by making it more convenient.

In this paper, we have presented a general framework that can be applied to infrastructure projects, and we have given as an example planning for the development of the hinterland connection of the Port of Zeebrugge. In addition to being state-of-the-art, SEMI is also a tool to present results to stakeholders in a clear way through the investment roadmap and hence to facilitate their involvement. This should improve the relationship between decision-makers and stakeholders and create greater supporting bases for projects. Eventually it would ensure more efficient projects, from an economic and societal perspective.

6. Acknowledgements

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CHAPTER 4

COST OVERRUNS OF BELGIAN TRANSPORT INFRASTRUCTURE PROJECTS: ANALYZING VARIATIONS OVER THREE LAND TRANSPORT MODES

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CHAPTER 4

COST OVERRUNS OF BELGIAN TRANSPORT INFRASTRUCTURE PROJECTS: ANALYZING VARIATIONS OVER THREE LAND TRANSPORT MODES AND TWO PROJECT PHASES

Laura Molinari, Elvira Haezendonck and Vincent Mabillard

Abstract Transport infrastructure agencies are increasingly coping with strong budget constraints, while being highly under pressure to manage and upgrade an infrastructure network that meets the increasing service level expectations of all its stakeholders. Sound infrastructure management therefore includes tight cost control, a long-term vision and budget planning. Belgium has long been structurally underinvesting in infrastructure, but is in recent years trying to clear the backlog. However, it seems that cost overruns for transport investment projects – paid by the same budget as structural maintenance projects – may seriously reduce the number of critical projects to be carried out in the next years, delaying the necessary catching up process as compared to neighboring countries' state of infrastructure (in the Netherlands, the UK, and Germany). This study analyzes quantitatively the cost developments, from the first publicly released estimates to the final execution costs, of 36 Belgian railway, road and inland waterway projects, representing a total final value of €1,059,754,416.37 in 2020 prices, or approximately almost 10% of all transport infrastructure investments (in % of CAPEX) in Belgium during the last two decades is captured in our sample. We obtain results on the cost variation itself, and on the phase of the project in which the deviation is higher. We also investigate the transport mode as the independent variable. We find that overruns are higher in the project stage before contract awarding, and that cost overruns for road projects exceed those of rail or inland navigation projects. This case-based quantitative analysis, together with the variables researched in the case analysis, will enable Belgian governing bodies and transport agencies, separately responsible for one mode per region, to learn from these deviations, and to prioritize the need to further explore causes and develop solutions.

1. Introduction

European infrastructure assets are suffering from a preceding period of underinvestment (Directorate-General for Mobility and Transport of the European Commission, 2019). An investment gap needs to be urgently filled to increase the service level until the ever-rising users' standards are reached, despite the limited financial resources of governments. Therefore, an infrastructure policy including a long-term plan of efficient public spending is required (European Commission, 2016). Transport infrastructure works, both new and renovation projects, are high on the agenda of policy makers aiming at responding to society's demand. During the execution of these projects, cost developments occur frequently and put pressure on efficient public spending. These cost deviations arise when final project costs end up higher or lower than initial estimated project costs, exceeding an acceptable deviation margin of 5%. The total budget can be more or less preserved due to some overruns being compensated by underruns in other projects, or by projects delayed or suspended, but it seems problematic because cost overruns are more frequent than cost underruns in transport infrastructure projects. This is demonstrated in many European studies, generally focusing on one country, and on infrastructure projects for only one transport mode (Andrić et al., 2019; Cantarelli, Flyvbjerg, et al., 2012; Cantarelli, Molin, et al., 2012; Cantarelli, van Wee et al., 2012; Dantata et al., 2006; Flyvbjerg et al., 2002, 2003; Lee, 2008; Love et al., 2017; Makovšek et al., 2012; Odeck, 2004; Pickrell, 1989; Singh, 2009). The evolution of research results and some more current studied projects do not show any improvement here, on the contrary. According to a report of the European Court of Auditors (2020), the Canal Seine Nord Europe, for example, was initially estimated at 1.7 billion euros (in 2019 prices) and is now already estimated at 5 billion euros (in 2019 prices), resulting in a cost overrun of already 3.3 billion euros or 194% for this unfinished set of projects. In Belgium, the Court of Audit recently executed two studies, one on cost and time developments of the Flanders' Missing Links road projects[6] and one on Walloon inland navigation projects, both indicating major budget overruns (Court of Audit of Belgium, 2018, 2020).

[6] In 2001, 27 road projects were defined as Missing Links projects by the Flemish government. All these projects concern the construction or adaptation of (new) main or primary roads. For more information please consult: Court of Audit of Belgium (2020). Realisatie van de missing links in de wegeninfrastructuur.

Despite the numerous studies already available, the results have not yet led to more on-budget projects and the problem even seems to worsen. Cantarelli, Flyvbjerg, et al. (2012) found that, when analyzing cost overruns, geographical location needs to be considered. Project management responsibilities and practices can differ over countries and regions, which then potentially impacts the magnitude of the projects' cost overruns. This makes country and region specific research on cost overruns relevant. With the purpose of guiding policy makers and transport infrastructure agencies in Belgium, this research investigates cost deviations of 36 Belgian transport infrastructure projects, with a total final amount of €1,059,754,416.37 euros in 2020 prices. Infrastructure projects for different transport modes are in Belgium uniquely managed by specific agencies in the regions, indicating that by researching cost developments over the different transport modes, we obtain results per tendering body. Causes of cost overruns can origin from different project characteristics, such as project size (larger projects may be more complex) and period of execution. The latter may indicate if the situation seems to rather improve or deteriorates. Analyzing the specific cost deviations for different project characteristics makes it possible to link these deviations to separate agencies and the responsible asset and project management teams. Besides that, it also allows to relate the overruns with the political and stakeholder desirability of the mode, for example due to environmental reasons and modal shift ambitions. Differentiation is also made over two project phases, i.e. the pre-construction and construction phase, the latter starting after the project has been awarded. While the first phase takes place while legitimizing the project to stakeholders, the second phase is characterized by the involvement of a consortium of partners executing the project. As a result, both phases may have their own dynamics leading to potential cost deviations. In the next section, an overview of the existing literature on cost overrun measurement is given. Next, the data and methodology used in this research are explained. In section four and five, the results of the statistical analysis are presented and discussed. Finally, conclusions are drawn and future research is suggested.

2. Literature review

2.1 Cost overruns

Many researchers have addressed the topic of cost overruns of a large range of infrastructure projects. Some of them have focused specifically on (public) transport infrastructure projects. As one of the earliest authors on the topic, Pickrell (1989) analyzed eight rail infrastructure projects from the United States and concluded that costs increased with 61% on average. Morris (1990) calculated an average cost overrun of 164.21% for the 23 Indian railways projects investigated. Other more recent studies on projects carried out in the same period as our sample, will be discussed in this section. Moreover, Table 4-13 in Appendix gives an overview of these studies and describes the author, publication date, country of focus, types of transport infrastructure projects investigated, sample size, average size of cost overrun and frequency of cost overruns. Studies are included in that overview when there is at least one year overlap with the reference period of our data. We found that most studies find quite large average cost overruns of 10%[7] to approx. 30%[8] (Andrić et al., 2019; Kostka and Anzinger, 2016), but most of them were uni or dual modal, and only few studies included multiple regions, none of which had with a unique tendering or government responsibility (Flyvbjerg et al., 2002, 2003; Singh, 2009; Lundberg et al., 2011; Cantarelli, van Wee et al., 2012; Cantarelli, Molin, et al., 2012; Cantarelli, Flyvbjerg et al., 2012; Kostka and Anzinger, 2016; Love et al., 2017; Andrić et al., 2019).

2.2 Determinants of cost overruns

Different studies analyze possible influences of various project determinants on the magnitude of cost deviations. Most frequently studied variables included: project type, project size, project duration, time period, project location and project phases. An overview of which study analyzed which determinant can be found in Table 4-1 later in this section.

2.2.1 Transport mode

Cantarelli, van Wee et al. (2012) state that differences over transport modes and project types should be researched, as these types are in most of the cases managed by different organizations, possibly resulting in a different organizational or institutional structure tendering and leading the projects. Road, rail and inland waterways are the transport modes considered in this paper. Besides that, fixed links, including bridges and tunnels, are in some cases considered as separate projects and therefore this category is also discussed. The

[7] The study from Roxas and Chalermpong (2008) found a lower average cost deviation of -1.2% but this was only applicable to a part of the sample consisting of only road projects. There was no total average calculated for the entire sample.

[8] Higher average cost deviations were found but these were only applicable to parts of the samples (Flyvbjerg et al., 2002, 2003; Lee, 2008; Singh, 2009; Cantarelli, van Wee, et al., 2012; Cantarelli, Molin, et al., 2012; Cantarelli, Flyvbjerg et al., 2012 and Kostka & Anzinger, 2016).

following ranges of cost overruns could be derived from the studies investigating projects of these types of transport modes.

- Road: 1.2% until 30.86% (eight studies, total of 766 projects);
- Rail: 10.6% until 94.84% (eight studies, total of 335 projects)[9];
- Inland waterways: 57% (one study, total of two projects);
- Fixed links: 2.3% until 33.8% (or 42% only for tunnels[10]) (four studies, total of 95 projects).

It seems that ranges for road and fixed link projects are smaller and that the ones for rail and inland navigation projects are larger. This is counter-intuitive, since we would think that road projects, because of their negative image in the modal-shift ambitions, are more contested today and that initial budgets are set lower to try to gain project acceptance. Fixed-link projects on the other hand are more complex in nature, making upfront calculations more difficult.

2.2.2 Project size

Results about the influence of the size of the project show contradiction. Some authors found a positive correlation between the size of the project and the cost deviation and others rather found a negative correlation. Odeck (2004) states that larger projects experience smaller overruns because they receive more attention related to project management. Next to that, economies of scale can also be larger for larger projects, causing lower cost overruns, especially for the length of roads in road projects (Chong and Hopkins, 2016). On the other hand, large projects tend to be more complex, which might result in larger overruns (Terrill and Danks, 2016).

2.2.3 Project duration

Singh (2009) advises to avoid projects with a long implementation period. In all dedicated studies, cost overruns increased with the length of the implementation phases and the total duration (Singh, 2009; Cantarelli, van Wee et al., 2012; Andrić et al., 2019). As the duration

[9] The studies from Pickrell (1989) and Morris (1990) also investigated rail projects but as the periods of the projects fall out of the reference period used in this study, these averages of cost overruns were not included in the analysis to define the range.
[10] Average based on a sample of two projects.

increases, projects can be more influenced by unexpected events, the declining state of the assets and currency exchange uncertainties (Singh, 2009).

2.2.4 Period of execution

Cost overruns in transport infrastructure projects have already been a problem since a long time, and early studies date back to 1989 and 1990 (Pickrell, 1989; Morris, 1990), but recent results still show high percentages of overruns, for example in Chong and Hopkins (2016) and Terrill and Danks (2016). A more positive evolution was expected, as estimation methods and tools also improved causing fewer forecast errors compared to the past, but this was not always demonstrated in practice (Cantarelli, Molin, et al., 2012; Flyvbjerg et al., 2002, 2003; Lundberg et al., 2011).

2.2.5 Project location

Different studies found variation in the magnitude of cost deviations over different regions and/or countries (Flyvbjerg et al., 2002, 2003; Roxas and Chalermpong, 2008; Singh, 2009; Cantarelli, Flyvbjerg et al., 2012; Kostka and Anzinger, 2016; Andrić et al., 2019; Terrill and Danks, 2016). According to Flyvbjerg et al. (2002) geography is important, as variations can be caused by differences in project management capacity building, as well as in political and economic circumstances (Cantarelli, Flyvbjerg, et al., 2012; Kostka and Anzinger, 2016).

2.2.6 Project phases

Few researchers focused on the differences over the project phases when investigating cost overruns. Two main phases can be distinguished: the pre-construction, defined as the period from the formal decision to build until the start of the construction, and the construction phase, which is the period from the start of construction works until the end of construction and start of operations (Cantarelli, Molin, et al., 2012; Cantarelli, van Wee et al., 2012). Both phases are characterized by different key stakeholders, with potentially diverging objectives. In the pre-construction phase stakeholders, such as community groups or other actors with various interests attempt to have their demands responded in the design. During the construction phase other stakeholders are involved, for instance the contractor(s) or heritage and environmental organizations when unforeseeable circumstances arise throughout construction works. As a result, varying cost deviations may exist between these phases each with their own challenges, and a phase-specific analysis would therefore allow to gain more insight. The paper of Cavalieri et al. (2019a) mentioned four phase-specific studies on the topic, and they also analyzed the different phases and cost deviations themselves. Generally, cost deviations appear to be the highest in the initial phase of the project (pre-construction phase) compared to the construction phase (Joint Legislative Audit and Review Commission (JLARC), 2000; Cantarelli, Molin, et al., 2012; Cantarelli, van Wee et al., 2012; Chong and Hopkins, 2016; Terrill and Danks, 2016). The second phase of the study from the Joint Legislative Audit and Review Commission (JLARC) (2000), the first three phases from Chong and Hopkins (2016) and respectively the second and third phase of Terrill and Danks (2016) and Cavalieri et al. (2019a) are comparable with the pre-construction phase defined in Cantarelli, Molin, et al. (2012) and Cantarelli, van Wee et al. (2012) and their following phase(s) with the construction phase. The definition of the concepts pre-construction and construction phase used in this study partly follow the ones from Cantarelli, Molin, et al. (2012) and Cantarelli, van Wee et al. (2012) but instead of using the formal decision to build as first moment, the moment of initial estimation is used, resulting in analyzing a broader project time frame. In fact, with an initial estimation, responsible politicians often disclose this amount and their engagement to invest. It is usually the start of a societal debate, and sets the minds of the public in terms of the required budget for a societal need. Formulas are explained more in detail in 3.3 Methodology.

Even when taking into account the extensive research already executed, above determinants still seem very relevant to study, and especially when they are related to the responsible agencies. In this case, those accountable for particular projects get insights for the investments they manage. While this paper focuses on an in-depth data analysis in the Belgian context, it may actually contribute in two ways. The Belgian transport infrastructure agencies are mostly individually responsible for one mode's infrastructure in one region. This pinpoints specific issues and facilitates potential causal relationships with determinants. But it also links problems to ownership and those in charge of remediating the cost deviations. Causes of potential cost overruns can only then be defined, for the different project phases, and for infrastructure projects for one mode of transport.

Table 4-1 Overview of recent quantitative studies and their determinants (Authors, 2023)

Author(s)	Country or region of focus	Project type	Size	Duration	Time period	Location	Project phases
Flyvbjerg et al. (2002)	World	●			●	●	
Flyvbjerg et al. (2003)							
Dantata et al. (2006)	United States		●		●		
Lee (2008)	Korea	●					
Roxas & Chalermpong (2008)	Asia	●	●			●	
Singh (2009)	India	●	●	●	●	●	
Lundberg et al. (2011)	Sweden	●	●		●		
Cantarelli, van Wee, et al. (2012)	The Netherlands	●	●	●			●
Cantarelli, Molin, et al. (2012)					●		●
Cantarelli, Flyvbjerg et al. (2012)		●				●	
Makovšek et al. (2012)	Slovenia						
Kostka & Anzinger (2016)	Germany		●			●	
Love et al. (2017)	Australia						
Andrić et al. (2019)	Asia	●	●	●		●	
Joint Legislative Audit and Review Commission (JLARC) (2000)	United States	●					●
Chong & Hopkins (2016)	Developing countries		●		●		●
Terrill and Danks (2016)	Australia	●	●			●	●
Cavalieri et al. (2019)	Italy						●

2.3 Explanations for cost overruns

Cost underestimation, either accidental or deliberate, and scope changes (Andersen et al., 2016; Cantarelli et al., 2010; Cantarelli, Molin et al., 2012; Cantarelli, Flyvbjerg et al., 2012; Shane et al., 2009) are mostly mentioned as causes for the pre-construction phase. Poor estimations can have different kinds of nature as stated by Flyvbjerg et al. (2002). They can have technical explanations, due to the capabilities of estimation techniques and the availability of data (for example inflation rates that were not considered sufficiently), strategic and political explanations (deliberately underestimating costs to assure the project will be executed because it fits in the political agenda or because of lobbying of the construction sector for a pipeline of works), and psychological explanations, estimating costs too optimistically to ensure some first level of public acceptance (Flyvbjerg et al., 2002; Cantarelli et al., 2010). Political explanations appear to be pertinent in explaining cost overruns (Cantarelli et al., 2010; Cantarelli, van Wee et al., 2012). One of the most occurring political explanations is strategic underestimation. This happens when the costs of a project are estimated at an unrealistic low level in the phase before the decision to build in order to increase societal acceptance of the project. Only later, the estimates are considerably raised towards the moment of the formal decision to build (Andersen et al., 2016; Cantarelli, Molin, et al., 2012; Cantarelli, van Wee et al., 2012). Next to that, scope changes can explain cost overruns in the pre-construction phase as well. These changes may go hand in hand with stakeholder opposition. Requests for changes and additional demands from stakeholders and other politicians result in unforeseen add-ons to the scope of the project, eventually cause the project price to rise (Cantarelli, van Wee et al., 2012; Simushi and Wium, 2020). In many cases responding to these demands is necessary to generate support for the project and a “license to build”.

Considering the construction phase, cost overruns could be associated with material and labor management (increasing prices, shortage, fall-out of staff, etc.), and with conflict management between the tendering government agency, the contractors and third parties, due to bounded reliability of contracting partners (Adam et al., 2017; Albtoush and Doh, 2019; Cavalieri et al., 2019b; Shane et al., 2009). Next to that, poor scheduling and additional work were also frequently mentioned (Adam et al., 2017; Chandragiri et al., 2021; Herrera et al., 2020).

Across the phases, cost overruns can be caused by poor management and organization structure and processes, poor communication between the contracting parties, but also with other third-party stakeholders, uncertain natural or environmental factors, such as bad weather or floods, economic factors that are external from the project, such as inflation, and technical-engineering challenges because of the complexity of the project (Adam et al., 2017; Asiedu and Adaku, 2019; Locatelli et al., 2017; Moschouli et al., 2018; Singh, 2009).

The literature indicates differences of cost deviations over various factors: project type or transport mode, project size, project duration, period of execution, location and project phases. As can be noticed from Table 4-1, all these factors have already been researched extensively in the scientific literature but were never combined all together. However, in order to give as specific recommendations as possible, the determinants need to be combined into one study. In Belgium, but also in other European (e.g. Germany) and non-European countries, transport infrastructure is managed by a separate agency in each region. Therefore, by combining all these elements and researching them in one particular context, recommendations can be given to the unique responsible organization. As in other countries, besides Belgium, the management of transport infrastructure is structured in a similar way, the proposed recommendations may also more broadly apply.

This research addresses this topic by analyzing 36 Belgian transport infrastructure projects and attempts to answer the following research questions.

1. What is the size of cost deviations in Belgium?
2. Does the size depend on the type of transport mode?
3. Is the size different in the pre-construction phase compared to the construction phase?
4. Did cost deviations improve over time?
5. Does the size vary depending on the region of execution in Belgium?
6. Does the duration of the project influence the magnitude of cost deviations?
7. Does a relation exist between the size of the project and the size of the cost deviations?

3. Data & methodology

3.1 Data

For this study, data was received from different Flemish, Walloon and Federal transport agencies in Belgium. On the federal level, the organizations *Infrabel* and *Tucrail* are responsible for railway infrastructure projects. On the regional level, *Agentschap Wegen & Verkeer* and *De Vlaamse Waterweg* are in Flanders respectively responsible for road and inland navigation projects and *Société Wallonne de Financement Complémentaire des infrastructures* (*SOFICO)* and *Service Public de Wallonie Mobilité et Infrastructures* respectively for road and inland navigation projects in Wallonia. The sample includes 36 infrastructure projects, with total final value of the projects of €1,059,754,416.376[11] (2020 prices) executed in the period 1997 (first initial estimation) until 2021 (last project completion). In the period 1997–2017[12], €42,263,448,349.38 was invested in Belgium in new infrastructure for road (€8,359,601,711.76), rail (€28,984,820,634.22) and inland navigation (€4,919,026,003.40) (2020 prices) (OECD, 2021). From these 36 projects, 15 projects concern railway[13], 10 inland navigation and 11 road (see Table 4-2). Additional information on the types of infrastructure interventions can be found in Table 4-3. Ten projects are artwork constructions, 20 are horizontal infrastructures (for example, roads, inland waterways and rail tracks) and six are surrounding physical infrastructure works (such as quay works and noise protection shields). For each project the following information was acquired.

- the initial estimation or the first internal or external published estimation;
- the date of the initial estimation;
- the estimation at the moment of the contract awarding or the estimation closest to the moment of the contract awarding if that estimation was not available;
- the date of the moment of the contract awarding;
- the final cost when construction works were finished or the latest available estimation if the final cost was not available yet (90% of the construction works had to be finished);
- the date when construction was finished and operations started;
- scope changes occurred during the project and their value;
- the type of transport mode.

[11] In this amount scope changes are still included.
[12] Data on more recent years was not available.
[13] Initially, information on 669 rail projects was acquired. With the goal of becoming a representative sample of rail projects compared to the number of projects of the other transport modes, the database of rail projects was narrowed based on similar project sizes, horizontal-physical infrastructures rather than digital infrastructures and region of execution and a comparable number of projects was selected.

Table 4-2 Data overview (Authors, 2023)

		Transport mode			Total
		Inland waterways	Road	Railways	
Region of execution	Flanders	5	5	12	22
	Wallonia	5	6	3	14
Total		10	11	15	36

Table 4-3 Types of infrastructure interventions (Authors, 2023)

		Intervention type			Total
		Artworks	Horizontal infrastructure	Surrounding physical infrastructure	
Transport mode	Inland waterways	• Lock (or parts): 3 • Bridge: 1	• Waterways: 1	• Weir: 2 • Bank reinforcement: 1 • Quay: 2	10
	Road	• Highway crossing: 1 • Bridge: 2	• Road works: 7	• Noise protection shields: 1	11
	Railways	• Bridge: 1 • Tunnel: 2	• Tracks: 4 • Track beds & surrounding works: 8	/	15
Total		10	20	6	36

3.2 Data corrections

In order to obtain a homogenous dataset, we had to make a few corrections to our sample. For a first correction, the history of the organizations and their VAT liability was analyzed. Between 2005 and 2008 there was a wave of externalizing government organizations in Belgium, resulting in some of these organizations becoming subject to VAT. Government organizations in Belgium can be either externally or internally independent agencies. Externally independent agencies are subject to VAT and internally independent agencies are not subject to VAT. If the organization was an externally independent agency and subject to VAT at the time of the cost, VAT was excluded from the project costs. If the organization was an internally independent agency and not subject to VAT at the time of the cost, VAT was included as VAT was a cost for that organization at that time. The VAT liability of one organization, the *De Vlaamse Waterweg*, evolved over time as their structure changed from being part of the government to an externally independent agency in 2005, and thus being subject to VAT[14]. During the analyzed period *Infrabel* and *SOFICO* remained externally independent agencies and *Service Public de Wallonie Mobilit*é *et Infrastructures* and *Agentschap Wegen en Verkeer* internally independent agencies.

For a second correction, all prices were corrected for inflation using the Belgian ABEX index from 1997 until 2021[15] (Association Belge des Experts – price evolution in the construction industry). The initial estimation and price of awarding were corrected until the year of the final price[16].

For a third correction, if the project consisted of sub-projects, being project parts with a separate budget and tendering but which could only be operationalized once all parts are constructed, as the initial estimation considered the whole project, the awarding prices and final costs of the sub-projects were summed up.

Finally, the price of awarding or the final cost was corrected for "unforeseeable" scope changes. For each project in our sample, the responsible government agency provided us with scope changes and their respective costs, which occurred during the project execution. Problematic cost deviations are related to what we could call "foreseeable" scope changes, i.e. those changes that should or at least could have been foreseen by the project team, given the assumed high level of expertise and project management capacity, e.g. material or labor shortages. When the conceptual design of the project changed (for example when it was decided to build an additional lock instead of just one) or when additional works were executed for which it was impossible to gauge their necessity upfront, these scope changes were defined as "unforeseeable" and their costs were deducted from the price of awarding or the final cost. Three in-depth interviews with experts[17] were conducted to be able to separate foreseeable from unforeseeable scope changes. The price of awarding was then corrected when the scope change occurred during the pre-construction phase and the final cost was corrected when the scope change occurred during the construction phase. A total of

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[14] In 2005, the agency was named Waterwegen en Zeekanaal NV, before being merged with NV De Scheepvaart into De Vlaamse Waterweg in 2017.

[15] At the time of the calculations the ABEX index of 2021 was not yet available, therefore the index of 2020 was used as the index for 2021.

[16] If a project consisted of different sub-projects, the costs were corrected to the year of the finalization of the first sub-project, which finally results in an underestimation of the cost overrun.

[17] The three experts work for one of the large engineering consulting firms active in Belgium, and were involved in the sampled projects.

€40,921,549.18 (in 2020 prices) was deducted from the prices due to unforeseeable scope changes, and which occurred in four of the 36 projects, in two projects during the pre-construction phase and in two projects during the construction phase.

3.3 Methodology

To be able to answer the research questions, a statistical analysis using the SPSS software was performed. The variables presented in Table 4-4 were defined. The variables “cost overrun including scope changes percentage” and “cost overrun excluding scope changes percentage” were calculated based on the following formulas (1) and (2).

$$CostOverrunInclScopeChangesPerc = \frac{Final\ cost\ -\ initial\ estimation}{initial\ estimation} \times 100 \quad (1)$$

$$(all\ in\ prices\ year\ of\ final\ cost, final\ cost\ without\ scope\ change\ correction)$$

$$CostOverrunExclScopeChangesPerc = \frac{Final\ cost\ -\ initial\ estimation}{initial\ estimation} \times 100 \quad (2)$$

$$(all\ in\ prices\ year\ of\ final\ cost, final\ cost\ with\ scope\ change\ correction)$$

The pre-construction phase starts with the initial estimation and ends when the contract was awarded. The construction phase starts when the contract was awarded and the construction began, and ends at the end of the construction or project delivery. For projects consisting of subprojects, and thus different contracts, the pre-construction period was calculated from the moment of first initial estimation until the moment of the first contract awarding and the construction phase from the first contract awarding until the last project part was delivered. Below the formulas of the variables cost overrun excluding scope changes in the pre-construction and construction phase in percentage are presented (3) and (4).

$$CostOverrunExclScopeChangesPreConPerc = \frac{Price\ at\ contract\ awarding\ -\ initial\ estimation}{initial\ estimation} \times 100 \quad (3)$$

$$\left(\begin{array}{c} all\ in\ prices\ year\ of\ final\ cost, price\ at\ contract\ awarding \\ with\ scope\ change\ correction \end{array}\right)$$

$$CostOverrunExclScopeChangesConPerc = \frac{Final\ cost\ -\ price\ at\ contract\ awarding}{price\ at\ contract\ awarding} \times 100 \quad (4)$$

$$(all\ in\ prices\ year\ of\ final\ cost, all\ prices\ with\ scope\ change\ correction)$$

Table 4-4 List of Variables (Authors, 2023)

Variable	Type of variable	Explanation
CostOverrunInclScopeChangesPerc	Continuous	Percentage cost overrun over the whole duration of costs including scope changes
CostOverrunExclScopeChangesPerc	Continuous	Percentage cost overrun over the whole duration of costs excluding scope changes
CostOverrunExclScopeChangesPreConPerc	Continuous	Percentage cost overrun in the pre-construction phase of costs excluding scope changes
CostOverrunExclScopeChangesConPerc	Continuous	Percentage cost overrun in the construction phase of costs excluding scope changes
Transport mode	Categorical	Type of transport mode
Project size	Categorical	Category based on project size
Project duration	Continuous	Total duration of the project from initial estimation until project completion
Region of execution	Categorical	Region in which the project was executed
Period	Categorical	Period in which the project was completed

In the data one substantial outlier was discovered with a percentage cost overrun of 373.81%. In the pre-construction phase costs increased with 226% and in the construction phase with 45%. A check with the tendering agency and the project manager indicated this extreme large cost overrun was caused by a very premature initial cost indication and the decision to change the contract from a traditional procurement contract to a Design and Build contract, in which the contractor takes the responsibility for the design and building phase (Mathew et al., 2021). In this case contractor inherits more risks, resulting in a higher contract price. This project was causing a distorted view of the results, so the outlier was excluded for further analysis.

Followed by the previous calculations, a statistical analysis was performed. As the study focuses on the difference in average cost overrun over a number of determinants, statistical tests to compare means were applied. Based on the existence of interdependency between the data points and the number of groups to be compared, a choice for a specific test was made. Paired samples t-tests were used to compare information on different determinants over all projects (as samples are related, for example the percentage of cost overruns including versus excluding scope changes and the two project phases). Non-related data were tested using independent samples t-tests (for example, two regions and two time periods). In contrast to the previous determinants, for transport modes three groups had to be compared (road, rail and inland waterways). Therefore, a one-way analysis of variance (ANOVA) test was more suited. In all cases, the number of data points was larger than 30, or the hypothesis for a normal distribution from the Kolmogorov Smirnov test was accepted. One exception on the use of tests for comparing means was made, as the possible influence of the total project duration was analyzed using a single linear regression analysis.

4. Results and analysis

The main goal of this research is to gain a deeper understanding of the cost overruns of transport infrastructure projects in Belgium and their variations over different determinants. In the following section the results will be presented and discussed.

4.1 Cost deviations in Belgium

Table 4-5 shows a summary of the most relevant descriptive statistics for the variables cost overruns including and excluding scope changes. The average cost overrun, scope changes excluded from the calculations, for the studied 35 Belgian transport infrastructure projects is 10.26%, indicating that final cost prices are on average 10.26% higher than initial estimations[18]. This average is not significantly different from an expected average equal to zero (t = 1.749, p = 0.089, N = 35, one sample t-test). This expected amount of zero is based on the expectation that people involved in making the estimations will always do their best to estimate an amount as close to the final cost as possible, resulting in a cost overrun or underrun of zero. Compared to when scope changes are excluded from the research, the average increases to 12.22% when scope changes are included. The difference between the average cost overrun including and excluding scope changes is not significant (t =1.393, p =0.173, N =35, paired samples t-test).

Cost overruns range from -46.50% (meaning that in this case a cost underrun occurred) to 109.69% (meaning that in this case the final cost price doubled compared to the initial estimation). When scope changes are included in the calculations, the factor even ranges from -46.50% to 152.37%, indicating that in the project with the largest cost overrun a scope change occurred. Consider now Table 4-6, when scope changes are excluded from the analysis, in 18 projects a cost underrun occurred and in 17 projects a cost overrun. However, in 16 of the 17 cases with a cost overrun, this overrun was larger than a generally accepted amount of 5%. It is important to note as well that the standard deviation, indicating spread between the values and the mean, is large (34.69%, see Table 4-5). This implies that the percentages cost overruns are larger than cost underruns as the distribution is skewed to the right (or positive skewness).

[18] When the outlier (discussed in Methodology) was included in the research, the cost overruns excluding scope changes increased to 20.36%.

Table 4-5 Descriptive statistics Cost overruns including and excluding scope changes (Authors, 2023)

	Cost overrun including scope changes in %	Cost overrun excluding scope changes in %
N	35	35
Minimum	-46.50%	-46.50%
Maximum	152.37%	109.69%
Mean	12.22%	10.26%
Standard Deviation	38.33%	34.69%

Table 4-6 Frequency of Cost overruns and Cost underruns (Authors, 2023)

	N° of projects	%
Cost Underrun	18	51.4%
Small Underrun (> -5%)	7	20.0%
Large Underrun (< -5%)	11	31.4%
Cost Overrun	17	48.6%
Small Overrun (< 5%)	1	2.9%
Large Overrun (> 5%)	16	45.7%
Total	35	100%

4.2 Difference in cost deviations between transport modes

This section describes the difference of cost deviations over the different transport modes. The projects included in this research were either inland navigation, road or rail projects. Table 4-7 shows a summary of the relevant statistics for this topic. Road projects have the largest average cost overruns (22.82%), followed by inland navigation projects (4.62%) and rail projects (4.42%). Road projects exceed the general average cost deviations and rail and inland navigation project cost overruns are lower. The one-way ANOVA test rejects the hypothesis of equal means of cost overruns over the transport modes ($p = 0.360$, $N = 35$, one-way ANOVA test).

Table 4-7 Descriptive statistics Cost deviations different transport modes (Authors, 2023)

	Inland Waterways	Road	Rail
N	9	11	15
Minimum	-46.50%	-39.88%	-28.25%
Maximum	82.61%	109.69%	51.79%
Mean	4.62%	22.82%	4.42%
Standard Deviation	36.93%	43.92%	24.19%

4.3 Difference in cost deviations between project phases

Next to the transport mode, the difference in cost overruns over different project phases was also investigated. As already mentioned in 3 Data & methodology, a price was received for three moments in time: moment of initial estimation, contract awarding and end of construction works. Based on this, it was possible to calculate three different average cost overruns compared to only one. Besides the general cost overrun which measures the deviation between the price at the end of the construction works and the initial estimation, the cost overrun of the pre-construction and construction phase can be calculated as well (see Figure 4-1). Table 4-8 shows the statistical values for each period. It can be noticed that cost overruns are on average higher in the pre-construction period (5.23%) compared to the construction period (4.90%). This difference is not statistically significant (t = 0.056, p = 0.956, N = 35, paired samples t-test).

Figure 4-1 Explanation different project phases (Authors, 2023)

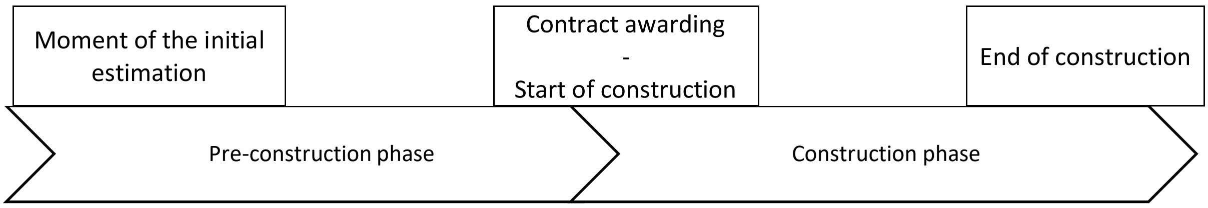


Table 4-8 Descriptive statistics Cost overruns different project phases (Authors, 2023)

	Cost overrun pre-construction phase	Cost overrun construction phase
N	35	35
Minimum	-38.00%	-36.42%
Maximum	89.83%	52.53%
Mean	5.23%	4.90%
Standard Deviation	26.89%	20.82%

4.4 Difference in cost deviations between transport modes over project phases

When combining the analysis of cost overruns over different transport modes and phases, additional results can be obtained. An overview of the calculated overruns for each mode in each phase can be found in Table 4-9. In the pre-construction phase, the highest cost overruns occur in road projects (20.88%) and cost developments are even negative for inland waterways (-2.12%) and rail projects (-1.84%), indicating cost underruns. In the construction phase rail projects experience the largest overruns (7.75%), compared to inland waterways (5.37%) and road projects (0.63%).

Table 4-9 Cost overruns different transport modes over two project phases (Authors, 2023)

Time period		Pre-construction phase	Construction phase
Transport mode	Inland waterways	-2.12%	5.37%
	Road	20.88%	0.63%
	Railways	-1.84%	7.75%

4.5 Analysis of cost deviations over two decades time

All projects in this sample were executed from 1997 to 2021. Two categories were created and each project was divided based on its year of completion.

- 1997–2008: 13 projects
- 2009–2021: 22 projects

The periods were split up into a period before and after 2008. This year marks the beginning of the great recession, which potentially caused a stream of better project and cost management due to the limited financial resources. But it is also a year in which different government entities in Belgium went through a reorganization.

Table 4-10 shows an overview of the minimum, maximum, average cost deviation and the standard deviations for each time period. Cost overruns were at their lowest point in the first period of completion (1997–2008, 2.8%) and at their highest point in the last period of completion (2009–2021, 14.7%). Although the difference over the periods appears to be large, the differences in means are not statistically significant (p =0.334, independent samples test).

Table 4-10 Average Cost deviations different periods (Authors, 2023)

	Cost deviation 1997-2008	Cost deviation 2009-2021
N	13	22
Minimum	-28.25%	-46.50%
Maximum	62.29%	109.69%
Mean	2.78%	14.68%
Std. Deviation	25.08%	39.16%

4.6 Cost deviations over two regions in Belgium: Flanders and Wallonia

Focusing on the difference in cost overruns between two regions in Belgium, it can be noticed from Table 4-11 that the average cost overrun of projects executed in Flanders is higher (9.05%) than the average of projects executed in Wallonia (12.07%). Overruns of projects executed in Wallonia seem to be higher than the general average (10.26%), while in Flanders they are lower. No significant difference between the averages of the two regions can be noticed (p =0.805, independent samples test).

Table 4-11 Average Cost deviations different regions (Authors, 2023)

	Cost deviation Flanders	Cost deviation Wallonia
N	21	14
Minimum	-46.50%	-21.99%
Maximum	109.69%	82.61%
Mean	9.05%	12.07%
Std. Deviation	39.31%	27.65%

4.7 Project size influencing project cost deviations

In order to analyze the variation over the determinant project size, projects were divided into three size categories based on their final cost price in 2020 prices. Following Cantarelli (2011), group composition is based on an equal distribution of number of projects in each group. This results in the following categories.

- Small < €5,000,000: 12 projects
- Medium €5,000,000 < €25,000,000: 12 projects
- Large > €25,000,000: 12 projects

The outlier was classified as a large project and because of its exclusion, the number of projects in the category large reduced to 11.

As shown by Table 4-12, medium sized projects tend to have the highest cost deviations (21.60%), compared to small (4.06%) and large (4.64%) projects. When comparing the cost deviations in the pre-construction and construction phase for each size category, the same conclusions can be made for the pre-construction phase (small: 3.53%, medium: 13.76% and large: 5.47%) but not for the construction phase. During the construction phase the highest overruns are occurring in small size projects (8.96%) compared to medium (7.52%) and large (-2.38%).

Table 4-12 Average Cost deviations different size categories (Authors, 2023)

	Small	Medium	Large
N	12	12	11
Minimum	-46.50%	-24.75%	-39.88%
Maximum	50.79%	82.61%	109.69%
Mean	4.06%	21.60%	4.64%
Std. Deviation	26.68%	35.67%	40.92%

4.8 Influence of the project's total duration

A project's total duration can be defined as the time period between the moment of the initial estimation and the start of the pre-construction phase and the moment of project completion. On average, the total duration of this sample is six years, for the pre-construction phase it is one year and for the construction phase five years. Inland waterways and road projects tend to take the longest (six years), compared to rail projects (five years). When dividing the projects into four groups by percentage cost deviation with an almost equal number of projects, it can be noticed that project duration is the highest for the projects with the lowest and highest cost deviations.

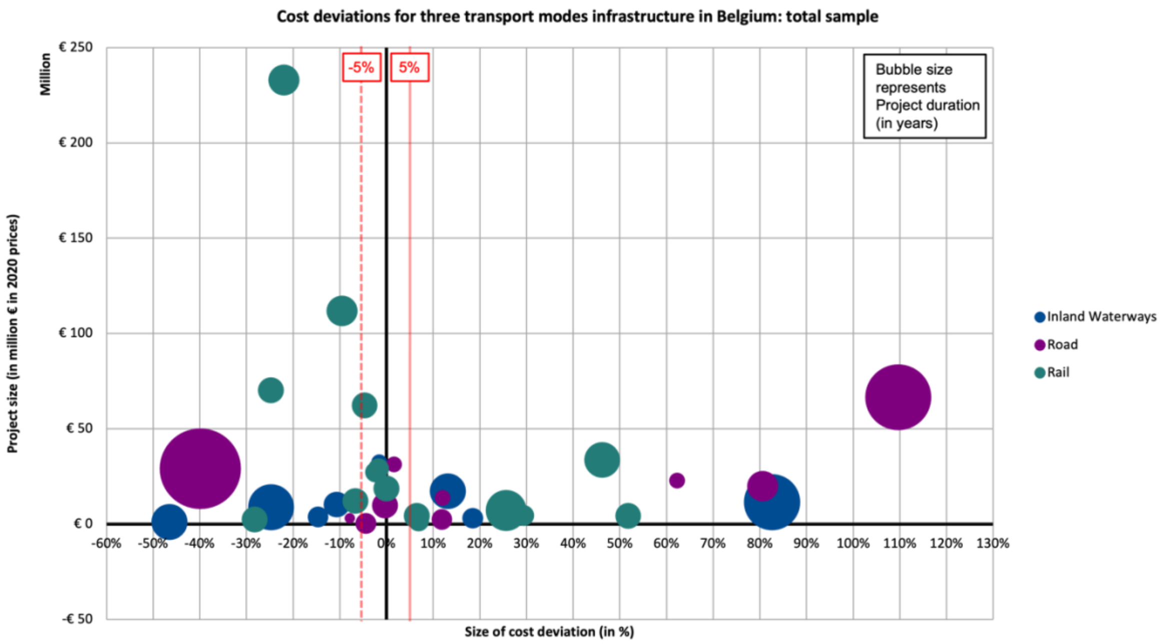
- Cost deviation >25%: 10 projects, average duration of seven years
- Cost deviation 25% < 0%: 7 projects, average duration of four years
- Cost deviation 0% < - 10%: 10 projects, average duration of four years
- Cost deviation < - 10%: 8 projects, average duration of seven years

A linear regression analysis shows that the project's total duration has no significant impact on the magnitude of cost deviation ($\beta = 0.170$; $p = 0.329$).

5. Discussion

In Figure 4-2 a graphical presentation of the results of the Belgian case study is shown. The x-axis represents the size of cost deviation and the y-axis the size of the project. Two red lines are showing an acceptable 5% cost deviation in both directions. The colors of the bubbles are each representing the type of transport mode, blue for inland waterways, purple for roads and green for railways. Finally, the bubble size represents the total duration of the project in years.

Figure 4-2 Cost deviations for three transport modes infrastructure in Belgium: total sample (Authors, 2023)



The average cost overrun in Belgium is 10.26%, meaning that projects prices rise on average with 1/10th of their initial estimated price. This percentage is lower compared to the averages found in studies executed worldwide, as discussed in the literature review. However, it is in line with the average found in the Netherlands (16.60%), a country that has been broadly compared to Belgium due to its economic and cultural similarities and being a neighboring country equally competitive in transport and logistic services at the heart of Europe (Cantarelli, Flyvbjerg, et al., 2012; Cantarelli, Molin, et al., 2012; Cantarelli, van Wee et al., 2012). The same applies for the study executed in Sweden by Lundberg et al. (2011), who found an average cost deviation of 15%. Compared to another similar country Germany, for which cost deviations were investigated by Kostka and Anzinger (2016) and an average of 33% was found for transportation projects, and the worldwide study by Flyvbjerg et al. (2002, 2003) in which an average of 27.6% was calculated, Belgian cost overruns appear to be somehow lower. Yet, they still largely exceed acceptable levels, especially in a context of negative comparative state of the Belgian (road) infrastructure with its neighboring countries and the worsening government financial situation.

Besides that, our analysis also indicates that no improvement took place over time when comparing average cost deviations of projects executed from 1997 to 2008 (2.78%) and from

2009 to 2021 (14.68%), as shown when comparing Figure 4-3 and Figure 4-4. This is against the expected improvement from the literature review and confirms the need for more research into this topic, and especially its causes, in Belgium. Results show that medium sized projects seem to have the highest cost deviations and that at this moment more attention is given to the small and large projects. Total duration seems to enforce magnitudes of cost deviations in both positive and negative directions, resulting in having no impact in total (see Figure 4-2). Cost overruns are the largest for road projects (22.82%) in Belgium, followed by inland navigation (4.62%) and rail projects (4.42%). In contrast to the literature review, overruns regarding road projects appear to be the highest in Belgium, while inland waterways' projects perform better. The average found for rail projects is within the range observed in the literature. Importantly, we add here that different transport modes and project types are, in most of the countries, managed by different organizations and government agencies. The different structures and project management practices of these various organizations and agencies may imply and explain the differences observed in cost overruns (Cantarelli, van Wee et al., 2012).

Cost overruns in Belgium are the highest in the pre-construction phase (i.e., the period between the first initial estimation until the moment of contract awarding, 5.23%) versus the construction phase (i.e., the period between the moment of contract awarding and the end of construction, 4.90%), as can be noticed by comparing Figure 4-5 and Figure 4-6. This could be caused by cost underestimation and scope changes, as suggested by Andersen et al. (2016). Nevertheless, the second cause cannot explain the cost overruns found in our study as awarding and final prices were corrected for scope changes, unless if it were all foreseeable scope changes. Since all scope changes were normally included in other studies, our correction results in an "underestimation" of the cost overruns in the context of benchmarking (Cantarelli, Molin, et al., 2012; Cantarelli, van Wee et al., 2012). Cost deviations are the highest for road projects during the pre-construction phase and it is clear that for this mode causes need to be found in this phase rather than in the construction phase. For inland waterways and rail projects, the opposite applies. This difference could confirm our belief that there is more opposition to road projects today. Further research is necessary to assess whether the deliberate underestimation of project costs in the pre-construction phase of road projects is the most prominent cause of cost overruns in Belgium.

Figure 4-3 Cost deviations for three transport modes infrastructure in Belgium: period 1997-2008 (Authors, 2023)

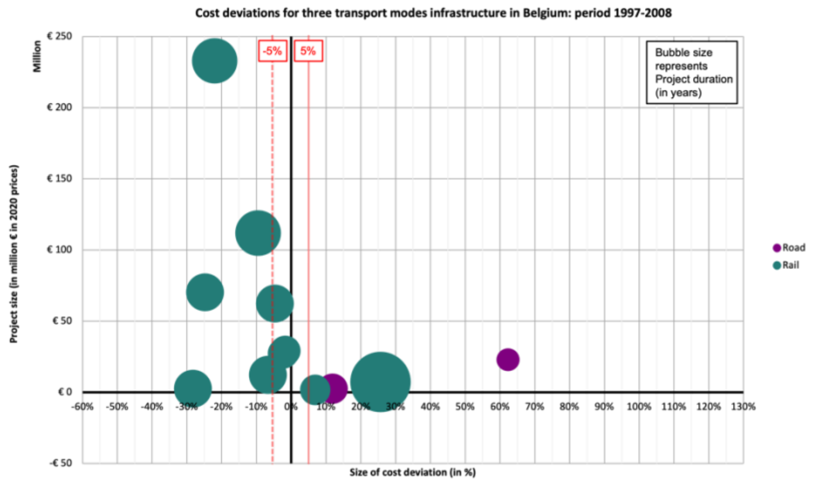


Figure 4-4 Cost deviations for three transport modes infrastructure in Belgium: period 2009-2021 (Authors, 2023)

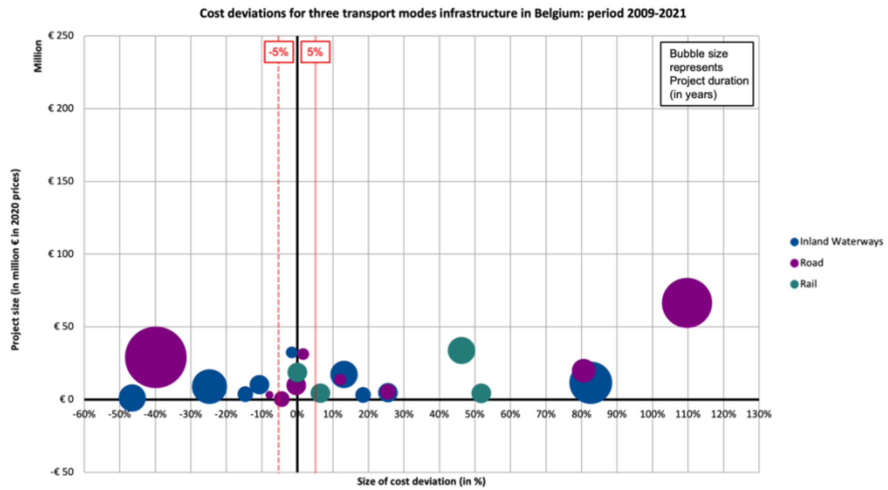


Figure 4-5 Cost deviations for three transport modes infrastructure in Belgium: pre-construction phase (Authors, 2023)

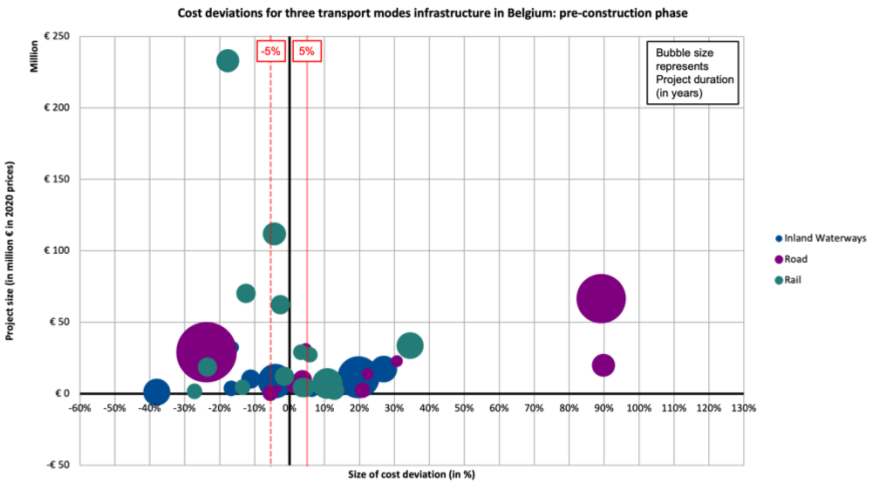
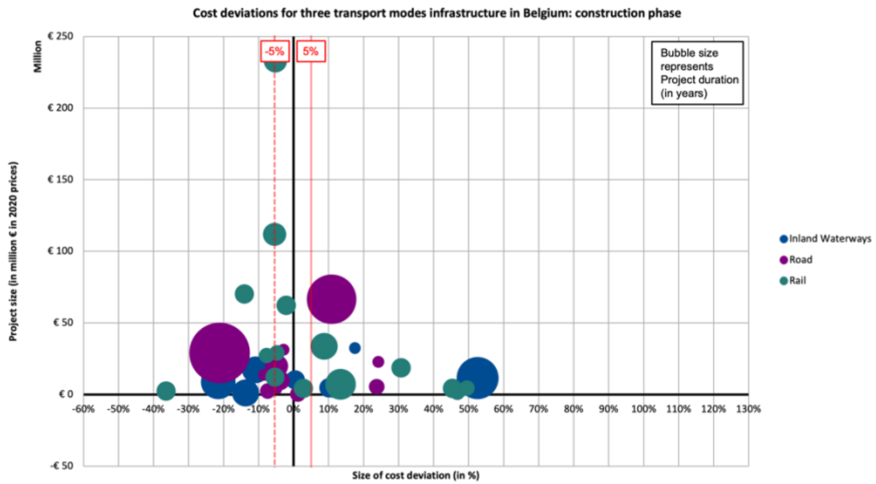


Figure 4-6 Cost deviations for three transport modes infrastructure in Belgium: construction phase (Authors, 2023)



6. Conclusion and policy recommendations

The fragmented and focused existing research on the topic will unlikely reveal the problem in such a way that accountable organizations can understand what really drives the issue. It is ultimately by combining all determinants and targeting organizations with a unique responsibility for a particular combination of mode and region, that we pinpoint the problem and provide more insight for policy makers and tendering agencies. This research attempts to correspond to that need by determining the size of cost overruns in Belgium for three transport modes, in two regions, for three size categories, over two periods and for two crucial phases of the transport infrastructure projects. We conclude that cost deviations in Belgium are on average lower than in other studies performed, but still significant, whereas no improvement over time can be noticed. The highest overruns occur for road and medium sized projects and for projects executed in Wallonia. Total duration increases for larger cost deviation cases but has no impact in general. Finally, more attention needs to be given to the on-budgeting during the pre-construction phase, especially for road projects.

Different policy implications can be derived from this study. First, in most of the projects in which cost overruns occurred in Belgium, the acceptable 5% deviation is exceeded. Therefore, governments and transport agencies need to put additional effort in controlling the project financials with these extensive overruns. Second, cost overruns appear in each transport mode and for each project size, and especially in road and medium sized projects in Belgium. Third, attention should be given to both the pre-construction and construction phase as cost overruns occur throughout the whole project lifecycle. Differences exist however over the transport modes for each project phase. For road projects, governments need to focus more on controlling costs in the pre-construction phase, compared to rail and inland waterways projects which have the highest deviations in the construction phase. Based on a first link with potential causes and percentages, strategic underestimation and design changes would appear the most in road infrastructure projects, while inland waterways and rail projects are likely to have more problems with contractor conflict management, material management, labor problems, additional changes during construction and poor planning. But further in-depth research would be needed to have more details on these causes and develop potential solutions in line with these causes.

7. Further research options

Based on the research, some further research paths can be defined. This can be done on the topic of cost overruns specific, but also on “project benefit” and “cost estimation” as broader concepts. First, causes can be defined for cost variations in each project phase for each transport mode. Second, additional research can be executed into the different specific causes of cost overruns such as strategic underestimation for the pre-construction and conflict management for the construction phase. Third, detailed research on the lifecycle and maintenance costs versus the projected costs can be executed. Fourth, results of traditional procurements contracts overruns can be compared with results on cost deviations of PPP projects and it can be assessed whether the type of contract indeed has an impact on potential cost overruns. Fifth, next to cost estimations, benefit estimations could be investigated as well. Cost-Benefit Analyses include both a benefit and a cost part and the balance between those two influences the decision of executing a project. If costs in general tend to overrun, but benefits also turn out higher than expected, based on ex-post social cost-benefit analyses of projects – which are rarely done –, then in the end a cost overrun is maybe not that big of a problem.

8. Research financing

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10. Appendix

Table 4-13 Overview of existing studies (Authors, 2023)

Author(s)	Country of focus	Type of projects	Sample size	Average size of cost overrun	Occurrence of cost overrun
Flyvbjerg et al. (2002) Flyvbjerg et al. (2003)	World	Rail, road and fixed links	• Total: 258 • Rail: 58 • Road: 167 • Fixed link: 33	• Total: 27.6% • Rail: 44.7% • Road: 20.4% • Fixed link: 33.8%	86%
Dantata et al. (2006)	United States	Rail transit projects	16	30%	81.25%
Lee (2008)	Korea	Road, rail, airport and port	• Total: 161 • Road: 138 • Rail: 16 • Airport: 2 • Port: 5	• Road: 10.76% • Rail: 47.64% • Airport: 60.39% • Port: 36.29%	• Total: 161 • Road: 87% • Rail: 93.75% • Airport: 100% • Port: 100%
Roxas & Chalermpong (2008)	Asia	Road and bridge	• Total: 129 • Road: 89 • Bridge: 40	• Total: NA • Road: -1.2% • Bridge: 2.3%	42%
Singh (2009)	India	Rail and road	• Total: 894 • Railways: 122 • Road transport and highways: 157	• Total average: 15.17% • Railways: 94.84% • Road transport and highways: 15.84%	• Total: 40.72% • Railways: 82.79% • Road transport and highways: 54.14%
Lundberg et al. (2011)	Sweden	Rail and road	• Total: 167 • Railways: 65 • Road: 102	• Total average: 15.0% • Railways: 21.1% • Road: 11.1%	NA
Cantarelli, van Wee, et al. (2012) Cantarelli, Molin, et al. (2012) Cantarelli, Flyvbjerg et al. (2012)	The Netherlands	Road, rail and fixed link	• Total: 78 • Rail: 26 • Road: 37 • Tunnel: 8 • Bridge: 7	• Total: 16.50% • Rail: 10.6% • Road: 18.8% • Tunnel: 34.9% • Bridge: 6.6%	55.10%
Makovšek et al. (2012)	Slovenia	Road	• Sample I: 20 • Sample II: 36	• Sample I: 30.86% • Sample II: 19.19%	• Sample I: 70% • Sample II: 61.11%

Kostka & Anzinger (2016)	Germany	Airport, bridge, rail, road, tunnel and waterway	• Total finished projects: 119 • Total finished projects Transportation: 36 • Airport: 4 • Bridge: 2 • Rail: 6 • Road: 20 • Tunnel: 2 • Waterway: 2	• Total average finished projects: 73% • Total average finished projects Transportation: 33% • Airport: 48% • Bridge: 11% • Rail: 34% • Road: 30% • Tunnel: 42% • Waterway: 57%	NA
Love et al. (2017)	Australia	Rail	16	23%	87.5%
Andrić et al. (2019)	Asia	Road, rail and energy	102	9.88%	56.86%

CHAPTER 5
RELATIONAL ISSUES AS CAUSES OF PERSISTING COST OVERRUNS IN PUBLIC INFRASTRUCTURE PROJECTS

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CHAPTER 5

RELATIONAL ISSUES AS CAUSES OF PERSISTING COST OVERRUNS IN PUBLIC INFRASTRUCTURE PROJECTS

Laura Molinari, Elvira Haezendonck, Katrien Van Rompay, Vincent Mabillard and Michael Dooms

Abstract Public authorities are expected to provide a salient infrastructure network, with only limited financial resources. Many of these projects go over budget and research into explanations for these cost overruns is necessary to provide solutions. We conclude that in Belgium, and broader, solutions need to be found for relational issues internal and external to the project core. Before a lot of attention was given to technical and legal project aspects, while we should focus more on the social part.

1. Introduction

Cost deviations, the case when a project's final cost differs from the initial estimation, can have a large impact on an authority's budget. Molinari et al. (2023) estimated average cost overruns in Belgium at 10.3% for public infrastructure projects. Other researchers worldwide found different magnitudes of cost deviations, but in all cases on average an increase occurred. Moreover, previous research shows that the problem of projects going over or under budget keeps persisting in Belgium and that the situation not improved, but even worsened when comparing two periods (1997-2008 vs 2009-2021) with each other (Molinari et al., 2023). One the one hand, cost overruns (initial estimation smaller than final cost) result in other projects' executions being suspended as a lower amount of financial resources remains available. On the other hand, against common belief, negative deviations or underruns (initial estimation larger than final cost) also negatively influence the execution of an organization's project portfolio. Spending less than initially estimated on one project leads to the fact that initially a lower budget would have been needed, losing the opportunity of realizing other (critical) projects that now ended up on the waiting list.

Governments need to work with tight budgets, and the energy crisis that started in 2022 reduced the available financial resources. However, large investments in infrastructure are of highest urgency, since the rising trade levels are requesting a robust and reliable transport infrastructure with increased capacity. At the same time, the COVID-19 pandemic highlighted the need for more investments in hospitals and residential care facilities. Sustainability on the environmental and social side also creates additional challenges. Transport infrastructure is thus expected to be suited for new ways of transport and buildings should be as net zero as possible. On the social side, among other challenges, social crises in prisons are asking for an upgrade of existing or build of new infrastructure.

In order to better understand and hopefully reduce infrastructure costs' deviations (either positive or negative), the root causes of these deviations need to be further researched. Some researchers already provided an overview of the different causes of cost overruns based on the literature (among others Adam et al., 2017 and Cavalieri et al., 2019). However, Aljohani et al. (2017) state that applying results from this literature to single countries is not sufficient. Differences between contexts call for country-specific research regarding cost overruns. Variation over countries can result from the dissimilarity in decision-making processes or other factors influencing the construction industry as a whole (Cantarelli et al., 2012 and El-Ahwal et al., 2016). This study responds to this need by first, systematically analyzing the global literature and second, questioning the results found from the global literature in Belgium. Consequently, the list for the global context was adapted to the situation and environment of the Belgian construction industry and based on the Belgian specific list, better, more suitable, solutions could be proposed and conclusions could be drawn. Because of limitations in the extent of the research, the study is limited to causes of cost overruns exclusively.

2. Methodology

To the extent of our knowledge, causes of cost overruns were not yet researched in Belgium. The unavailability of sources in Belgium led us to review the literature and gain first insights into the topic. Results from this analysis of the literature were subsequently tested in the Belgian context through an online survey. The methodological approach to analysing the causes of cost overruns is quite rare. Therefore, not only the country specific research but also the methodology could be of added value for research on this topic. Our research was executed in two phases. Phase 1 concerns the global context, whether phase 2 focuses on the application in the Belgian context.

2.1 Phase 1: Literature review

The first step included carrying out a systematic literature review to determine a list of the most frequently occurred and cited causes. This list is in a later phase used as input for the survey. First, a list of relevant scientific peer reviewed journals was made. The list was compiled based on four sources, i.e., three of the most recent literature reviews on cost overruns (Adam et al., 2017; Cavalieri et al., 2019 and Odeck, 2019) and a ranking of construction management journals (Chau, 1997). In total, a list of 54 journals was gathered. Two journals appeared to be journals that were already included in the list under a different name, so these were excluded. Second, using the *Publish or Perish* software, a search in Scopus was carried out based on a combination of key words. The possible key words can be divided into four categories:

- Category 1: infrastructure; construction
- Category 2: cost; budget

- Category 3: overrun; deviation; escalation; variation; extension
- Category 4: cause; reason; explanation; factor; determinant

Categories 1 and 2 were combined with either category 3 and 4 or category 3 or 4 separately, for example: infrastructure cost overrun cause, infrastructure cost cause and infrastructure cost overrun. The key words were based on two academic sources (Adam et al., 2017 and Herrera et al., 2020) and were supplemented with synonyms by the researchers. The time period was set on 2000 until 2022, as transport infrastructure assets have a lifespan of minimum 20 to 30 years and usually even longer. Therefore, a broad time period is necessary to cover all important moments of decision making and to complete an asset's whole lifecycle. However, Cavalieri et al. (2019) state that before 2000, only case studies of a small number of projects on cost overruns of transport infrastructure projects were carried out, with per definition limited generalizability. As a consequence, 2000 was chosen as the starting date. English as main language of the article was set as the final criterion. The search for articles was carried out in the period February-March 2022. 56 papers were found corresponding to the criteria set. The list of papers analysed can be found in Appendix, Table 5-6.

Following the collection of these papers, a content analysis using the software Nvivo was carried out. Cost overrun explanations were identified in the different papers and linked to a list of causes. The causes were labelled as generic terms based on the explanations found. Throughout the coding procedure, ten categories with their corresponding causes were created. Categories were partially based on the categories created by Adam et al. (2017). These categories were created with a specific focus on infrastructure projects with a public purpose, which make them suitable for this study on Belgian public infrastructure projects. The list is not exhaustive, but categories are described in a general way, which allows to easily categorize all causes in a comprehensive way. Some other authors categorized causes by stakeholder groups (incl. project core actors). This approach was however assessed as inappropriate for this study for two reasons. First, the study covers all stakeholder groups in Belgium and was sent to various respondents. Second, the aim was to first create a general overview of all causes with a potential influence on cost overruns and to assign the impact of causes to stakeholders as a second step. Some categories were added to the list of Adam et al. (2017) in attempt to make it more complete (Process and conflict management, Government, Site management and partly External factors). Others were renamed to better fit the underlying causes, such as: project management and contract definition, Governance, Human behaviour, Finance and Material and equipment. Using the Nvivo software, a ranking of these categories and causes for the global context could be developed.

2.2 Phase 2: Survey

The second step included the creation of a survey using the defined list of categories and causes from phase 1 as input. In order to collect information on explanations of cost overruns in Belgium, the survey was sent to different stakeholders involved in public infrastructure projects. Having this broad variation of groups, allows to better represent the entire Belgian sector. Stakeholder groups questioned were public tendering authorities, (general) contractors, engineering & design offices, project financiers (equity, banks…) & insurance companies, other consulting services (finance, legal etc.) and other experts (academics, Court of Auditors…).

At the beginning of the survey, respondents were asked to indicate the infrastructure domain(s) and contract type(s) in which they have experience. Furthermore, they were also asked to assign a number on a scale from 1 to 10 to the different domains and contract types based on size of cost overruns according to their own personal experience, assigning 1 means low-cost overruns and 10 means high overruns. As we do not expect each respondent to have experience in each domain and/or contract type, only the domains and contract types in which they have experience were shown and the option to answer 'no opinion' was also provided. The domains of infrastructure and contract types are shown in Table 5-1. Infrastructure domains, consisting of horizontal (or transport) infrastructure and vertical infrastructure (or buildings) were defined based on a conversation with representatives of the ten largest construction companies in Belgium. The list of contract types on the other hand was based on the different contract forms defined by the PPP expertise center of Flanders (Vlaams Kenniscentrum PPS, 2018). These seven types are used in Belgium to facilitate the execution of public infrastructure projects.

Table 5-1 Different domains of infrastructure and contract types (Authors, 2023)

Infrastructure domains:	Contract types:
<u>Horizontal infrastructure:</u> • Road infrastructure • Rail infrastructure • Water infrastructure (maritime and inland waterways)	<u>Traditional contracts:</u> • Traditional procurement
<u>Vertical infrastructure:</u> • Education, recreation and social housing (e.g. schools, swimming pools, sport infrastructure, museums, student housing,...) • Public buildings (e.g. prisons, courthouses and administrative buildings) • Hospitals and residential care facilities	<u>Public Private Partnership (PPP) contracts:</u> • Engineering & Construct (E&C) • Design & Build (DB) • Design, Build & Finance (DBF) • Design, Build & Maintenance (DBM) • Design, Build, Finance & Maintenance (DBFM) • Design, Build, Finance, Maintenance & Operate (DBFMO) and concession

Further in the survey, we asked questions on the categories and causes defined through the literature review. The questions for each category were threefold. First, we asked to assess the importance in terms of frequency of occurrence of each sub cause by asking them to rank the causes. Second, the respondents were asked to assess the causes' impact on the construction sector in Belgium in general, and third of each category on different groups of stakeholders. In the second part, we used 5-point Likert scales (No impact at all – Low impact – Medium impact – High impact – Major impact). The third part asked the respondents to assign 100% (as measure of impact) over the stakeholder groups. They were allowed to assign 100% to one group and 0% to the remaining groups. Assigning 100% to a group meant that this group was paying for the total amount of cost overruns occurred. Possible stakeholder groups were public tendering authorities, (general) contractors and engineering & design offices. An option 'others' was also added with the possibility specify to which group they were referring to. Finally, respondents were asked to choose the five most occurring causes of cost overruns (from the list of causes used in the previous questions) in their opinion and to rank them.

The survey allowed to create a ranking of causes specifically relevant in our national context and to gain deeper understanding in the problems occurring in Belgium. Furthermore, the impact assessment of the causes showed its impact on the sector in general and on the different stakeholders specifically.

The survey, created with Qualtrics, and was sent to 151 potential respondents. The targeted sample consisted in about one third of public tendering authorities (44 invitations), 20% of contractors (33 invitations), 15% of engineering and design offices (22 invitations), and about one third of project financiers and insurance companies, consultants, and independent experts (52 invitations).

In the final phase, answers were retrieved and data were prepared to be analysed in the SPSS software. Based on the results, the retrieved information was discussed, and conclusions were drawn. In the conclusion, results from the literature review and the survey are compared, to define the causes of cost overruns both in general and in Belgium, to identify possible differences.

3. Results and discussion

3.1 The global context

Following on the search in Scopus by the Publish or Perish software based on the set requirements in the context of the literature review, 71 papers were found (of which 56 were analysed in Nvivo due to access restrictions). The Nvivo analysis resulted in a list of 43 causes of cost overrun, all occurring globally in infrastructure projects. These causes were grouped into ten categories based on the nature of the cause. In Table 5-2, a list of the ten categories with their explanation of the content can be found, together with the list of causes included in that specific category. The goal of the analysis was not to create an exhaustive list of causes of cost overruns, but to list and analyze all causes found in literature resulting from the systematic search.

Table 5-2: Categories of causes (Authors, 2022, partially based on the categories created by Adam, et al.,2017)

Categories:	Explanation:	Causes:
Category 1: Project management and contract definition	The category project management and contract definition represents the causes for the cost overruns related to project governance, labor management, stakeholder management and scope, time and cost management.	• Labor quality • Labor quantity • Poor quality of technical documents and studies • Poor estimation of scope, time and cost • Inadequate project governance • Scope time and cost management • Stakeholder management
Category 2: Process and conflict management	The category process and conflict management represents the causes related with the procedure followed to get to the contract and the management of conflicts resulting from the contract.	• Conflicts on scope, time and cost • Conflicts on trust between partners • Contract processes
Category 3: Government	The category government represents the causes related with government policies and processes.	• Bidder specifications and behaviour • Changes political environment • Fraudulent practices • Government policy not in line with activities • Legal requirements (tax policy, labor policy, environmental policy) • Tender specifications and procedures • Permit risks
Category 4: Governance	The category governance represents the causes related with the governance structure, processes and decision-making practices and the structure of the project team.	• Incompetent actors • Project structure and decision-making processes
Category 5: Communication	The category communication represents the causes related with communication and coordination between the different project actors and the information sharing.	• Lack of communication • Lack of coordination • Lack of information sharing
Category 6: Human behaviour	The category human behaviour represents the causes related with a person's psychological behaviour, for example optimism bias and deception.	• Intentional misrepresentation of estimations • Optimistic behaviour of the estimators

Category 7: Finance	The category finance represents the causes related with payments, variations of prices of resources and raw materials and the financial health of project actors.	• Financial difficulties of actors and cash flow problems • High interest rates • Increased prices of raw materials, labor and equipment • Insurance problems • Late payments • Source of financial resources
Category 8: Site management	The category site management represents the causes related with the actual execution of the project and includes factors on reworks, site and working conditions, on site safety management and the use of specific construction methods.	• Delays in execution • Lack of use of adequate and innovative construction methods and tools • On site security and safety management • Poor conditions of construction site • Rework • Suspension of work
Category 9: Material and equipment	The category material and equipment represents the causes related with materials and equipment used for construction. It consists of the supply of material and equipment, material quality and production and adequate usage and maintenance cost of equipment.	• Material & equipment inadequate use • Material & equipment maintenance and end-of-life processes • Material & equipment procurement • Material & equipment type changes • Poor quality of material & equipment
Category 10: External factors	The category external factors represents the causes related with the factors outside of the project control related to the economy and the natural environment.	• Economic factors • Natural factors

To define the most important reasons for causing cost overruns worldwide, a ranking of the causes was created in terms of decreasing number of times mentioned in the literature. Table 5-3 below lists the ten causes appearing the most frequent in literature. Poor management of scope, time and cost appears on the first place, indicating that it can be seen as the most frequently mentioned, and thus occurring, cause of cost overruns globally. Poor management of scope, time and cost is followed by poor quality of technical documents and studies, inadequate project governance, poor estimation of scope, time and cost and material & equipment procurement in the top five. As can be noticed, a connection could exist between the first four causes of the list, all being related to the project's specifications and its governance (and all included in category 1: project management and contract definition). The high frequency of problems with these two project parts globally indicates the high importance and attention that should be given to these. The hypothesis could be drawn that if the construction sector in Belgium is incurring similar problems to the worldwide situation, the highest ranked causes need to reflect problems with the project's specifications and its governance and being part of category 1.

Table 5-3 Top 10 causes globally (Authors, 2023)

Top 10 causes of cost overruns for infrastructure projects global

Causes		Number of citations
1.	Poor management of scope, time and cost	114
2.	Poor quality of technical documents and studies	73
3.	Inadequate project governance	67
4.	Poor estimation of scope, time and cost	61
5.	Material & equipment procurement	49
6.	Increased prices of raw materials, labor and equipment	37
7.	Lack of labor quality	25
8.	Tender specifications and procedures	24
9.	Contract processes	23
10.	Legal requirements	22

The result of poor management of scope, time and cost appearing on the first place could have been expected for two reasons. First, the wording of this cause is widely encompassing and can directly be linked to cost overruns as poor management of cost can look like another formulation of the term cost overruns. Second, not adequately monitoring a project's scope, planned duration and budget immediately leads to a possible deviation of the budget. For other two causes from the top five, a related explanation could be given. The quality of drawings and technical documentation has a connection with the scope and design of the project. This causes that a poor scope definition immediately results in incomplete documents. In turn, this impacts the initial estimation and management of the project's scope, followed by the duration and cost. The literature confirms the poor initial determination of scope and continuous changes during execution (see, inter alia Creedy et al., 2010; Enhassi et al., 2010; Memon & Rahman, 2013; Rosenfeld, 2013; Adam et al., 2017 and Cavalieri et al., 2019).

Not directly connected with the previous causes, inadequate project governance includes the general management of the project, team interactions and experience. Its high rank on the list was caused by the frequent expressing of problems with manager capabilities and team capabilities on a technical (with for example project type and/or complexity) and social level (with managing and collaborating in teams). The importance of the social level and its impact on cost overruns was given as an explanation for cost increases by for example Adam et al. (2017) and Balali et al. (2020). The impact of the technical level is more straightforward. As indicated by Kaliba et al. (2009), Enhassi et al. (2010), Jung et al. (2015) and Adam et al. (2017), the complexity, type and scale of a project could affect a project's cost performance.

Finally, appearing on the fifth place are problems with material and equipment procurement. The shortage of material and equipment and issues with delivery have been reported as possible explanations for cost overruns for a long time (Frimpong et al., 2003 and Enhassi et al., 2010), but also remained important in more recent years (see among others Adam et al., 2017 and Kavuma et al., 2019). Material and equipment procurement issues could have a significant impact on a project's time schedule and budget. Different issues such as shortage and availability, limited number of suppliers and delays, were also mentioned (Enhassi et al., 2010; Memon & Rahman, 2013; Rahman et al, 2013 and Adam et al., 2017).

Causes included in category 1 (project management and contract definition) were discussed most frequently in literature. This implies that global research defines this category as the most important for explaining cost overruns. Being assessed on the same measurement (number of times mentioned) as the previous ranking of causes, it is not surprising that five causes included in the top ten make part of the first category. This confirms again the importance of Category 1 when looking for possible explanations for cost overruns.

The following section explores the causes that occur the most and have the highest impact on the public infrastructure sector in Belgium, with the aim of creating a ranking of importance adapted to the country's context. Besides that, the Belgian ranking is compared to the global one presented above.

3.2 The Belgian context

3.2.1 Information on the respondents

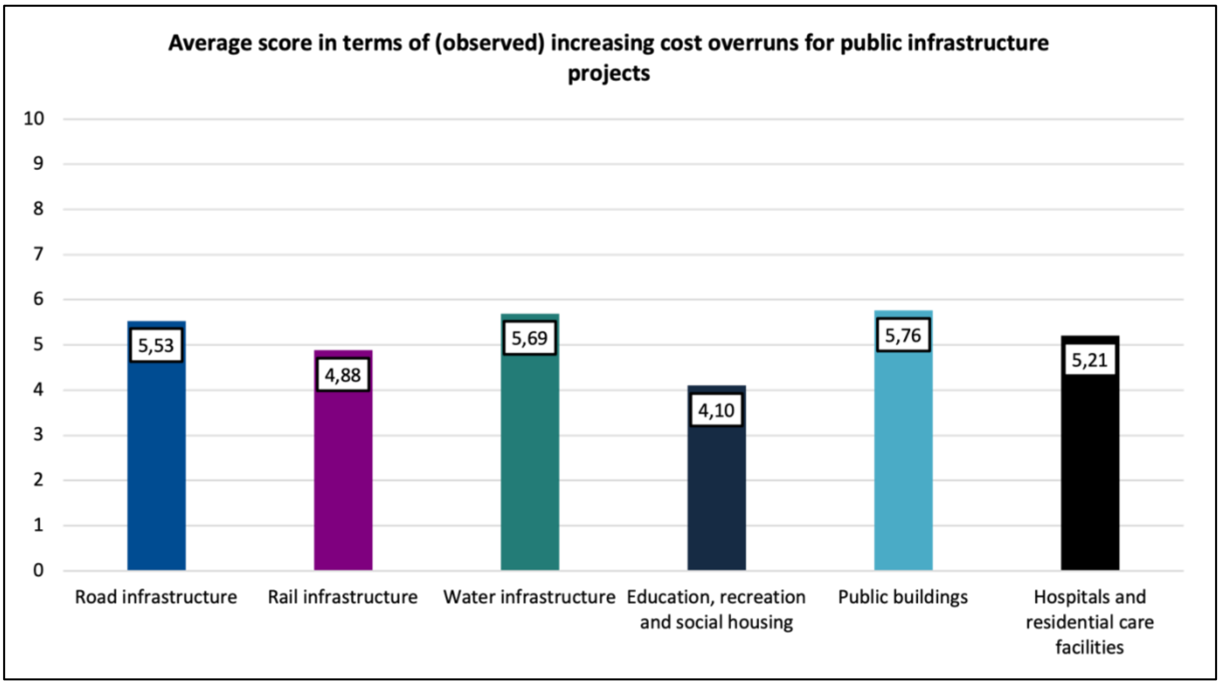
As mentioned earlier, the survey was sent out through an online tool to 151 potential respondents. Of the sample, 52 respondents (34%) filled in the survey. The highest response rate can be found within the group of contractors (55% responded). As the contractors are members of the organization for which this study has been executed, this could have been expected. The second highest response rate was achieved for the other independent experts (45%) and the public tendering authorities share the third place with the engineering and design offices (36%). Consequently, for the groups project financiers and insurance companies and other consulting services, the lowest rates can be found (10% and 14%, respectively). Related to the representation of each actor group compared to the total responses, the public tendering authorities (31%) and (general) contractors (35%) were each representing about one third. This was the reason for the research group to merge the remaining categories (engineering and design offices, financiers and insurers, other consulting (legal, finance,…) and other independent experts) into one group for the analyses. The aforementioned group was called 'Supporting services to main actors'. This could increase the chance for significant results when comparing the different groups in the analyses.

More information on the respondents include their level of expertise in the Belgian infrastructure context. Almost 70% have more than 20 years of experience in the sector and 98% more than 10 years. The high percentages give the assurance for good and reliable data, resulting in results with a higher level of quality. In addition, a good distribution of experience over all possible domains was found, as each domain is for about 50% represented by the respondents. This allows to retrieve conclusions on all domains based on reliable data. Five respondents have experience in all domains of infrastructure. This might seem low, however, more than 65% has experience in three domains or more. Since different domains require specific experience and skills, the low number of respondents active in all fields was expected. The highest experience can be found in road projects. Road projects require a specific expertise as well but are included in the activities of a large part of the organizations. Related to the contract types, almost the total sample (94%) has experience with traditional procurement contracts. As these contracts are used the most frequent for public construction projects, this is in line with the expectations. Besides that, it is remarkable that 90% of the respondents has experience with at least one type of PPP contracts. The lowest experience can be found for DBFMO and concession contracts. DBFMO and concession contracts have the highest level of private partner involvement and are, at the moment of the study, the least frequent executed in Belgium. Consequently, the low level of expertise with these contracts can be explained. Four respondents indicated to have experience in all contract types, while more than 50% of the respondents have experience in four contract types or more.

3.2.2 Magnitude of cost overruns for different infrastructure domains and contract types

Cost overruns are frequently linked with the type of infrastructure and contract (see e.g., Molinari, Haezendonck and Mabillard, 2023 and Verweij and van Meerkerk, 2021). Therefore, the respondents were asked to score both potential influencing types from one to ten based on observed increasing cost overruns for public infrastructure projects in Belgium. Only the types for which the respondents had indicated to have experience in, were presented in these questions.

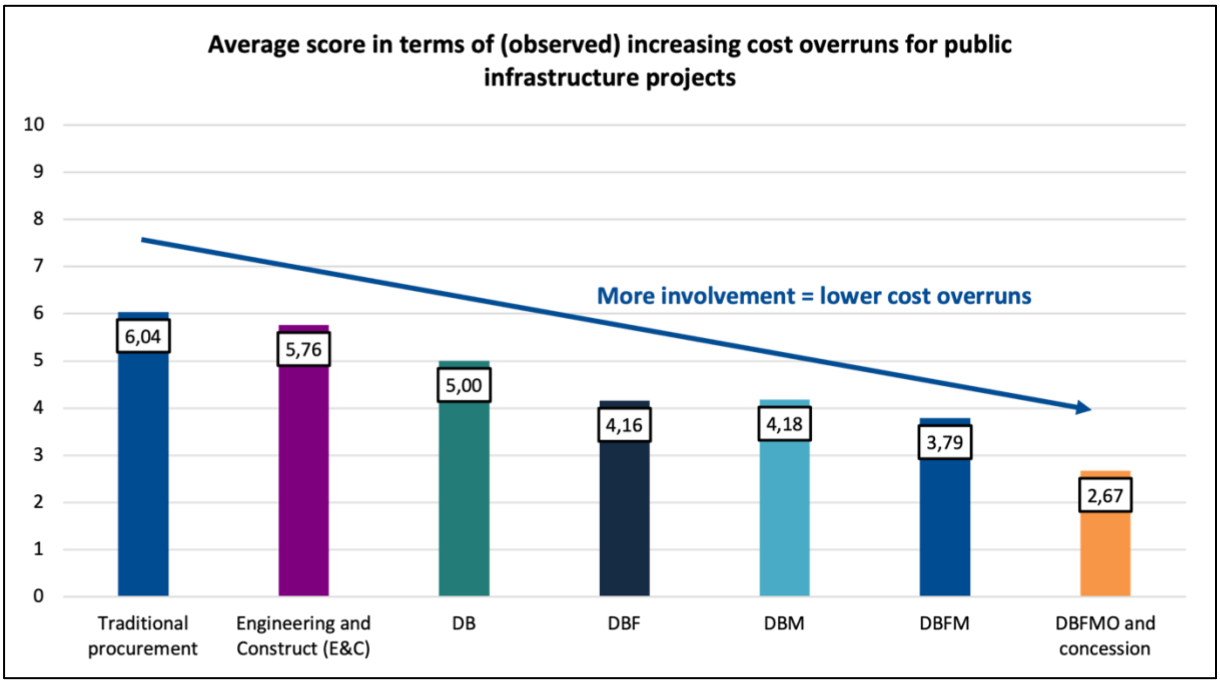
Figure 5-1 Average scores for the different domains of infrastructure (Authors, 2023)



As observed in Figure 5-1, the highest score can be found for public buildings (5.76), however the differences between the averages for each domain are not significant (Friedman test, p=0.677) and the variation between the given scores is large (ranging from 4.29 for education, recreation and social housing to 5.51 for hospitals). This non-significance for different averages indicates that all averages can be assumed as equal. The average scores range from 4 until 6, with a score of 5 indicating medium cost overruns. Consequently, it can be concluded that cost overruns occur in all type of projects, resulting in the overruns being not relatable with the type. On the other hand, two domains had statistically significant different scores, education, recreation and social housing and public buildings (Paired samples test, p=0.018). Two explanations can be given. First, it can be assumed that the stakeholder's supporting base for education, recreation and social housing would be higher compared to the base for public buildings as also prisons were included in that last category. The prison of Haren (Brussels) was recently executed and a large number of contractors and other parties were involved in this project. The project experienced a significant amount of critic by stakeholders. As a limited number of projects of this kind are being executed, it could be possible that the respondents had the aforementioned project in mind when filling out the survey. Secondly, during conversations with the contractors it was mentioned that different parties had a good experience with the management of the large educational public-private-partnership project in Flanders called ‘Scholen van Morgen’. The score for educational projects might have been influenced by that. No significant variation was found over scores assigned by the different stakeholder groups, indicating that all respondents share the same opinion.

Equal to the domains of infrastructure, the types of contracts were also questioned. Results are shown in Figure 5-2.

Figure 5-2 Average scores for the different contract types (Authors, 2023)



The highest average score was found for traditional procurement contracts (6.04), followed by a decreasing trend towards the public-private-partnerships with the highest rate of involvement of private partners (DBFMO and concession). As noticed in Figure 3, cost overruns inversely commensurate with the involvement of private parties. From the decreasing observation, it can be concluded that the higher the involvement of private parties, the lower cost overruns turn out to be. The difference between the scores was also statistically significant (Friedman test, $p=0.002$), as well as the difference in scores between traditional procurement and DBFMO and concession contracts (paired samples test, $p<0.001$, $N=30$). Figure 4 also shows a stepwise decreasing trend, indicating that already each participation of private parties has a positive effect on project performance. The score only slightly increases between DBF and DBM contracts. Contractors stated that the risk taken by them in a DBF contract is smaller when comparing to the risks of a DBM contract, as the former one includes the responsibility of the maintenance phase. Like the domains of infrastructure, opinions from stakeholder groups did not differ.

3.2.3 Possible explanations for cost overruns

3.2.3.1 A ranking for the Belgian public construction industry.

As explained in the methodology, the list of causes defined the literature was used as an input for the survey in order to define the most important causes for cost overruns for public infrastructure projects in Belgium. Respondents were asked to choose the five most important causes of cost overruns. They were also asked to rank them and create their top five. A statistical analysis based on the number of times the cause was chosen to make part of a respondent's top five, and the average rank that was given to the causes, revealed the following list of the ten most important causes in the order of decreasing importance (Table 5-4).

Table 5-4 Top 10 causes for Belgium (Authors, 2023)

Top 10 causes of cost overruns for public infrastructure projects in Belgium

Causes		Number of times chosen for top 5	Average rank
1.	Poor quality of technical documents and studies	27	2,02
2.	Poor estimation of scope, time and cost	23	1,48
3.	Permit risks	24	1,25
4.	Conflicts on trust between partners	15	0,88
5.	Conflicts on scope, time and cost	15	0,87
6.	Increased prices of raw materials, labor and equipment	14	0,87
7.	Delays in execution	12	0,77
8.	Inadequate project governance	11	0,73
9.	Poor stakeholder management	13	0,73
10.	Lack of coordination	9	0,58

The difference in ranking between the causes presented above is statistically significant (Friedman test, $p=0.001$), confirming the right order of importance. It can be noticed that mostly managerial and process management causes are included in the list, indicating their significant high contribution to cost overruns in Belgium. A remark needs to be made on the timing of the execution of the study. The research was executed during a period of economic recession in Belgium, caused by the global COVID-19 crisis and the war between Ukraine and Russia, resulting in higher prices in general and in the construction sector but also in procurement problems. This might have influenced the place of increased prices of raw materials, labor and equipment in the list. The causes poor quality of technical documents and studies, poor estimation of scope, time and cost, and conflicts on scope, time and cost could all be linked to each other as difficulties with one of them might influence the others. However, no significant correlation was found between the causes. A connection between other causes from the list like permit risks, delays in execution, and poor stakeholder management could also be found. Permit risks turn out to have a significant impact on cost overruns in Belgium. Confirmed during conversations with contractors and by a study on the evaluation of environmental permits in Flanders from IDEA Consult (2021) commissioned by Departement Omgeving (Flanders – Belgium), still some considerable issues arise in the process of getting a permit. Mostly on the duration, complexity, transparency, digitalization and collaboration of or during the process. Because of the previously mentioned potential reasons, problems with stakeholder management (like the communities living close to the construction site or administrations on a local level) delays might be caused. Conflicts on trust between partners, inadequate project governance, and lack of coordination occur more on the social capabilities level and collaboration and communication between project partners.

3.2.3.2 Comparing the ranking for Belgium with the global results.

Responding to the goal of the study, the list of top ten causes for Belgium can be compared with the list globally. In order to also exclude regional differences, a list for European countries was also created. A distinction could be made in the systematic literature review based on the country indicated in the paper for which a case study was carried out. But, due to data limitations, only a top five list was created. Below, the three lists (Belgium, Europe, global) are presented in Table 5-5. Causes from the Belgian list not appearing globally or in Europe (and thus not in their respectively top ten and top five) are indicated in bold and can be specifically linked to the context in Belgium. These five causes are of major importance to look at in the Belgian context and should be solved as a priority. It on the other hand does not mean that these causes cannot be reasons for cost overruns internationally, but it could be possible that they are seen as less important there.

Explanations for the high importance of these causes in Belgium can be found in three different areas: the complex institutional context with numerous government levels, the urban sprawl and the broad public say in projects. The Belgian complexity makes it difficult to agree on certain factors related with a public infrastructure project, but also to coordinate and communicate. This complexity results directly in the causes *Lack of coordination* and *Delays in execution*, but more indirectly also in *Conflicts on trust between partners* and *Poor stakeholder management*. Additionally, Belgium is highly densely populated as a country due to the urban sprawl, which implies that wherever a public project will be executed, a small community will be located in the immediate neighborhood. Complemented with the importance of the public say in Belgium, facilitated by the large accessibility to start an appeal procedure for large complex projects, assigning *permits* and *stakeholder management* is easily hampered. All difficulties which again lead to potential *Conflicts on trust between partners*.

Table 5-5 Comparison of the top causes (Authors, 2023)

Top 10 causes of cost overruns for public infrastructure projects Belgium	Top 10 causes of cost overruns for infrastructure projects global	Top 5 causes of cost overruns for infrastructure projects Europe
1. Poor quality of technical documents and studies	1. Poor management of scope, time and cost	1. Poor estimation of scope, time and cost
2. Poor estimation of scope, time and cost	2. Poor quality of technical documents and studies	2. Optimistic behavior of the estimators
3. Permit risks	3. Inadequate project governance	3. Poor quality of technical documents and studies
4. Conflicts on trust between partners	4. Poor estimation of scope, time and cost	4. Poor management of scope, time and cost
5. Conflicts on scope, time and cost	5. Material & equipment procurement	5. Conflicts on scope, time and cost
6. Increased prices of raw materials, labor and equipment	6. Increased prices of raw materials, labor and equipment	
7. Delays in execution	7. Lack of labor quality	
8. Inadequate project governance	8. Tender specifications and procedures	
9. Poor stakeholder management	9. Contract processes	
10. Lack of coordination	10. Legal requirements	

3.2.4 Assessing the impact of the causes on cost overruns

Going further in detail, the level of impact caused by these reasons was researched. Considering the possibility of a cause occurring frequently but having only a small impact on the total overrun, more detailed research was required. The highest average impact was found for increased prices of raw materials, labor and equipment, followed by conflicts on scope, time and trust, and then permit risks. Taking into account that all these factors appear the highest in the full list of potential causes, additional attention needs to be given to them as they also appear to have a high to major impact on the total amount of cost overruns experienced. Mitigating these risks and their significant impact should therefore be high on the agenda of the actors. The differences between the average impact of the top ten are significant (repeated measures ANOVA, $p<0.001$). An important note here is that the study was executed in a period of increasing inflation and material procurement problems, which might explain the high assigned impact to increased prices of raw materials, labor and equipment.

It is possible to assess the importance of the top ten factors by combining the frequency of occurrence and the average impact of a cause. This allows to define the causes with the highest priority identified, i.e., having a high frequency and impact. The use of this analysis (also known as a risk assessment matrix) pinpoints the most important causes to focus on with a result to reduce project cost overruns. Subsequently, suitable risk mitigation strategies (*see project management: avoid, reduce, transfer and accept*) could be developed. *Poor quality of technical documents and studies* and *Poor estimation of scope, time and cost* can both be identified as being high risk causes and should be considered as the ones in need of the most attention regarding potential risk mitigation in order to remain on budget for a project.

3.2.5 Distributing the impact occurred due to cost overruns.

After identifying the magnitude of impact of causes and its frequency of occurrence, this research goes one step further. In this section the impact generated (in terms of additional costs paid due to cost overruns) is distributed over the different actor groups. Respondents were asked to assign a part of 100% (with the total additional costs equal to 100%) to each (or some) of the actor groups. Almost half of the total impact (49%) was assigned to the public tendering authorities, followed by 40.5% to the (general) contractors). The remaining 11% was distributed over the groups engineering & design offices (7.7%) and others (2.8%). The market in general, subcontractors, stakeholders, government departments, banks, equity investors, society and taxpayers were mentioned for the group others. It can be concluded that the percentage impact borne by the public tendering authorities is underestimated as different groups indicated in others can be included in the group public tendering authorities as well. This disparity between the actor groups and the nearly 50% (or more see above), goes against the belief of the (general) contractors who assume they pay the largest share. The discrepancy between their convictions and the results shows more research is needed.

Finally, the impact distributed to the different actor groups was analysed. Herewith, the viewpoints on the actual situation in the public construction market can be defined for each of the respondent groups, providing useful input for developing potential solutions. Public tendering authorities and general contractors are both assigning a larger part to themselves (respectively 53.4% compared to 49% and 50.7% compared to 40.5%), indicating that from their viewpoint they are both suffering the most from additional costs caused by reasons for cost overruns. Public tendering authorities are assigning a greater impact to engineering & design offices (E&D) (10.3%), while the impact assigned by (general) contractors to the E&D group decreased (2%) compared to the impact assigned by the whole group. For the remaining respondent group consisting of the supporting services to main actors, the share assigned to public tendering authorities almost remains equal, while the share for (general) contractors decreased (35.6%) and the shares for E&D and others both increased (respectively 11% and 6.2%). Notwithstanding the previous, the shares assigned by the third group (supporting services to main actors) are still similar to the total shares found. Only for percentage of impact assigned to the (general) contractors and engineering & design offices, significant differences over the assigning respondent groups were found (Kruskal Wallis Test for (general) contractors ($p<0.001$) and for engineering & design offices ($p=0.002$)). This implies that all respondent groups share their opinion on the impact borne by public tendering authorities and others.

4. Discussion and conclusion

Governments' budgets are restricted, while demands from users regarding infrastructure are only increasing. This challenge asks for efficient spending of the limited resources available. With the end goal of providing solutions to reduce cost overruns of public infrastructure projects, in this study possible explanations for budget increases are determined. Due to differences in a country's context and political environment, causes for cost overruns will differ as well. We determined the most important causes for projects in the global and Belgian contexts through a systematic literature review and a survey. Ten causes were identified as the most important ones for Belgium: (1) Poor quality of technical documents and studies, (2) Poor estimation of scope, time and cost, **(3) Permit risks**, **(4) Conflicts on trust between partners**, (5) Conflicts on scope, time and cost, (6) Increased prices of raw materials, labor and equipment, **(7) Delays in execution**, (8) Inadequate project governance, **(9) Poor stakeholder management** and **(10) Lack of coordination.** These causes should be high on the agenda when looking for solutions to reduce cost overruns of projects and to achieve better project and financial performance. The five causes indicated in bold did not appear in the list of the most mentioned reasons neither globally nor in Europe. This does not imply that these five causes are not occurring outside Belgium, but they might not be considered as important elsewhere. The Belgium-specific causes can all be related to a type of relationship management, internal and external to the project core. Internally, issues are appearing in the collaboration between the project's core actors, namely the tendering authority (or project owner) and the contractor (or supplier). Externally, problems occur with additional stakeholders (being largely present in complex infrastructure projects). From these findings, it is clear that solutions need to be found in the management of the relations between actors and the collaboration processes. In the past, attempts have been made to solve project issues by focusing on the technical and legal aspects (for example improving drawings, making contracts larger and more complex), while this study clearly shows that attention needs to be given to the social side. Previous research from Molinari et al. (2023) already showed that the situation of cost overruns in Belgium worsened, meaning that another direction for potential solutions needs to be followed.

Besides a list of the most important reasons for cost overruns in Belgium, research also showed that after analysing seven possible contract types, a significant decreasing trend for cost overruns was found for an increasing share of involvement of private parties. In other words, more involvement from private parties results in lower cost overruns for public infrastructure projects. This result confirms that the use of PPP contracts leads to better project performance. Additionally, the stepwise decreasing trend of scores of cost overruns indicated that even with the lowest share of private involvement in the project, better project performance can already be achieved. Therefore, research into the management of these contracts, and more specific on a social level, is of high importance to come up with possible solutions.

The ability to link the full list of causes with contract management and collaboration between parties indicates the need for more research into the practices of contract management and collaboration in public infrastructure projects. The stepwise decreasing trend of cost overruns when involvement of private parties is increased and 90% of the additional costs incurred paid by two signing parties (50% public tendering authorities and 40% contractors) also goes into that direction. It proves that solutions need to be found in contract management and collaboration if the negative impact of cost overruns wants to be reduced and an improved project performance wants to be realized.

For practitioners, a clear suggestion can be made instead of investing significant amounts of money and time on legal contracts and technical documents, focusing on the collaborative approach for public infrastructure projects should be key. While we found that issues still exist in 'hard', legal aspects, these issues are extensively addressed in developed countries. In contrast, the 'social' aspects call for much more attention. This was also acknowledged by Spohr et al. (2022), stating that successful partnerships are based on building trust and investments in good collaborations.

5. Limitations

Some limitations can be noted for this research. First, emphasis was placed on public infrastructure projects, excluding private infrastructure projects. Being at least as important as the public infrastructure sector, analyses should also be performed on the market of private projects. Reasons for cost overruns and the dynamics of these projects are however significantly different from public projects. As a result, combining both types of projects is complicated and research should be performed separately. Second, only causes of cost overruns were assessed. Cost is only one of three concepts of the project's iron triangle, besides time and quality. This leaves the search open for explanations for a deviation of other concepts specific but also for project performance as a whole. Additionally, cost underruns (the case in which projects go under budget) occur as well. Against common belief, this could also have a negative impact on the infrastructure investment policy and the corresponding budget. Estimating costs of a project too high could exclude another project from being realized because of the restricted budget. This results eventually in executing fewer projects than actually possible. Finally, 52 responses were gathered for the survey. Despite having reached a threshold of than 50 respondents, the quality of the research could have been improved with additional answers.

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8. Appendix

Table 5-6 Papers analyzed in literature review (Authors, 2023)

Authors	Title	Year
Abduh, Soemardi & Wirahadikusumah	Indonesian construction supply chains cost structure and factors: A case study of two projects	2012
Adam, Josephson & Lindahl	Aggregation of factors causing cost overruns and time delays in large public construction projects: Trends and implications	2017
Ahiaga-Dagbui & Smith	Rethinking construction cost overruns: Cognition, learning and estimation	2014
Ahiaga-Dagbui & Smith	Dealing with construction cost overruns using data mining	2014
Alananga Lucian & Kusiluka	Significant cost-push factors in owner-built incremental housing construction in Tanzania	2015
Andrić, Mahamadu, Wang, Zou & Zhong	The cost performance and causes of overruns in infrastructure development projects in Asia	2019
Aziz, Memon, Rahman & Karim	Controlling cost overrun factors in construction projects in Malaysia	2013
Balali, Moehler, & Valipour	Ranking cost overrun factors in the mega hospital construction projects using Delphi-SWARA method: an Iranian case study	2020
Blomberg, Cotellesso, Sitzabee & Thal	Discovery of internal and external factors causing military construction cost premiums	2014
Brockman	Interpersonal conflict in construction: Cost, cause, and consequence	2014
Cantarelli, Van Wee, Molin & Flyvbjerg	Different cost performance: Different determinants?. The case of cost overruns in Dutch transport infrastructure projects.	2012
Cantarelli, Molin, Van Wee & Flyvbjerg	Characteristics of cost overruns for Dutch transport infrastructure projects and the importance of the decision to build and project phases	2012
Cantarelli, Flyvbjerg, Van Wee & Molin	Lock-in and its influence on the project performance of large-scale transportation infrastructure projects: Investigating the way in which lock-in can emerge and affect cost overruns	2010
Cavalieri, Cristaudo, & Guccio	Tales on the dark side of the transport infrastructure provision: a systematic literature review of the determinants of cost overruns	2019
Cavalieri, Cristaudo, & Guccio	On the magnitude of cost overruns throughout the project life-cycle: An assessment for the Italian transport infrastructure projects	2019
Chang & Ko	New Approach to Estimating the Standard Deviations of Lognormal Cost Variables in the Monte Carlo Analysis of Construction Risks	2017
Creedy, Skitmore & Wong	Evaluation of risk factors leading to cost overrun in delivery of highway construction projects	2010
Derakhshanalavijeh & Teixeira	Cost overrun in construction projects in developing countries, Gas-Oil industry of Iran as a case study	2017
Durdyev	Review of construction journals on causes of project cost overruns	2020
Enshassi, Kumaraswamy & Al-Najjar	Significant factors causing time and cost overruns in construction projects in the Gaza strip: Contractors' perspective	2010
Enshassi, Al-Najjar & Kumaraswamy	Delays and cost overruns in the construction projects in the Gaza Strip	2009
Flyvbjerg, Holm & Buhl	What causes cost overrun in transport infrastructure projects?	2004
Flyvbjerg	Cost overruns and demand shortfalls in urban rail and other infrastructure	2007
Flyvbjerg, Holm & Buhl	How common and how large are cost overruns in transport infrastructure projects?	2003

Forcada, Gangolells, Casals & Macarulla	Factors Affecting Rework Costs in Construction	2017
Frimpong, Oluwoye & Crawford	Causes of delay and cost overruns in construction of groundwater projects in a developing country	2003
Huo, Ren, Cai, Shen, Liu, Zhu & Wu	Measurement and Dependence Analysis of Cost Overruns in Megatransport Infrastructure Projects: Case Study in Hong Kong	2018
Jung, Kim & Lee	The computer-based contingency estimation through analysis cost overrun risk of public construction project	2016
Kaliba, Muya & Mumba	Cost escalation and schedule delays in road construction projects in Zambia	2009
Kavuma, Ock & Jang	Factors influencing Time and Cost Overruns on Freeform Construction Projects	2019
Ketabi & Heravi	Developing a framework for evaluating construction project safety levels and optimal cost allocation to safety influential factors	2021
Lee & Kim	Analysis of cost-increasing risk factors in modular construction in Korea using FMEA	2017
Li, Arditi & Wang	Determinants of transaction costs in construction projects	2015
Li, Arditi & Wang	Factors that affect transaction costs in construction projects	2013
Liu & Zhu	Improving cost estimates of construction projects using phased cost factors	2007
Love, Edwards & Irani	Moving beyond optimism bias and strategic misrepresentation: An explanation for social infrastructure project cost overruns	2012
Love, Ahiaga-Dagbui & Irani	Cost overruns in transportation infrastructure projects: Sowing the seeds for a probabilistic theory of causation	2016
Love & Li	Quantifying the causes and costs of rework in construction	2000
Memon & Rahman	Analysis of cost overrun factors for small scale construction projects in Malaysia using PLS-SEM method	2013
Odeck	Cost overruns in road construction - what are their sizes and determinants?	2004
Olawale & Sun	Cost and time control of construction projects: Inhibiting factors and mitigating measures in practice	2010
Oyegoke, Powell, Ajayi, Godawatte& Akenroye	Factors affecting the selection of effective cost control techniques in the UK construction industry	2021
Pham, Luu, Kim & Vien	Assessing the Impact of Cost Overrun Causes in Transmission Lines Construction Projects	2020
Pinheiro Catalão, Cruz & Miranda Sarmento	Exogenous determinants of cost deviations and overruns in local infrastructure projects	2019
Rahman, Memon, Aziz & Abdullah	Modeling causes of cost overrun in large construction projects with partial least square-sem approach: Contractor's perspective	2013
Rahman, Memon & Karim	Relationship between factors of construction resources affecting project cost	2013
Rosenfeld	Root-cause analysis of construction-cost overruns	2014
Shane, Molenaar, Anderson & Schexnayder	Construction project cost escalation factors	2009
Shehu, Endut & Akintoye	Factors contributing to project time and hence cost overrun in the Malaysian construction industry	2014
Shehu, Endut, Akintoye & Holt	Cost overrun in the Malaysian construction industry projects: A deeper insight	2014
Shoar, Yiu, Payan & Parchamijalal	Modeling cost overrun in building construction projects using the interpretive structural modeling approach: a developing country perspective	2022
Sinesilassie, Tabish & Jha	Critical factors affecting cost performance: a case of Ethiopian public construction projects	2018

Swei, Gregory & Kirchain	Construction cost estimation: A parametric approach for better estimates of expected cost and variation	2017
Touran & Lopez	Modeling cost escalation in large infrastructure projects	2006
Wahab & Wang	Factors-driven comparison between BIM-based and traditional 2D quantity takeoff in construction cost estimation	2021
Zhu, Hu, Xu & Tang	Predicting the Impact of Country-Related Risks on Cost Overrun for Overseas Infrastructure Projects	2021

CHAPTER 6

GENERAL CONCLUSION, RECOMMENDATIONS AND FURTHER RESEARCH PATHS

Laura Molinari

CHAPTER 6

GENERAL CONCLUSION, RECOMMENDATIONS AND FURTHER RESEARCH PATHS

In this final chapter, research questions are answered and general conclusions from the previous chapters are drawn. We identify what could be done to improve the efficiency of infrastructure management in a country such as Belgium. Subsequently, the conclusion is translated into recommendations applicable in practice, discussing how these suggested improvements could be implemented. To conclude, contributions for academia and practice are summarized and avenues for further research are discussed.

1. General conclusion

The aim of this dissertation was to analyze ways to improve the efficiency of a country's infrastructure asset management practices, over the whole life cycle of the assets and considering the identified challenges of supply and demand, and with a final goal of achieving an infrastructure network that could support the creation of economic and social value for a country and assists in additional welfare development. Through this dissertation, the general research question was answered by providing some key pathways for improvement.

General research question: How can a country such as Belgium improve the efficiency of its infrastructure asset management over the whole life cycle, considering the challenges on the demand and supply side?

Each chapter analyzed options for a specific phase of the life cycle of infrastructure development, starting from the initiation phase until the construction phase. The different chapters and phases relate to a specific research sub-question (see infra). As a consequence, the general research question is answered by a list of improvements identified in the separate chapters. Further in this section, opportunities per phase are discussed, answering the research (sub-)questions and the general research question.

- **RQ1:** What are efficient infrastructure asset management strategies for a country and how can these be developed? *Chapter 2 relates to the initiation phase.*
- **RQ2:** What should be the decision-making framework for a country to decide on infrastructure investments in times of uncertainty and growing stakeholder interest? *Chapter 3 relates to the planning phase.*

- **RQ3:** Which inefficiencies can be defined in infrastructure spending and project development? *Chapter 4 relates to both the design and construction phase.*
- **RQ4:** What are the root causes of inefficient spending through increasing costs of projects and possible avenues for improvement? *Chapter 5 relates to both the design and construction phase.*

1.1 Opportunities in the initiation phase of IAM – Strategies for IAM

Various interpretations exist for the concept of infrastructure asset management (IAM) and a general definition for IAM can still be considered as *"work in progress"*. We state that, although some only consider the maintenance phase, the whole life cycle should be taken into account when defining a strategic plan for infrastructure management in order maximize the value creation. Similar to different views on the definition of IAM, we also found that goals used for (in this case, public horizontal) infrastructure management differ over transport types (road, rail and inland navigation). In line with the *iron triangle of project management*, a responsible agency can decide to focus either on cost effectiveness, on safety or on service availability.

Achieving efficient infrastructure management can only be done when following a clearly defined and sound strategic plan with a long-term focus. The variations in the understanding of IAM as a concept and the choice of objectives for IAM, leads to disparities in the ways of how organizations and agencies can manage their infrastructure assets specifically. Some frameworks for IAM already exist, ranging from specific technical IAM applications to more generic strategic IAM (SIAM) applications. However, the identified differences support the need for a more tailored approach.

Not holding on to the fact that each organization needs to follow the same defined framework and instead acknowledging the differences, can be seen as an opportunity to improve IAM. Organizations develop strategies as a roadmap to achieve their set objectives. Therefore, a strategy is different depending on the defined goals and a *"one-fits-all"* strategy does not exist. In too many cases it is expected that everyone should be guided by the same plan. But differences over organizations in their primary objectives makes it clear that this is not the right approach to follow and that tailored strategies need to be developed. Notwithstanding the above, organizations could benefit from a list of guidelines to help them creating their plan. We respond to this need by providing a list of eight key-success factors which could be followed when developing their own strategic IAM plan. Future testing of these factors should give insight in whether this list is exhaustive. The factors could form the basis of each SIAM framework, but still leave room for customization based on the objectives set by the organization in question. The list of key-success factors can be found below and are explained in Chapter 2.

(1) the accountability of context factors' influences on the government policy[19];
(2) the translation of the policy into organizational objectives;
(3) the possibility of non-asset solutions;
(4) the development of transport mode specific goals;
(5) the alignment between the government strategy and asset strategy;
(6) the optimization of options;
(7) the introduction of feedback loops; and
(8) organizational and knowledge management.

1.2 Opportunities in the planning phase of IAM – Decision framework for infrastructure investments

When objectives and strategies are defined, the plan can be executed by realizing projects. Opportunities for efficiency arise in this phase in the selection of the to be realized projects. Currently, major challenges for infrastructure include the changing nature of demand, as indicated in Chapter 1, and the interdependency between different infrastructure assets. For example, when we want to increase the capacity of a waterway, the height of bridges can be raised to allow larger vessels to pass through the canal. However, the increased capacity will only be achieved if all bridges are heightened, otherwise the vessel can only pass in one part. As a result, infrastructure assets are interconnected with each other and thus infrastructure projects are interrelated. Likewise, adaptations in the use of one infrastructure type might influence the use of another infrastructure type. Continuing with the same example, increasing the capacity of a waterway by raising the bridges might generate additional traffic on the waterway and as a consequence for an inland port located on that same waterway. Infrastructure developments cannot be seen as stand-alone projects (cf. raising one bridge),

[19] The factor *"accountability of context factors' influences on the government policy"* implies the consideration of the impact of context factors on the government policy when defining a Strategic Infrastructure Asset Management (SIAM) plan.

but should be handled as a set of projects or a scenario of investments (cf. raising all bridges and potentially, depending on the additional traffic generated, increasing the capacity of the inland port). Additionally, changing demands and the following uncertainty related to it, makes infrastructure development even more complex, because what seems necessary today may not be the ideal, or politically or technology-wise preferable solution in a year or so, due to incremental insights. The Social-Economic Monitoring Instrument (SEMI) provides a tool to improve decision-making and supports decisions incrementally and dynamically based on the progress of insights and data of stakeholders involved such as main users of transport. It attempts to take these challenges into account by evaluating projects as a network of interdependent projects (and not stand-alone projects) over different periods of time (and not only at one point in time). Besides the rising uncertainty and complexity of an infrastructure network, having a public supporting base for the project has become increasingly difficult. The public raises concerns on social and environmental issues, but also may have its own preference for a specific project alternative at the outset of a project or may change its mind during the phases of one project, impacting a following project which is related to the first one. Also here SEMI provides added value as it (1) includes stakeholders in the data collection to decide on the investments and (2) presents the possibility of execution of their preferred alternative in a clear and objective way.

SEMI is a decision support tool for policy makers, bearing the responsibility of infrastructure development, which can help them in making better informed decisions. Next to its public application, SEMI can also be used in the private sector to help companies with planning their series of infrastructure investments. The tool allows the realization of projects which are probably more resilient to uncertainty and which could be better welcomed by the general public, because of its inherent dynamic approach. Furthermore, it facilitates following a long-term vision plan (see Chapter 2) by policymakers. Nonetheless, the willingness of politicians to follow a long-term plan is required.

1.3 Opportunities in the design and construction phase of IAM – Efficient spending of resources and project execution

Strategic infrastructure asset management does not end when a pipeline of projects has been decided. With the aim of achieving the objectives set in the SIAM plan, it also includes the project’s execution phase, consisting of a design and construction period. During the design phase, first budget estimations are made. We found possible improvements for infrastructure spending in the difference between the initial budget estimation and the final project's cost, or the so-called *cost deviations*. As discussed in Chapter 4 and Chapter 5, besides remaining on budget, either *cost overruns* (final cost turns out higher compared to initial estimation), or *cost underruns* (final cost turns out lower compared to initial estimation) occur. Both are inefficient in terms of infrastructure spending. Governments have to present their long-term vision plan (as defined in Chapter 2) with their decided number of projects scheduled for realization (as defined in Chapter 3) based on a fixed budget which was granted to them. Yet, variations in final costs of projects compared to initial budgets can have a major impact on the initial plan. It can result in not being able to realize all projects within the given budget (*in case of cost overruns*) or the budget was not used in its full efficiency and more projects could have been realized (*in the case of cost underruns*). In either case, the objectives set for infrastructure will not be achieved and the situation will be suboptimal. Referring to what we found, project's final costs are on average 10% higher compared to initial estimations, while the share of projects being under and over budget was almost 50%-50%. Remarkably, projects executed in the last decade performed worse in terms of cost overruns. Besides time periods, other project characteristics were analyzed, being project size, region of execution, project duration and project phase (pre- and construction phase). Contrary to what was found in literature, no significant variations over these characteristics existed. This means that in the Belgian context cost overruns cannot be linked to specifications inherent to the project and that the situation is more complex. Based on the extensive experience of the construction sector, making realizing larger vs smaller projects and longer vs shorter projects not more difficult, this could have been expected. Because of the non-significance, explanations and paths for improvements regarding cost overruns had to be found elsewhere.

A survey on reasons for the found inefficiencies occurring during project design and construction provided more insights. It confirmed the finding of the infrastructure type having no real impact on cost overruns' variations. By contrast, significancy in favor of Public-Private-Partnership contracts (PPP) compared to traditional procurement was found when comparing different contract delivery types. Increasing involvement of private parties seems to result in lower cost overruns of executed public infrastructure projects, which entails that public agencies would benefit from collaborating with private partners over the entire execution (design and construction) phase. This potential benefit should however not imply that every project has to be realized under a PPP contract. Not for all projects added value will be created by putting it on the market in this contract form. A thorough ex-ante analysis will still be required to assess the potential PPP worthiness of a project. Moreover, the analysis reveals ten possible options for improvements (see Chapter 5). These include improved project details (such as improving the quality of technical documents and studies), as well as more relational related efforts in projects (for example decrease risks for obtaining permits). In Belgium, but also worldwide, many attempts have already been made to mitigate causes related to the project details by enlarging the content of contractual documents. Less attention on the other hand, has been given to the relational options, while these appear to be of high importance. We therefore identify improvements on the relational side of the project (internal and external to the core) as possible ways to make project execution more efficient. Also project spending can be influenced as these improvements might result in decreasing the gap between the final cost and initial estimation.

The question however arises whether cost overruns are or can whatsoever to be avoided. This research took the assumption of cost overruns being equal to poor project performance, yet from the iron triangle of project management we know that two other project priorities may exist, i.e. service level for inland waterways and security for railways. Besides cost, other objectives could also be the project's scope and timing. Project management literature also indicates (Larson & Gray, 2018) that these factors should be weighed against each other and that only one can be chosen as the main objective, i.e. the so-called "constraint", and the other two have then to be optimized or accepted. Additionally, Chapter 2 -2 discusses the disparities among objectives per transport mode. We can state that good cost management is only one of the possible options to achieve good project performance and hence a project's performance should be assessed based on the targeted objectives. Increased project budgets could also occur because of changes made to the project's scope and quality or the project's timeline. Mitigating conflicts with stakeholders or ensuring that a permit is granted could be proper reasons to raise a budget. In addition to external stakeholders, politicians might benefit from accelerating the realization of a specific project in accordance with their agenda. We could argue the justification, but as a consequence of the short government terms, we cannot ignore its existence. Politicians only have a short period to realize the goals set for a specific government term. The closer to the end of that term and new elections, the more they might want to realize some additional projects in order to gain confidence from citizens and extra votes. Reflecting back on the causes of cost overruns identified in Chapter 5, this could partially explain the large presence of different relational and stakeholder related factors in the list.

To conclude, the improvements identified to increase project spending and execution efficiency, should only be applied when cost management was taken as a main objective for the project. Notwithstanding the above, some of the proposed measures might also facilitate the achievement of the other two main objectives (quality and timing). Better coordination can, for example, influence the project's timeline. Furthermore, even when cost effectiveness is not the primer project objective from the tendering authority, additional costs will still impact their budget. Research in Chapter 5 showed that the largest part of additional cost occurred during project execution are borne by the tendering authority, leading to less projects realized in a given period, delay or lower quality for the unrealized projects and/or lower budgets for the next budgetary period. An additional cost for the tendering authority implies that this is eventually *"paid"* by the taxpayers and the general public. Therefore, even when the primer goal of the tendering authority regarding the specific project is not keeping costs low, but for example increasing the project quality, they might still benefit from applying the proposed improvements. It allows to decrease their costs but also, for the greater good, the costs paid by the taxpayers.

As a summary, four ways to improve the efficiency of infrastructure management were developed throughout the manuscript:

1. Eight key-success factors for a sound SIAM framework and plan.
2. SEMI as a dynamic decision-support tool to evaluate project alternatives including more than one project or infrastructure work, and combined or incremental investments.
3. Keep cost overruns under control (below 5% deviation) and focus to keep them as low as possible when cost effectiveness is the main objective.
4. Focus on solving relational issues during the realization of megaprojects, rather than on technical issues, in view of mitigating significant cost overruns.

2. Recommendations for policy and practice

After identifying what can be done to improve infrastructure management efficiency, we focus now on how it can be implemented in practice.

Firstly, the long lifespan of infrastructure and the interconnectedness of many parts of infrastructure networks requires governmental agencies to follow a long-term infrastructure management plan. As discussed in Chapter 1, this is however at odds with the short government terms. In order to reduce the barriers of the short term versus the long-term objectives, a SIAM plan should be developed. This will not only facilitate a better and more efficient infrastructure management, but it will also eliminate silo-mentality between agencies considerably. Nonetheless, allowing room for variations in objectives is needed. Especially in the case of transport infrastructure where different types ask for constraining different factors. As a consequence, we cannot and we should not try to develop a one-fits-all strategy for all agencies. Governmental agencies should consider developing a SIAM plan, in which the proposed key-success factors can be included. This will align all different agencies, without compromising on the ability to follow dispersed objectives.

Secondly, our developed project investment evaluation tool SEMI should be implemented. When implementing SEMI, it is important to implement all parts of the tool. More specific, SEMI should not be applied only once, but the value added lays in the recurrent application of it. The strength of the tool lies within its dynamic aspect. Only when re-calculating SEMI every fixed number of years, it will counter for uncertainty and network interdependency. Another strength is the degree of stakeholder involvement. SEMI requires updated information as input from stakeholders. Therefore, stakeholder interaction cannot be ignored in this process. Although the SEMI tool appears as a golden ticket to better infrastructure management, there is one necessary condition to succeed: the government and their corresponding agencies should be willing to apply a long-term strategy and focus on long-term objectives, even across government terms.

Thirdly, government agencies should give more attention to the contract form in which a project will be realized. PPP projects, whether private parties are involved in the entire project process or not, appear to perform better in respect to cost overruns. Nevertheless, we do not say that as from now every project needs to be realized in PPP format. Government agencies should carefully assess the PPP worthiness and readiness of a project before opting for this form of contract. The development of an ex-ante PPP tool will be required to be able to conduct that type of test.

Finally, besides the contractual side, resources will have to be devoted to the social relationship with the stakeholders involved with the respective project. With involved stakeholders, stakeholders internal to the project core such as contractors and external to the project core such as local municipalities or environmental associations are meant. The analysis of causes of cost overruns proved two interesting insights, additional costs incur from issues with the contractual and social relationships between other project actors and stakeholders. Contractual issues have already been addressed to a large extent in the previous years by the creation of multiple standardized contract forms describing elements as time, cost and quality (such as FIDIC and New Engineering Contract (NEC), see NEC (2014) for a comparison). Social relationships on the contrary remain challenging in the construction industry, although good relationships between project owner and contractor are seen as a success factor of project performance (Suprapto et al., 2015). For example, collaboration issues between the project's key-actors (project owner and contractor) and problems with stakeholder management (concerning external actors) can hinder a swift project execution. As private sector involvement during the project process seems to be advantageous for project performance, good collaboration between public and private actors is required. However, both parties seem to be counteracting rather than cooperating (Suprapto et al., 2015). Owner-contractor relationships in public construction can therefore benefit from additional research into aspects stimulating collaboration. In addition, the difficulty of creating a supporting base for large infrastructure projects has only increased in the past decades. Therefore, project developers should invest more in reducing the impact of these challenges. They should set up programs to include stakeholders from the very beginning of a project until it is ready to use and acknowledge the dynamics of their preferences. The preferred project option of a stakeholder does not remain fixed. Implementing large infrastructure projects spans over a long period of time. During this, either stakeholders holding power or having interest in the project can change, or preferences of these stakeholder groups can change. SEMI as discussed in Chapter 3 and above, can facilitate this required stakeholder involvement and the changes in their demands, as SEMI is a dynamic process which is repeated every fixed number of years and allows to include opinions, data and preferences from a changing group of interested actors.

3. Contributions in the field of academia and practice

This dissertation contributed to academia by expanding the theory on (strategic) infrastructure asset management, project management, project selection, public spending and different perspectives on public management (PM).

First, key-success factors for a SIAM plan were identified based on analyzing and synthesizing a range of existing SIAM frameworks and applied to three transport modes in Belgium.

Second, a new project evaluation tool SEMI was developed, which is an improvement of the existing and widely used SCBA tool combined with some notes from ROT. Moreover, this evaluation tool was also rolled out for the first time to show its possibilities for application.

Third, we identified similarities with the perspectives on PM as discussed in Chapter 1 (cfr. PA, NPM and NPG). The importance of the evolution from a rather resource efficiency oriented approach (NPM) to a more collaborative stakeholder approach (NPG) was also noticed throughout this dissertation. In Chapter 2, we clearly identified silo-mentality (as a consequence of decentralization) as one of the main challenges for a sound infrastructure management strategy. Besides that, we discovered that cost-effectiveness is not the sole possible objective for infrastructure management. As an implication, the element of improved cost efficiency from the NPM perspective loses value. NPG on the other hand embraces the other dimensions of the iron triangle, more specific the scope dimension. Realizing a successful infrastructure project with a scope in line with the demands from society, can be achieved through increased stakeholder input and participation. Applying PM with an NPG perspective could help governments attaining this goal.

Chapter 3 showed the need for a holistic approach to public investment decision-making, with increased attention to stakeholders' opinions. This approach is required over all types of infrastructure and thus over all departments, colliding again with the decentralized departments as described in NPM. The consideration of external stakeholders is however embraced by NPG as it stresses the need for interorganizational relationships. Chapter 4 and Chapter 5 prove that cost effectiveness is not always the right indicator to follow when evaluating project (and department) performance. Output could for example also take the form of stakeholder satisfaction. This leads to another clash with two main elements of NPM, output-oriented and performance-related. We learned that in terms of PM, we should look for the suitable way of managing for each organization depending on its objectives and corresponding strategies, and that one-fits-all does not exist. However, it is clear that the NPG perspective on PM could be a step in the right direction. Collaboration is of significant importance in infrastructure realization and has a positive influence on project performance in the broad view of the concept (not only related to cost overruns).

Additionally, we fill the gap for more country-specific research in the field of cost overruns and explanations for cost overruns. More detailed research was requested because of the existing institutional differences between countries and differences in the state of the construction sector in general. With our research, insights on issues related to project development in developed countries, in which the responsibilities for infrastructure management are decentralized and increased welfare is posing additional challenges (ex. transport, health, education, etc.) and globalization blurred the boundaries between other countries, asking for a reliable infrastructure network, are enlarged.

In the field of practice, we give recommendations for the improvement of infrastructure management of countries and cross-national regions (such as the EU). Through this, we support countries with solving the mismatch between infrastructure demands and the current supply, with only limited additional resources. *Instead of requiring more resources, we are releasing extra resources by doing things differently.* We contribute by providing governmental agencies with tools to make their infrastructure management more efficient and give recommendations on how to implement these tools.

4. Limitations and paths for further research

As a final note, limitations of this dissertation and further research avenues are discussed. We can explain both based on three aspects: the dissertation's scope, methodology and results. Starting with the scope, we focused on horizontal and vertical infrastructure with a public goal. As a consequence, all other infrastructure types were excluded. Underground public infrastructure, such as water distribution and utility pipelines and sewage are posing a major challenge for infrastructure asset management in the future. Over the years, these infrastructure types have been neglected, which results in them being in a deteriorating state and in need of additional investments. Responsible agencies are asking for help and indicate these types tend to be forgotten or assessed as inferior to other types. They say *out of sight, out of mind*, this is unfortunately also the case with underground infrastructure. Attention in further research should go to these infrastructure types as they, besides other economic and social infrastructure, also contribute to welfare creation. Aside from the infrastructure type, the focus was also set on the first phases of infrastructure development, excluding the maintenance and end-of-life phase. Despite the importance of new infrastructure, the large investments required to fill the maintenance backlog of our ageing infrastructure network cannot be ignored. Given that for saving material reasons, or for timing or budgetary issues to decide on new investments, the willingness to extend the lifetime of infrastructure may increase.

Additionally, the end value of infrastructure is not equal to zero, but could be positive or negative. When it is decided to decommission, or to no longer use an infrastructure asset, its final value is in most cases estimated as zero today. This while the infrastructure asset still exists and can have a negative value when it for example lies where a new structure should be built. It could also have a positive value if it can still be used as part of the new structure, for its materials or for another purpose. Circularity and its effect on public infrastructure form a broader opportunity for further research. Its importance does not only increase in general, but major challenges exist in the construction sector specific. Until now, recycled materials are not yet completely valued in public procurement processes. The higher price of circular alternatives is one of the biggest challenges for circular procurement (Sönnichsen & Clement, 2020) because at the same time, lowest price remains the primary criterion in public tendering for infrastructure projects (Chiappinelli & Zipperer, 2017; Mélon, 2020). As a result, bidders including circular alternatives in their offers will not end on the first place to win the contract because of a higher price. Attempts have been made by the European Union to promote evaluation criteria other than the lowest purchasing price, by introducing the *Most Economically Advantageous Tender (MEAT)* in 2014 as an alternative for contractor selection (Ratcliff et al., 2022). The price used a base to evaluate the MEAT is the cost calculated using Life-cycle Cost (LCC). LCC does not only include the Total Cost of Ownership (TCO) of an asset, but also the related environmental impact (Chiappinelli & Zipperer, 2017). Although positive progress has been made in this topic, there is still room left for improvement.

Subsequently, limitations and paths for further research concerning the methodology are discussed. The majority of the papers in this dissertation were focused on the Belgian case or Belgian respondents. Although most conclusions and recommendations are applicable to countries and regions with a similar governmental context, additional case studies are needed to strengthen the results found. Conclusions will be influenced by the large variations over countries, for example among others, differences in the local construction sector and governance and decision-making processes (Cantarelli et al., 2012 and El-Ahwal et al., 2016). Moreover, the number of datapoints used in Chapter 4 and Chapter 5 should be extended. In Chapter 4 36 infrastructure projects were analyzed and in Chapter 5 52 answers were obtained for the survey. Nonetheless already considerable numbers for both were obtained, more datapoints will increase the significancy of the analyses. Chapter 3 explains the initial conceptual development of SEMI and the first application of the tool. In order to be fully fine-tuned, the tool should be applied to other infrastructure types and under different circumstances.

Based on the results obtained in this manuscript, suggestions for further research can be categorized in two separate fields, being strategic management of infrastructure and improved project performance. Chapter 2 concludes by stating that a one-fits-all strategy does not exist. Following on this statement, further research into these infrastructure type-specific strategies is suggested. Defining and applying these strategies allows government agencies to manage their infrastructure assets better so that user demands can be met. Finally, results from Chapter 4 and Chapter 5 indicate future research possibilities in improving project performance, without solely looking at cost management and considering different objectives such as quality obtained and value creation for various stakeholders involved. Value for internal project stakeholders could be generated by improving the collaboration between them. On the other hand, external stakeholders' value could be created through a better consideration of their wishes and needs and a better involvement throughout the process. As a consequence, additional research is required in the relational dynamics between the project core actors and the project core actors and external stakeholders.

5. References

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