Ali Foroutan Mirhosseini

Towards a Deeper Understanding of the Cost Performance of Large-scale Road Projects

Thesis for the degree of Philosophiae Doctor

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Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

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Abstract

The issue of cost overruns in large-scale infrastructure projects is a major concern for many countries, including Norway. Despite efforts to manage project costs, cost inaccuracy remains a persistent problem in road construction projects, resulting in significant financial losses, delays, and negative social and environmental impacts. Therefore, it is essential to identify the factors contributing to cost inaccuracy and develop effective cost management strategies to ensure the success of these projects.

This thesis aims to address this problem by exploring the critical importance of cost performance evaluation in the Norwegian road projects' governance framework. Two broad research objectives have guided the research process for this thesis. The first research objective (RO1) was to further understand the concept of cost overrun and the influential parameters affecting cost inaccuracies in Norway. The second research objective (RO2) was to predict the cost performance of large-scale road (LSR) projects using past project data (a data set of 52 LSR projects). To achieve these objectives, the research employed a variety of methods, including surveys, case studies, and data analysis using advanced machine learning techniques such as artificial neural networks (ANNs) and generative adversarial networks (GANs).

The research findings revealed the three main reasons for cost overruns in road projects during the construction phase in Norway: scope changes, market conditions, and unforeseen ground conditions. These factors can significantly impact the project's budget, and it is essential to consider them during the planning phase to minimize the risk of cost overruns. The research also found that it is necessary to consider not only the construction phase but also the planning phase, as many factors that can cause cost overruns often originate from decisions made during the planning phase.

To minimize the risk of cost overruns due to scope changes and market conditions, the research suggested several strategies, including well-defined project scope, open communication, collaboration, thorough risk analysis, monitoring market conditions, local sourcing of materials and equipment, and collaboration with suppliers, subcontractors, and stakeholders. It is also crucial to conduct thorough geological and geotechnical investigations before starting construction and have a contingency plan in place to minimize the risk of unforeseen ground conditions causing cost overruns.

The research also suggested revising the calculation method used in Norway to account for cost increases in the planning period and/or budget increases during the construction phase. The current method may not be a reflection of the actual cost performance of a project, and including ex-post evaluations in project governance systems to assess tactical and long-term strategic success could provide a more accurate assessment of project success.

To improve on traditional cost estimation models which may be inadequate for capturing road projects' complex and dynamic nature, machine learning (ML) algorithms were explored. ML algorithms were seen to improve accuracy in analysis and feature selection, which helps identify important factors contributing to cost overruns while eliminating irrelevant or redundant variables. This thesis also shows the potential for deep learning methods to address small sample size challenges and the advantages of using ANNs over traditional regression models in predicting the cost performance of LSR projects. The results showed that the ANNs significantly outperformed traditional regression models in predicting cost performance. The study employed data generation techniques, specifically Conditional Tabular GAN (CTGAN), to overcome the challenge of small sample size in cost performance prediction. This approach facilitated the training and evaluation of three classifiers, yielding impressive results in terms of high accuracy and F1 scores across all classifiers. Overall, the use of these new and more sophisticated algorithms showed promise and could be beneficial in overcoming the challenges of cost estimation and management in the Norwegian road construction industry.

In conclusion, this thesis provides critical insights into the factors contributing to cost inaccuracy in Norwegian road projects and offers promising avenues for improving cost performance evaluation using advanced machine learning techniques. The findings of the research can inform the development of effective cost-management strategies and contribute to the successful delivery of large-scale infrastructure projects in Norway and other countries facing similar challenges. However, further research is needed to explore and refine these methods and strategies to ensure their effectiveness and applicability in different contexts.

Acknowledgement

In the midst of this momentous achievement, I carry within me the deepest pains in my heart for losing my beloved mother, just a few months ago. Throughout the entirety of my studies, her love, encouragement, and support were the pillars that fortified my determination. Though she is no longer physically present to witness the culmination of my doctoral journey, her memory and the impact she had on my life remain a constant source of inspiration. With sadness, yet determination, *I dedicate this thesis to her cherished memory, ensuring that her legacy of strength, resilience, and steady belief in my abilities lives on.*

To my supervisor, Prof. Kelly Pitera, and co-supervisor, Prof. James Odeck, I express my profound gratitude for their understanding and compassion during this difficult time. Their consistent support and encouragement provided me with the strength to navigate the challenges I faced, both academically and personally. Their empathy and flexibility allowed me the time and space needed to grieve and heal. I am forever grateful for their guidance and mentorship, which helped shape my research and sharpen my scholarly abilities.

To my family, especially my father, Reza, sister Armita, Sayna, Amirreza, and Aunt Maryam, I am deeply grateful for your resolute support throughout my doctoral journey, particularly during the difficult times of grieving my beloved mother, Farahnaz. Your presence and understanding have been a source of strength that I will forever cherish.

To Lisa, I express my heartfelt appreciation and gratitude for her support, understanding, and unique personality. Her presence during this challenging period brought moments of joy and respite, and her belief in my abilities remained steadfast. I will forever cherish the memories we shared and the impact she had on my life.

I am deeply grateful to my close friends and colleagues, who have been a constant source of strength, support, and humor throughout my doctoral journey. In particular, I want to express my heartfelt appreciation to Amid, Ashkan, Golpar, Jalal, Khashayar, Arman, Anita, Silvia, Diego, Roghayeh, Albert, Xuemei, Hao, Maryam, Markus, Ellen, and Amin for their encouragement, understanding, and companionship. Your belief in me, even during the darkest moments, has been a guiding light. Thank you for always being there, for your love, and for reminding me to find joy beyond academia.

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%B	Percentage of bridge length to the total road length	**NPRA**	Norwegian Public Roads Administration
%T	Percentage of tunnel length to the total road length	**NPV**	Net Present Value
AI	Artificial Intelligence	**PC**	Pre-construction phase
ANN	Artificial Neural Network	**PCO**	Percentage Cost overrun
CA	Conceptual Appraisal	**PF**	Planning Factors
CBA	Cost-Benefit Analysis	**PLS-SEM**	Partial Least Squares Structural Equation Modeling
CBRI	Correlation Based Regression Imputation	**PM**	Project Management and Contractual Relationship
CF	Construction Factors	**QA (1/2)**	Quality Assurance (1/2)
CFS	Correlation-based Feature Selection	**R**	Region of construction
CT	Construction time in year	**RBF**	Radial Basis Function
CTGAN	Conditional Tabular GAN	**RBFNN**	Radial Basis Function Neural Network
DQA2	The cost deviation percentage from the QA2 report	**RBFNN-GP**	RBFNN-Gaussian Process
EX	External	**RII**	Relative Importance Index
Final	Final cost	**RMSE**	Root Mean Squared Error
GAN	Generative Adversarial Networks	**RO (1/2)**	Research Objective (1/2)
LSR	Large-scale Road	**SM**	Contractor's Site Management
MAPE	Mean Absolute Percentage Error	**SVM**	Support Vector Machine
ML	Machine Learning	**TL**	Total road length in meters
MLP	Multi-Layer Perceptron	**TPC**	Time lapse between the parliamentary decision and construction start
MPCO	Mean Percentage Cost Overrun	**XGBoost**	Extreme Gradient Boosting (Classifier)
MSE	Mean Squared Error	**YC**	Year construction completed
NC	Number of contractors	**year**	Decision-making year

1. Introduction

1.1. Cost overrun: A recurring problem in large-scale transportation projects

Transportation infrastructures are expensive public expenditures that are essential to a country's economic development. While they are necessary for a well-functioning transportation network, they may incur higher costs than expected (namely, cost overrun), negatively affecting the country's economy. Cost overrun has been a severe issue in large-scale transportation projects for decades. Yet, despite broad research and organizational reforms, it has remained a controversial topic that continues to draw attention. High-profile cases of cost overrun in large-scale transportation infrastructure projects around the world include:

- The undersea Channel Tunnel, where construction costs increased from GBP 2600M to GBP 4650M (in 1985 prices), indicating an 80% cost overrun (Flyvbjerg, Bruzelius et al. 2003),
- The Central Artery/Tunnel 'Big Dig' project, a complex underground highway in Boston (US), with a cost overrun of USD 11M (in 2003 prices), thus a 275% increase in the estimated costs (Flyvbjerg, Bruzelius et al. 2003),
- The Hong Kong-Zhuhai-Macau Bridge (HZMB), which links the western end of Macau and mainland China to the eastern end of Hong Kong, spanning across the Pearl River Delta, estimated at USD 5.4B, with a final cost of around USD 18.8B (in 2018 prices) (Situ 2022),
- The Honolulu rail transit line with cost estimations increasing upward from USD 5.4B (in 2021 prices) to USD 11.4B, while the project is not yet delivered (Vartabedian 2021), and
- The USD 400M cost overrun on Spadina subway extension in Toronto, Canada (Siemiatycki 2016).

Cost overruns are also occurring within large-scale road (LSR) projects in Norway, often attracting media attention and public concern (see Fig. 1).

Fire veiprosjekter i Nord-Norge – to milliarder i overskridelser

Det bygges for fullt på veiene over hele Nord-Norge. Men én etter én sprekker budsjettene. – Statens vegvesen må bli flinkere til å si nei, mener forsker.

Bente H Johansen
Journalist

Statssekretær Tom Cato Karlsen (tv), regionvegsjef Torbjørn Naimak (i midten) og Albert Hæhre i Hæhre entreprenør tok de første spadetakene på E6 Helgeland nord i september 2015. Siden den gang har prosjektet blitt 444 millioner kroner dyrere. Som en konsekvens av det, ble det i statsbudsjettet for 2017 bestemt at det skal bygges mindre vei på strekningen.
FOTO: FRANK NYGÅRD / NRK

Publication year: 2017

E6 Frya-Sjoa én milliard dyrere

Utbygginga av E6 i Gudbrandsdalen blir ca. én milliard dyrere enn beregnet. Dette tilsvarer ca. 13 prosent over kostnadsrammen som ble vedtatt i Stortinget. Hovedårsaken ligger i økte priser fra entreprenørene. Staten tar mesteparten av kostnadsøkningen mens ca. 123 millioner kroner skal dekkes inn med bompenger.

Utsyn over E6-utbygginga i Sør-Fron. Foto: Foto: Eli Ramstad, Statens vegvesen

Publication year: 2014

Riksrevisjonen: - Betydelige overskridelser på flere Vegvesen-prosjekt

Publisert 05.11.2013 13:45

Publication year: 2013

Fig. 1. Examples of several articles from Norwegian newspapers. To the top-left: 'Four road projects in North-Norway – two billion in cost overrun' to the top-right: 'E6 Frya-Sjoa 1 billion more expensive', and bottom: 'Considerable cost overrun on several NPRA road projects

Cost overruns can adversely impact the economy of a country in several ways. First, cost overruns originating from inaccurate cost estimations (cost inaccuracies) may indicate the implementation of the wrong projects. When inaccurate cost estimations are presented to the decision-makers, the ranking of projects will be affected; hence, the most beneficial projects are not always selected. However, if the accurate cost estimations were presented to decision-makers, and a project was found to be less favorable, they could either not select the project, modify the project proposal, select another project, or invest in other social benefits (Odeck 2004). In addition, the extra budget needed to complete a project, which was initially estimated to be cheaper, could be budgeted for other projects (Flyvbjerg, Bruzelius et al. 2003). Therefore, it results in fewer projects selected, funded, and implemented. Furthermore, cost overruns can lead to project delays associated with the bureaucracy of securing the extra budget. These delays can lead to further cost overruns by increasing the project cost.

1.2. Motivation

Like the rest of the world, the cost overrun has been a serious challenge in Norway. In the last two decades of the twentieth century, significant cost overruns in road projects in Norway were prevalent, resulting in a large media outcry, blaming the Norwegian Public Roads Administration (NPRA) that the cost increases were out of their control. At the same time, there was neither a mechanism for quality control nor cost estimates (Odeck 2014).

To curb significant cost overruns in the road sector and have a better system for overseeing quality control of the roads being constructed, the Norwegian government introduced a governance framework from the Ministry of Finance in 2000. The main principle within the framework was that each large project's cost estimations and management base would go through external Quality Assurance (current QA2) before the project could be submitted to Parliament for financing, with the primary objective of controlling cost overruns. The framework was extended in 2005 by adding a Conceptual Appraisal (CA) stage (current QA1) before the Cabinet decides whether to proceed to the pre-project phase. The conceptual appraisal evaluates the possible solutions for meeting societal needs.

The QA regime has enabled researchers in various fields, from risk analysis and project management to applied logical and critical assessment, to track large-scale projects in Norway and research different aspects of such projects. Several studies have also demonstrated that QA2, which was originally introduced to limit cost overruns and improve the cost performance of the projects, has controlled cost overruns substantially, and many projects are completed within the cost frame now (Welde 2017). Yet, overruns continue to occur, and there is still room for improvement.

The existing literature (see Chapter 2) most often presents cost overrun in large sample sizes with worldwide scope and primarily focuses on the overrun's magnitude, distribution, and frequency. Research in this field frequently involves many projects with several individual project-related characteristics, where results reflect different project aspects often related to the construction phase, which may affect the final cost performance (Flyvbjerg, Skamris Holm et al. 2003, Cantarelli, Flyvbjerg et al. 2012). Simple statistical methods are used for data analysis and evaluating the most important parameters affecting cost overrun, the distribution and the magnitude of cost overrun, etc., where the results are inconclusive in some cases. This approach does not provide insight into projects' cost performance in the context of an individual country, as using the results of research with worldwide coverage for a particular country may include the danger of *ecological fallacy* (inferring for an individual based on aggregate data for a group). Thus, there is a need for the evaluation of project performance for individual countries (i.e., Norway) to give a better understanding of the issue of cost overrun specific to that country, including the corresponding reasons and explanations for overruns, and lessons learned from studies based on existing projects to improve the cost performance of future projects.

Additionally, the planning phase is often overlooked in the literature related to cost overrun, even though aspects of the planning phase can significantly impact the project's cost performance. For example, Odeck (2019) demonstrates that cost growth during the planning phase can be higher than during the construction phase. Initial idea development, project scoping, and initial cost estimations are shaped at the early stages of the planning phase. Many parameters can affect the project idea/scope during the planning phase, which may also directly/indirectly affect the project's cost performance during construction. Therefore, further research into the planning phase will contribute to the literature on cost overruns and the efficacy of the project governance system.

Simple statistical methods used within cost overrun studies do not provide a deep understanding of causes and explanations or result in definitive conclusions, particularly when considering the parameters which affect cost overrun. Welde (2017), for instance, examined the cost performance of 78 Norwegian LSR projects completed after the introduction of the QA and found that cost overrun still exists even with the QA program. Yet, he did not find any clear correlations between the parameters studied and the final cost overrun using simple linear regression methods. Thus, there are opportunities to explore the use of alternative methods within the study of cost performance. Machine Learning (ML) methods as a subset of Artificial Intelligence (AI) are becoming popular in many applications, from recognizing handwritten to designing pilot driving systems for autonomous vehicles. However, these advanced methods have yet to receive much attention in the field of transportation economics.

Furthermore, limited data availability poses a challenge, particularly when aiming for generalized findings within specialized contexts like cost performance prediction for LSR projects. Various techniques can be leveraged to minimize such challenges, thus enhancing the validity of predictive models. Considering the understood abilities of AI-driven techniques from other contexts, this study employs such strategies to address data scarcity concerns, thus working to mitigate the potential limitations in generalization given data constraints.

1.3. Research objectives

The main aim of this study is *'to acquire a better understanding of cost performance of LSR projects in Norway.'* There is often a focus on cost overruns, which are more prevalent and well-known to practitioners and stakeholders involved in such projects, than cost underruns. Yet, the terms *'cost inaccuracy'* and *'Percentage Cost Overrun (PCO)'* are used in the quantitative parts of this study (RO1.4 and RO2), where both cost overruns and underruns are considered since both indicate inaccurate cost estimations. The research addresses the three previously identified gaps, 1) a country-specific focus, 2) considerations of the planning phase, and 3) applications of ML methods to contribute to the existing literature on this topic.

There are two main research objectives addressed in this research:

RO1. *To further understand the concept of cost overrun and the influential parameters affecting cost inaccuracies in large-scale road projects in Norway.*

Given the diversity of studies on cost overrun and parameters affecting it, which is a multiplex system, exploring RO1 is addressed through a multi-method approach:

1. A thorough review of the available literature to understand cost overrun, including influential parameters, methods of calculation, cost performance, project governance and management, and other relevant concepts,
2. A survey study of experts in LSR projects in Norway to expand knowledge on the perception of influential parameters leading to cost overrun during both planning and construction phases in Norway,

3. An in-depth ex-post analysis of a newly built road project to gain a better insight into the challenges and uncertainties during the construction phase, which affect the cost performance of a case study LSR project in Norway, and finally,
4. Use of ML methods (i.e., feature selection) to better understand the interdependence of the parameters contributing to the cost performance of LSR projects and detect the most influential ones to minimize the risk of cost inaccuracy.

RO2. *To predict the cost performance of large-scale road projects using past project data.*

This objective focuses on exploring new ML-based methods for cost performance analysis and is addressed by applying a multi-step approach using several machine learning methods:

1. The prediction of missing data using an advanced correlation-based algorithm as a part of the data collection and preprocessing,
2. The elimination of irrelevant parameters using a feature selection method (as part of RO1) to refine data for further analysis,
3. An investigation of newly developed regression-based Artificial Neural Networks (ANNs) to:
    i. Predict the cost performance of future LSR projects.
    ii. Compare the accuracy of the (new) models with traditional regression methods,
4. The application of a recently developed learning-based data generation method to increase the accuracy of the prediction models.

The project data used in this study is primarily collected through the Concept Research Program[1] and includes 52 LSR projects. Each project has 11 independent explanatory variables, which are assumed to incorporate the target variable (i.e., cost overrun) of the projects.

[1] Concept Research Program develops ways to improve the choice of conceptual solution, use of resources and enhance the effect of major public investments. For more information, visit: https://www.ntnu.edu/concept/about-the-programme

1.4. Research scope

The focus of this research is specified and limited as follows:

- This thesis focuses on state funded LSR projects. Projects funded by the private sector or at the municipal level were not considered.
- Only large-scale projects were evaluated. According to the QA program, projects with budgets greater than NOK 750M (as of year 2019) are considered large-scale projects.
- The geographical scope and project data used are limited to Norway.
- Data on large-scale projects were mainly from after 2005, when the completed version of QA (including QA1 and QA2) was introduced and implemented. However, a few projects have not been subjected to QA1.

The above-mentioned limitations indicate that while some parts of the findings of this study might not be directly applicable to other settings than Norway, the overall focuses discussed are likely to be of interest beyond the Norwegian context. Additionally, the methodology used in this study is a novel approach, which combines qualitative investigation of influential causes affecting the cost accuracy of LSR projects with quantitative assessment of the cost performance of such projects to predict the cost performance of future projects. The ML models proposed in this study, with improved accuracy compared to conventional models, are specifically compatible with small sample sizes and can greatly contribute to the development of analysis methods used in the literature on cost performance worldwide.

1.5. List of papers

This thesis is built based on four individual research papers:

Paper 1 (RO1):

Foroutan Mirhosseini, A., Pitera, K., Odeck, J., & Welde, M. (2022). Sustainable Project Management: Reducing the Risk of Cost Inaccuracy Using a PLS-SEM Approach. *Sustainability*, *14*(2), 960.

Paper 2 (RO1):

Foroutan Mirhosseini, A., Pitera, K., Odeck, J., *'Ex-post evaluation of project efficiency and effectiveness within a Norwegian highway project'*. The paper is accepted for publication in the journal of *Case Studies on Transport Policy*.

Paper 3 (RO1 and RO2):

Foroutan Mirhosseini, A., Pitera, K., Odeck, J., Rouhi, A., Barmoudeh, L., Welde, M., *'Application of Artificial Neural Networks to Investigate Cost Overrun of Road Projects.'* The paper has received comments and requires revision. The original submission was made to the Journal of *Research in Transportation Economics* in February 2023. As of August 21, 2023, the paper is in the process of being revised based on the feedback provided from the first round of review.

Paper 4 (RO2):

Foroutan Mirhosseini, A., Pitera, K., Odeck, J., Rouhi, A., *'Small Data, Big Predictions: Synthetic Data Generation using CTGAN to predict Cost Performance of Road Projects'*. In progress.

1.6. Outline of the thesis

Following the introduction of this thesis presented in this chapter, Chapter 2 provides a brief overview of the study's theoretical background and reviews the existing literature. Chapter 3 presents the research design and the data collection and analysis methods. Chapters 4 and 5 present the results and discussion, addressing research objectives 1 and 2, respectively. Finally, Chapter 6 summarizes the main findings, discusses the main contributions of this thesis, limitations, and presents suggestions for further research.

2. Theoretical background

The key definitions and topics on which this thesis is built are defined and explained within this chapter, including relevant literature reviews. The concept of project success is discussed to describe how this thesis's objective and contribution are placed within the concept and elements of project success, most notably cost overrun. Project governance is explained in order to connect to the project governance framework in Norway to cost performance for LSR projects. The last section of this chapter presents a general overview of the concept of AI and the application of newly developed machine learning methods in the field of transportation economics and, more specifically, within the cost performance of LSR projects. Fig. 2. presents the structure of this chapter.

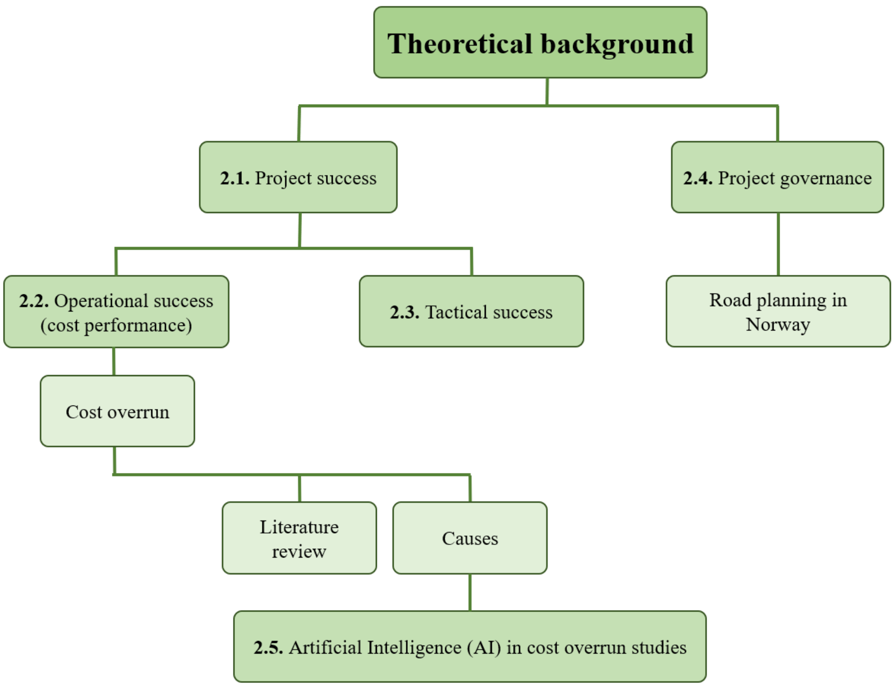


Fig. 2. Structure of theoretical background review

2.1. Project success

It is hard to find a globally accepted definition for the concept of 'project success.' The definition has been interpreted and developed among various individuals, institutes, and governments around the world, as Pinto and Slevin (1988) stated that: 'the concept of project success has remained unclearly described both in the project management literature and, indeed, often within the psyche of project managers.'

Traditionally, the three primary parameters of *cost*, *time*, and *scope* have been considered by project management experts as the main criteria for a successful project (Morris 2013). However, in recent years, it has been understood that in addition to the aforementioned parameters, a more comprehensive strategic view of projects is needed to ensure project success since the projects, especially infrastructure projects, are supposed to deliver societal benefits (Volden 2019). In particular, large-scale infrastructure projects funded mainly by the governments (which themselves are representatives of the whole society) are supposed to create value, provide monetary and non-monetary benefits for the society, and in simple terms, improve social welfare. In order to simplify the definition of project success within this research, a highly cited study by Samset (2003) is referred to, in which a successful project is defined as a project which fulfills three different criteria of operational, tactical, and strategic success.

As shown in Fig. 3, operational success is a short-term evaluation level where short-term targets, including *cost* and *time* performance, are assessed when the project is implemented. Tactical success covers a broader scope and examines whether the project has achieved its objectives or whether it is beneficial to society, considering all positive and negative side effects. Finally, strategic success has the broadest focus, considering long-term needs satisfaction or long-term economic impact.

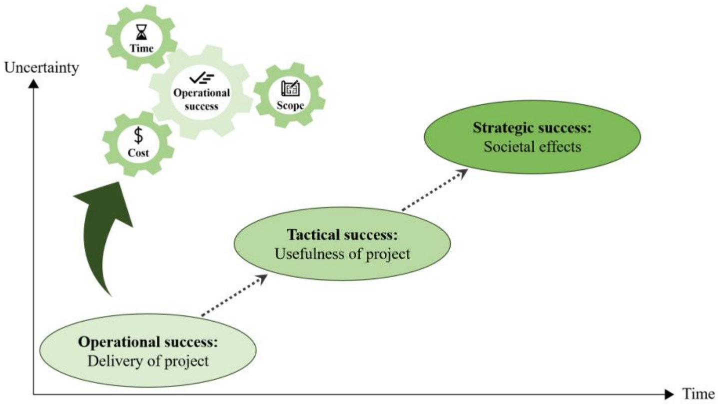


Fig. 3. Measures of project success (reproduced from Samset (2003))

The main scope of much of this research is connected to the operational level of project performance and, specifically, the cost performance of the LSR projects in Norway. Not performing well at the operational level leads to cost and time overruns, indicating operational failure of the project. Failing at the operational level may directly or indirectly affect the tactical or strategic performance of the project. Therefore, the successful delivery of a project within the time/cost frame (i.e., operationally successful) plays an essential role in overall project success. Yet, these levels of success are all highly influenced by the planning stage, in which societal needs, proposals and alternatives, uncertainty analysis, and cost estimations are made. Hence, it can be inferred that a well-functioning project planning system can result in an operationally successful project, further leading to success tactically and strategically (Samset 2003).

As the first step towards more operationally successful projects, it is relevant to study the concept of cost overrun, the influential parameters affecting it, and the possible ways to minimize it in order to be able to improve the cost performance of a project, which is a criterion of project's operational success evaluation.

2.2. Cost performance; a measure of operational success

As mentioned, project management experts have traditionally focused on three parameters, cost, time, and scope, also known as the *'iron triangle,'* to assess a project's success. While adjustments to the scope affect the cost and time of the project, evaluating the time and especially cost performance (the focus of this study) of the projects has drawn more attention in the literature (Volden 2019).

2.2.1. Cost Overrun

Cost overrun has had numerous interpretations in the literature as well as different premises for calculation. In this study and based on a review of the literature, the following definition for cost overrun is used:

'Cost overrun is measured based on the difference between actual and estimated costs, where the result is positive. A negative value would imply a cost underrun (Flyvbjerg, Skamris Holm et al. 2003, Cantarelli 2011, Odeck 2019)'.

Actual costs are all real costs right after the project's completion. Estimated costs, however, have been determined differently among various studies. Since the planning process for projects differs from country to country, the moment considered for estimated costs can also be different. This difference can also impact comparing the results of studies on cost overrun between countries. In this thesis, the estimated costs are determined at the time of the formal decision to build the project or the so-called 'decision-date,' 'the time of the decision to proceed' or 'go-decision' (Cantarelli 2011).

Cost overrun is a different concept from 'cost escalation', as cost escalation is a term utilized to state a predicted growth in the final budget (e.g., due to inflation). However, according to previous research, terms such as 'cost growth,' 'cost increase,' or 'budget increase' imply cost overrun (Odeck 2019). Traditionally, cost overrun has been interpreted as an indication of project operational failure and inefficient allocation of resources (Flyvbjerg, Skamris Holm et al. 2003, Odeck 2004, Cantarelli 2011). However, underruns are as unfavorable as they originate from inaccurate estimations, resulting in excess funding that could be saved or spent on other projects, and, therefore, can be as unfortunate as cost overruns. Unlike cost overrun, cost underrun has not been found to be as prevalent and has received limited research attention.

There are several ways of calculating the magnitude of cost overrun. In this study, cost overrun is expressed by percentage error. If AC and EC represent the Actual and Estimated Costs, the PCO (Percentage of Cost Overrun) can be calculated as follows:

$$PCO = \frac{(AC-EC)}{EC} \times 100 \quad (1)$$

Where AC and EC are converted to Net Present Value (NPV) (Odeck, Hagen et al. 2010), and PCO > 0 indicates cost overrun, whereas PCO < 0 implies cost underrun.

2.2.2. Review of the literature on cost overrun

Many studies have been carried out worldwide on the cost performance of transportation infrastructure projects. The studies of Merewitz (1973), Pickrell (1992), and Skamris and Flyvbjerg (1997) are among the first that aimed to evaluate transportation projects' cost performance. However, there were several criticisms: the studies mainly included either small sample sizes or single cases; also, some of their analysis methods have been seriously criticized. For instance, Merewitz (1973) compared the cost overrun in the San Francisco Bay Area Rapid Transit system with several other types of public investments in the US, finding an average cost overrun of 50% in his study sample containing 66 transport projects. However, the inflation rate was not considered in his calculations. In another study, a small sample size of eight railway projects was investigated by Pickrell (1992). The results showed that seven out of eight ended up with cost overruns ranging from 17% to 150%. Further review of past studies demonstrates that cost overrun has been more common than cost underrun (Odeck 2004, Siemiatycki 2009, Cantarelli, Flyvbjerg et al. 2012, Cantarelli, Molin et al. 2012, Love, Ahiaga-Dagbui et al. 2016).

Over time, there has been development in studies' data accuracy and analysis methods. Studies by Flyvbjerg, Skamris Holm et al. (2003), and Odeck (2004) are among the leading works in this area. Their studies included 258 and 620 transport projects in their study samples, respectively, and have different focuses within their research approaches. Flyvbjerg, Skamris Holm et al. (2003) covered 258 projects from 20 countries and estimated the Mean Percentage Cost Overrun (MPCO) based on geographical region and project type. The results demonstrated an MPCO of 45%, 34%, and 20% for rail, fixed links (tunnels and bridges), and roads, respectively. From a geographical perspective, they found that developing countries have higher cost overruns and poorer cost track records compared to Europe and North America. Moreover, rails and roads showed an MPCO of 34.2% and 22.4% in Europe, while these values were observed to be 40.8% and 8.4% in North America.

Odeck (2004) developed an econometric model in order to statistically evaluate if any of the parameters, including project region, project size, project type, and project completion year, influence the magnitude of cost overrun. He found that project type had no impact on the level of cost overrun. In contrast, the other parameters, including project completion time and project region, influenced the magnitude of cost overruns. Another promising finding of the study was that the accumulative percentage and the magnitude of cost overrun appeared to be more prevalent in small projects (i.e., projects with budgets less than NOK 15M in 2002 prices) than in large projects (i.e., projects with budgets more than NOK 350M).

In another study, Cantarelli, Flyvbjerg et al. (2012) investigated the effect of project type, project size, and implementation phase in the Netherlands and worldwide and found that the length of the implementation phase and pre-construction phase are important parameters, as the percentage of cost overrun increases by 5% with each additional year of the pre-construction phase (Cantarelli, Flyvbjerg et al. 2012). In a study conducted by Berechman and Wu (2006), 163 road projects were evaluated in Vancouver, Canada, where an average overrun of 5.9%, varying from -52 to 134%, was observed. Fouracre, Allport et al. (1990) performed a study for the UK Transport and Road Research Laboratory (TRRL) and found that most of the projects had actual costs higher than their estimations.

Table 1 presents a sample of the literature review on cost overrun according to the year published, author, type of study, region/country of the study, the number of projects evaluated, and the average overrun reported. The methodology used for conducting the literature review is described in Chapter 3. As can be observed from Table 1, cost overruns are prevalent around the world, and overruns are more common than underruns. This is in line with the claims made by Flyvbjerg, Skamris Holm et al. (2003), Odeck (2004), Cantarelli, Flyvbjerg et al. (2012), and Cantarelli, Molin et al. (2012) that cost overrun is continuously a problem in large transportation infrastructures, and are more common than underruns. However, the studies in Table 1 are significantly different regarding their sample size, the percentage cost overrun, and especially the region where the study was conducted. The mean percentage cost overrun in the reviewed studies was determined to be 30.42%, with a mean sample size of 444.5 projects, which statistically agrees with the statements above regarding the prevalence of overruns and significant variation within the number of cases. The variation within the percentage cost overrun can also be attributed to which price type was used (e.g., nominal or real), differences in calculation methods, and different time points considered when calculating estimated and actual costs.

Table 1. The characteristics of the reviewed studies

Study no.	Authors	Type of study	Region/country of study	No. of projects	Average % overrun
1	Bordat, McCullouch et al. (2004)	Journal	US	2668	4.5
2	Flyvbjerg, Bruzelius et al. (2003)	Journal	World	258	20
3	Lee (2008)	Journal	South Korea	138	11
4	Blanc-Brude, Goldsmith et al. (2006, 2009)	Report	Europe	227	24
5	Odeck (2004)	Journal	Norway	620	9
6	Merewitz (1973)	Journal	US	49	26
7	Riksrevisionsverket (1994)	Report	Sweden	8	86
8	Skamris and Flyvbjerg (1997)		Denmark	7	14
9	Wu (2006)	Thesis	Canada	50	82
10	Odeck, Welde et al. (2015)	Journal	Norway	40	47.5
11	Ellis Jr, Pyeon et al. (2007)	Report	US	3130	9
12	Singh (2010)	Report	India	157	15.8
13	Kaliba, Muya et al. (2009)	Journal	Zambia	8	69
14	Samarghandi, Mousavi et al. (2016)	Journal	Iran	86	15.4
15	Creedy, Skitmore et al. (2010)	Journal	Australia	231	16
16	Cantarelli, Flyvbjerg et al. (2012)	Journal	Netherlands	37	18.6
17	UK National Audit Office (2007)	Report	UK	36	6

18	Roxas and Chalermpong (2008)	Conference	Philippines	85	5.4
19	Makovšek, Tominc et al. (2012)	Journal	Slovenia	56	19
20	Anguera (2006)	Journal	France/UK	1	99
21	Chapulut, Taroux et al. (2005)	Conference	France	5	13.3
22	Pickrell (1992)	Journal	US	8	61
23	Arkansas DOT (2002) [in Bordat, McCullouch et al. (2004)]	Report	US	1377	3.98
24	Missouri DOT (2002) [in Bordat, McCullouch et al. (2004)]	Report	US	670	3.7
25	Tennessee (2002) [in Bordat, McCullouch et al. (2004)]	Report	US	2196	8.13
26	Texas (2002) [in Bordat, McCullouch et al. (2004)]	Report	US	2917	4.6
27	Nicolaisen (2012)	Thesis	Europe	94	16.2
28	Rajan, Gopinath et al. (2014)	Journal	India	145	17.5
29	Park and Papadopoulou (2012)	Journal	India	14	10.26
30	Chevroulet and Reynaud (2010)	Conference	Europe	6	51
31	Odeck and Skjeseth (1995)	Journal	Norway	12	5
32	Roxas and Chalermpong (2008)	Conference	Thailand	129	- 0.13
33	Al-Hazim (2015)	Journal	Jordan	9	214
34	Rwakarehe and Mfinanga (2014)	Journal	Tanzania	7	44
35	Lundberg, Jenpanitsub et al. (2011)	Journal	Sweden	167	15
Mean				444.5	30.42

2.2.3. Causes of cost overrun

The causes of cost overrun have been discussed in numerous studies, including Flyvbjerg, Skamris, Holm et al. (2003), Siemiatycki (2009), Cantarelli (2011), Lin and Tang (2006), and Odeck (2014). For example, Morris (1990) found that price increase is the leading cause of cost overrun, while poor project design, delay in implementation, and lack of coordination between different parties are the subsequent causes. Lee (2008) examined 161 social overhead capital projects in Korea and concluded that changes in scope, delays during construction, and unreasonable estimation were the leading causes of cost overrun. Herrera et al. (2020) conducted a systematic review to evaluate the most critical causes of cost overrun in road construction projects worldwide. Among the 38 identified factors, failures in design, price variation of materials, inadequate project planning, project scope changes, and design changes were determined to be the most influential. Research by Hall (1982), Nijkamp and Ubbels (1999), Kaliba, and Muya et al. (2009) gives further insight into different parameters influencing cost overrun.

Once causes have been identified, they can be categorized concerning explanation. According to Cantarelli (2011), the difference between '*cause*' and '*explanation*' is defined as causes implying the parameters and variables that affect cost overrun, or, in simple terms, 'result in' cost overrun, while the explanation's definition is broader and may include several causes. Cantarelli (2011) has proposed a categorization for the causes of cost overrun comprised of four main explanations: technical, economical, psychological, and political. Table 2 is adapted from the study mentioned above by Cantarelli (2011), which presents an overview of the main causes of cost overrun as seen in the literature. While earlier Table 1 showed that the magnitude of cost overrun varies significantly within international studies, the causes of cost, as presented in Table 2, might be similar regardless of geographical region. Yet, to gain a deeper understanding of the causes and explanations of cost overruns within a country, country-specific case studies are needed as a generalization of the results from one country to the next may create the risk of ecological fallacy (Van Wee 2007, Volden 2019).

Table 2. Causes, explanations and corresponding theories [adopted from (Cantarelli 2011)]

Explanation	Examples of causes	Relevant studies
Technical	• Poor project design • Price increase • Change in scope • Incomplete estimates • Uncertainties such as inefficient decision-making or planning process • Improper organizational structure	(Flyvbjerg, Bruzelius et al. 2003) (Faludi 1973, Pickrell 1992) (Bruzelius, Flyvbjerg et al. 2002, Lee 2008, Kaliba, Muya et al. 2009, Mahmud, Ogunlana et al. 2021)
Economical	Deliberate underestimation because of: • Lack of incentives or resources • Poor financing • Inefficient contract management • Strategic behavior • Ineffective use of resources	(Pickrell 1992, Odeck 2004) (Hall 1982, Skamris and Flyvbjerg 1997, Love and Ahiaga-Dagbui 2018)
Psychological	• Vigilant attitude toward risk • People's cognitive bias • Politicians' optimism bias	(Kahneman and Lovallo 1993, Skamris and Flyvbjerg 1997)
Political	• Intentional cost underestimation • Manipulation of estimations	(Hall 1982, Odeck 2004) (Wachs 1982, Flyvbjerg, Skamris Holm et al. 2003, Pinheiro Catalão, Cruz et al. 2019, Mahmud, Ogunlana et al. 2021)

Within Table 2, the primary focus is on the construction phase, which is also representative of the literature on cost overruns. The causes of overrun within the planning phase are also relevant. Further elaboration on the planning phase is discussed later in the chapter.

From the literature, it was possible to identify causes of cost overrun specific to the planning phase, as shown in Table 3 (Memon, Rahman et al. 2011, Larsen, Shen et al. 2016, Rajakumar 2016, Samarghandi, Mousavi et al. 2016). It is to be mentioned that similar categorization as the construction phase does not exist in the literature, given the narrow focus on the planning phase.

Table 3. Factors affecting cost increase in the planning phase

Num.	Factor
1	Local wishes without cost responsibility
2	Defective estimation
3	Long processing time
4	Those who get the benefit are not the ones who pay
5	Changes in rules and regulations
6	Project optimism
7	Poor project management
8	Lack of follow-up
9	Changes in the society expectations
10	City projects are detailed and costly to estimate
13	Technological development
14	Weak incentives to reduce planning time
15	Little transparency
17	Increased funding hides cost growth
18	Changed/different staffing

2.2.4. Procurement and Contracting Strategies

Efficient project management strategies are pivotal in mitigating cost overruns in LSR projects. Procurement and contracting practices are determinants of project outcomes, and decisions can significantly impact project success. Procurement decisions encompass a range of choices including project delivery methods, tendering processes, contract types, and risk allocation. An effective procurement strategy can address the interests of various project participants and establish a robust framework for effective cost management. Conversely, an ill-suited procurement strategy can result in misaligned incentives, inadequate risk management, and ultimately, cost overruns (Flyvbjerg, Bruzelius et al. 2003).

The Principal-Agent (PA) theory is a fundamental concept in understanding the dynamics of LSR projects and offers insights into the intricate relationship between project owners (principals) and contractors (agents). PA theory explores how, in the context of LSR projects, information asymmetry often emerges as a significant contributor to cost overruns. This theory is foundational in addressing the challenges that arise due to differences in access to crucial project details, risks, and uncertainties among stakeholders. These disparities in information create challenges within decision-making and resource allocation. Contractors, equipped with specialized knowledge of construction processes and associated risks, may minimize the potential for cost escalation during the bidding phase to secure contracts (so-called perverse incentives) (Volden 2019). Conversely, project owners might lack comprehensive insights into construction intricacies, leading to incomplete cost estimates. Such information disparities can result in moral hazard and adverse selection. Contractors might engage in opportunistic behaviors that raise costs, while owners might unknowingly choose contractors whose cost estimates fail to accurately reflect project realities. Thus, the interplay of perverse incentives and PA theory significantly influences cost performance. This is particularly evident in government-funded projects where perverse incentives can lead to the misalignment of specific groups' interests with the overarching societal project goals (Müller and Turner 2005, Volden 2019).

Moreover, effective procurement strategies play a significant role in determining project outcomes. Choices regarding project delivery methods, tendering processes, contract types, and risk allocation are integral parts of procurement decisions. A well-structured procurement strategy can align the interests of various project participants and establish a robust framework for effective cost management. Conversely, selecting an inappropriate procurement strategy can result in misaligned incentives, inadequate risk management, and ultimately, cost overruns (Bruzelius, Flyvbjerg et al. 2002). This highlights the interconnectedness of procurement and contracting practices in influencing cost accuracy within LSR projects. Addressing these challenges necessitates enhancing information transparency and flow. Rigorous project assessment, public involvement, and comprehensive evaluations can serve to mitigate information asymmetry. The reduction of conflicts of interest is also important. Strategies such as co-financing or shared liability can encourage accountability and ensure project viability. A comprehensive governance framework is useful in navigating the complexities involved and curbing perverse incentives, thereby preventing the occurrence of cost overruns. These multifaceted aspects of procurement, information management, and governance collectively shape the landscape of cost management in LSR projects (Ewerhart and Fieseler 2003, Wondimu 2019).

As mentioned above, contracting and project delivery methods have considerable influence over project outcomes, shaping contractor behavior and risk-sharing that can then influence cost performance and potential overruns in LSR projects. Well-structured contracts can actively encourage efficient cost management, while inadequately designed contracts may lead to misaligned incentives and the potential for cost escalation. In Norway, the prevalent design–bid–build unit price contracts assign the risk of inaccurate quantity estimation to clients. This approach, while promoting transparency, also carries the risk of cost escalation should quantities deviate substantially from estimates. Unit price contracts are particularly well-suited to projects featuring known elements but uncertain quantities. However, traditional contracting approaches that exclude contractor involvement can contribute to poor project management and scope modifications (Welde and Dahl 2021).

More recently, efforts aimed at enhancing project delivery have prompted a shift toward early contractor involvement and greater risk transfer to contractors. This evolution encourages contractors to account for potential changes and additions in their bids, enhancing cost certainty for clients but potentially increasing costs for contractors. These various contract types, each with its own set of advantages and challenges, contribute to the complexity of managing LSR projects. Relevant factors contributing to cost overruns encompass inadequate project management, design challenges, unforeseen external events, and deficiencies in client organizational capacity and competence (Volden 2019, Welde and Dahl 2021). The variability in reported outcomes across different studies often stems from differences in the basis of comparison. These diverse contracting methods collectively shape the landscape of cost management in such projects, setting the stage for further exploration of how they influence project cost accuracy.

2.3. Tactical success

To achieve true success, public investments must not only be cost and time-efficient, but also perform well on both tactical and strategic levels (Volden 2019). Tactical performance, which is broader than operational performance, examines whether the project has met its predetermined goals and is relevant to current societal priorities and needs. This evaluation should be conducted after the project is completed (Samset 2003). This level of success takes into account the user's perspective and inherent uncertainties (Volden 2018, Volden 2019). At the tactical level, effectiveness is used as the measure of project success (OECD 2002). Despite the importance of evaluating both tactical and strategic success, few studies have examined the effectiveness of road infrastructure projects, underscoring the need for further research in this area.

The success of a road project in Norway was evaluated by Welde (2018), who focused on its tactical success five years after opening. He measured the project's impact on severe traffic accidents and deaths, as well as the number of commuters using the road. His findings revealed a 75% decrease in deaths or serious injuries and a 20% reduction in travel time due to decreased congestion. In another study, using the Norwegian six-factor evaluation framework, Volden (2018) assessed the success of 20 infrastructure projects from various sectors in Norway, including roads, railways, and defense. While all 20 projects were operationally successful, she found tactical and strategic performance variations. Some projects were highly relevant and sustainable but had low benefit-cost efficiency, and vice versa. Volden suggested that cross-sector learning could aid in developing evaluation measures and methods.

2.4. Project governance

As noted above, cost inaccuracies can occur not only in the project's construction phase but also within the planning phase. To thoroughly study changes in cost inaccuracies in the early planning phase, it is necessary to have a general understanding of the project governance framework, as well as how it is implemented within a specific country of study, here in Norway.

2.4.1. Definition

Project governance schemes are meant to ensure that critical decisions are made at the proper level. Public project governance should include a chain of evaluations, assessments, and scales that provide accountability and transparency, appointed roles in the project, and simultaneously support the project managers in fulfilling the tasks within the project (Morris and Geraldi 2011). There have been various definitions in the literature for project governance (Müller, Shao et al. 2016, PMI 2017). Most relevant to this research is the definition given by Samset (2003), in which project governance is defined as the necessary measures to ensure operational success determined by efficient time and cost performance and tactical and strategic success in terms of impact on society and users. An example of a project governance framework is shown in Fig. 4 (Samset and Volden 2014, Volden 2019). It consists of:

1) Planning stage: includes the idea, concept, and pre-project development, until the formal approval and budget allocation (or so-called 'front-end' phase (Welde and Odeck 2017))

2) Construction (project management) stage: includes both detailed engineering and construction stages.

3) Operation (and maintenance) stage: occurs after completion of the project when the project is open for service. Ex-post analysis are performed at this stage, and long-term effects are recognized at this stage.

Decision points and quality assessment points are also shown, which may vary from one framework to another.

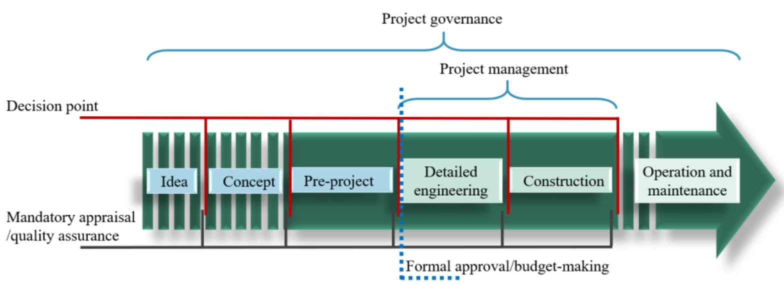


Fig. 4. An example of project governance framework (Volden 2019)

Commonly, cost overrun is calculated based on the difference between estimated costs right before the construction starts and final actual costs after the completion of the project. However, according to the literature, cost increases during the planning phase are mostly found to be considerably higher than that of the construction phase (Fig. 5) (Welde and Odeck 2017).

Particularly at the very early stages of project initiation and conception, when the uncertainty level is at its highest and the available information is very limited, cost estimations fluctuate significantly (Samset and Volden 2017). Fig. 5 highlights the importance of the planning phase in potential development of costs in a project.

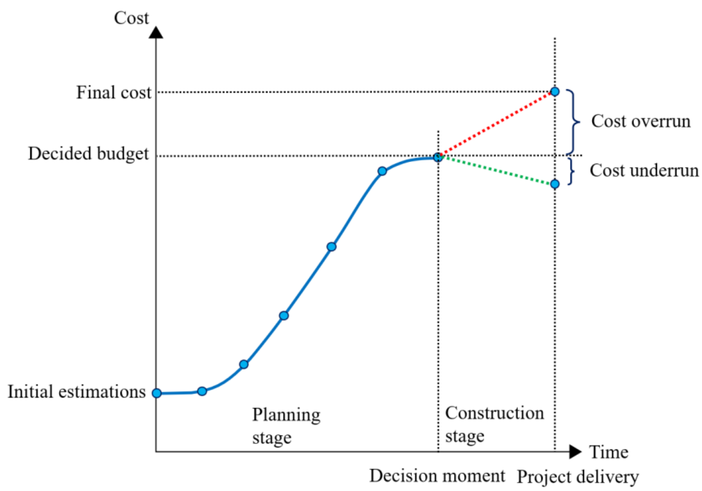


Fig. 5. Cost escalations during the planning stage (reproduced from (Samset 2003))

2.4.2. Road planning in Norway

Based on the general governance framework schemes for planning public infrastructure projects as described previously, the Norwegian framework for LSR projects is presented in Fig. 6. Key aspects of the framework include the conceptual appraisal (CA), quality assurance 1 (QA1), and quality assurance 2 (QA2).

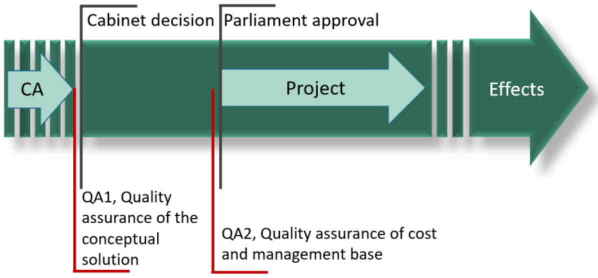


Fig. 6. Norwegian planning framework for large public projects (Samset and Volden 2014)

At the project initiation and as a basis for QA1, the responsible agency or the sectoral ministry prepares a CA report, which consists of needs analysis (the project's relevancy to the needs and priorities in society), overall strategy (project's objectives and short- and long-term effects), general requirements (e.g., functional, operational, and economic), specification of alternative solutions, alternatives analysis (a Cost-Benefit Analysis (CBA) of at least two alternatives plus zero alternative (current situation or no project)), and the rankings of the alternatives and recommendations (Volden 2019). Quality assurers check the documentation, perform a separate independent CBA, and deliver their recommendations regarding the ranking of the alternatives. The assessments and evaluations are documented in the QA1 report, which will be delivered to the sector ministry and Ministry of Finance. If the suggested investment alternative is selected, it processes to the pre-project stage, and the QA1 stage is done.

The QA2 stage begins after the Cabinet decision and before Parliament approval. The ministry or the agency provides in the QA2 report a steering document including a complete estimation of costs, as well as an assessment of at least two alternative contract strategies. Like QA1, quality assurers perform a separate evaluation of costs and give recommendations regarding the proposed budget and the proper project management strategy during QA2. QA2 provides the responsible ministry with an independent review of the cost and management base before submission to Parliament for approval and budget allocation.

'Steering frame' and *'cost frame'* are the two important parameters in the Norwegian planning governance framework that are set at the pre-project stage. The steering frame is the budget given to the responsible agency, while the cost frame is the total budget approved by Parliament. These

frames are typically set at P(50) and P(85), respectively, where P(X) is the probability of X% that the final investment cost will be at or below this level, as estimated by external quality assurers based on stochastic estimations. According to the Norwegian definition of cost overrun, if project costs exceed the cost frame (or determined P(85)), it is interpreted as cost overrun. In other words, a project can exceed the steering frame without cost overrun, (Klakegg and Volden 2016).

2.5. Artificial Intelligence in cost overrun studies

Artificial Intelligence (AI) refers to the development of intelligent machines that can perform tasks that typically require human intelligence, such as visual perception, speech recognition, decision-making, and natural language processing. AI has a wide range of applications in various industries, including healthcare, finance, entertainment, and also transportation. In transportation, AI has been used within the context of autonomous vehicles, traffic management, and predictive maintenance. With its ability to automate complex tasks and analyze vast amounts of data, AI has the potential to transform many aspects of our lives and revolutionize the way we work and interact with technology. This section briefly introduces machine learning, neural networks, and deep learning as subsets of AI (see Fig. 7) and their applications in the field of cost performance.

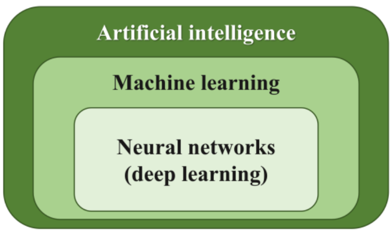


Fig. 7. Machine Learning is a subset of Artificial Intelligence and Deep Learning is a complex part of Machine Learning.

2.5.1. Machine learning

Machine learning is an application of AI and computer science that allows systems to automatically learn and improve from experience without being explicitly programmed. Machine learning focuses on using data, algorithms, and computer program development to imitate how humans learn, gradually improving its accuracy without being assisted by humans.

The learning process begins with observations (data), such as examples or instructions, in order to look for patterns and correlations in data using statistical techniques. Algorithms are trained to make classifications or predictions based on the observations provided, uncovering critical insights within projects which subsequently drive decision-making. Machine learning algorithms are commonly categorized as supervised or unsupervised (Fig. 8) (Goodfellow, Pouget-Abadie et al. 2014):

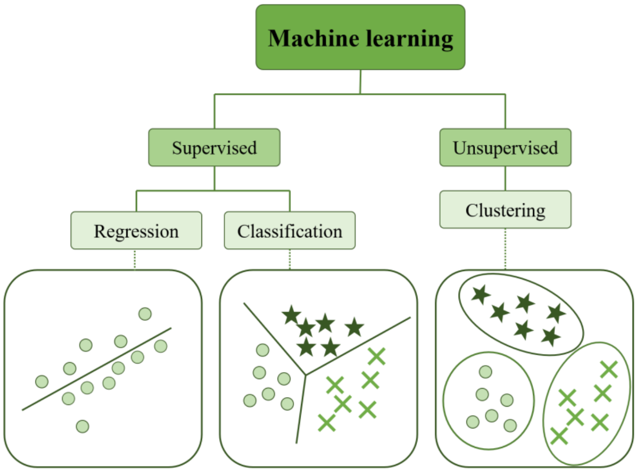


Fig. 8. Two common machine learning algorithms

i) Supervised learning: A typical machine learning problem uses a model to make a prediction (e.g., predictive modeling). A dataset with multiple samples is required to train the model, including input variables (X) and their corresponding output class labels (Y). The model is trained by input data and function to make predictions about the output values and is corrected (i.e., improved) to make outputs more similar to the expected outputs. Supervised learning aims to map inputs to outputs, given a labeled set of input-output pairs (Fig. 9. a).

ii) Unsupervised learning: Unlike supervised learning, there is no prediction, thus, no output in unsupervised learning, as the model is only given the input variables. Unsupervised algorithms are commonly used when the information used to train is neither classified nor labeled. Since the model does not predict anything, there will be no correction. The main goal of unsupervised learning is just to find interesting patterns in the data, while there is no apparent error metric to use (Fig. 9. b)

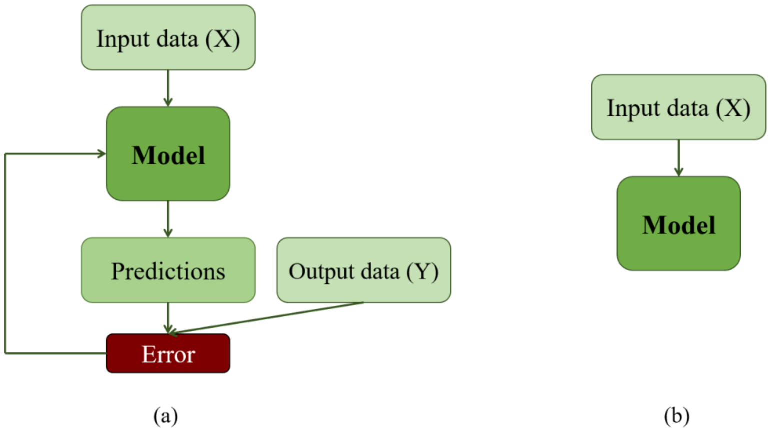


Fig. 9. a) Supervised, and b) unsupervised learning methods

Regression, classification, and clustering are known as the 'Big 3' machine learning tasks. In addition, dimensionality reduction algorithms, including feature selection and feature extraction, are also considered machine learning tasks. Regression, classification, and feature selection are used within this thesis and described below, while clustering and feature extraction are out of the scope of this study.

Regression is the task of modeling and predicting continuous, numeric variables and within ML, is a supervised learning method. It is a statistical method to model the relationship between a dependent and independent variable with one or more independent variables. In other words, regression analysis assists understanding how the value of the dependent variable changes corresponding to an independent variable. It predicts a variety of continuous/real values ranging from temperature, age, and salary to cost estimations, real-estate prices, and stock price movements.

Like regression, *classification* is a supervised learning task for modeling and predicting categorical variables. It is defined as the process of recognition, understanding, and grouping objects into predetermined categories known as 'sub-populations.' In simple words, classification is a means of 'pattern recognition.' With the assistance of preset training datasets, classification in machine learning programs use numerous algorithms to classify future datasets into relevant categories. Its algorithms utilize input training data to predict the probability that the following data will fall into one of the preset categories. Many regression algorithms have classification counterparts, and the classification algorithms are adjusted to predict a class (or class probabilities) instead of real numbers. Document classification, product categorization, and spam filtering are among the vast array of classification applications.

Feature selection is described as the process of separating the most relevant, non-redundant, and consistent features (variables or attributes) for further use in model development. Feature selection reduces the dimensionality (number of features) of the data set. The main objective of feature selection is to improve the accuracy and performance of the predictive model while reducing the computational cost of modeling (Rouhi and Nezamabadi-Pour 2020)

2.5.2. Neural networks and deep learning

Artificial neural networks (ANNs) are a type of machine learning technique that is essential to deep learning algorithms. They are inspired by the human brain and simulate the behavior of biological neurons. ANNs consist of layers of nodes, including an input layer, one or more hidden layers, and an output layer (Fig. 10). Each node has a weight and threshold. If the output of any node exceeds the threshold, that node is activated and transmits data to the next layer. ANNs improve their accuracy over time through learning from training data. Once properly trained, ANNs can be used to classify and cluster data quickly and accurately. They are primarily used for pattern recognition, classification, and optimization tasks.

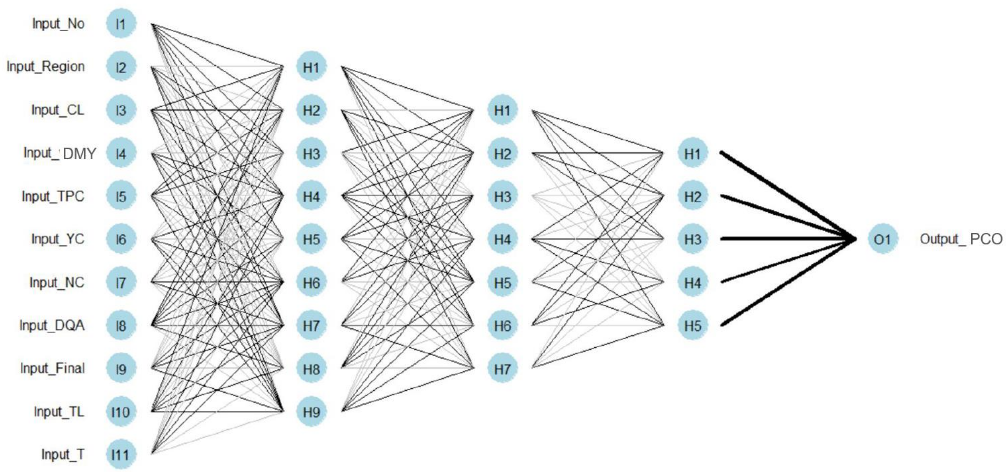


Fig. 10. The visualization of neural network with three hidden layers.

Deep learning indicates multi-layer neural networks which can learn complex patterns. They use 'hidden layers' between inputs and outputs to model intermediary representations of the data. Deep learning and neural networks are often used interchangeably, which can be confusing. It should be noted here that 'deep' in deep learning refers to the depth of layers in a neural network, meaning that a neural network with more than three layers can be considered a deep learning algorithm. Thus, a neural network with two or three layers is considered a primary neural network.

2.5.3. Data generation

Data generation is a technique used to increase the size of a dataset by generating new samples from the existing ones. There are various data generation methods, including geometric transformations, such as rotation, scaling, translation, and color transformations, and generative methods, such as Variational Autoencoders (VAEs), Auto-regressive models, Deep Belief Networks (DBNs), and Generative Adversarial Networks (GANs). Data generation can improve the performance of machine learning models by reducing overfitting and improving generalization. The choice of data generation method depends on the type of data and the specific requirements of the machine learning problem. In this study, a GAN-based data generation method has been used in order to produce synthetic data similar to real data and improve the accuracy of prediction.

GANs are methods of generative modeling based on deep learning methods. Generative modeling involves discovering and learning the regularities or patterns in input data so that the model can be used to generate new data. GANs are a way of training a generative model, in which the problem is framed as a supervised learning problem with two sub-models: generator and discriminator. The generator model is trained to generate new synthetic examples, and the discriminator model classifies the samples (Goodfellow, Pouget-Abadie et al. 2014, Chollet 2017). The generator model takes a fixed-length random vector drawn randomly from a Gaussian distribution as input and generates a sample in the domain. Then, the discriminator model, which is a standard classification model, takes an example (real or generated) and predicts a binary class label. GANs are algorithmic architectures that use two neural networks (i.e., generator and discriminator), competing against each other in order to generate new, synthetic instances of data that can pass for real data (Fig. 11) (Goodfellow, Pouget-Abadie et al. 2014).

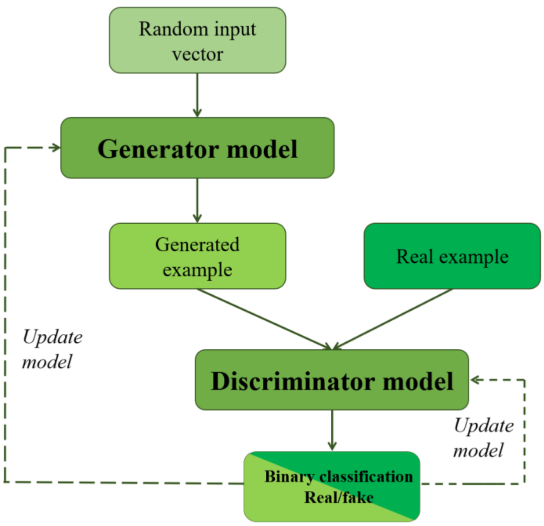


Fig. 11. Generative Adversarial Network Model Architecture

2.5.4. Application of AI within cost performance of road projects

ML as a subset of AI is relevant in cost performance studies for road projects due to the complex and uncertain nature of infrastructure projects, which leads to substantial cost inaccuracies (Afzal, Yunfei et al. 2021). Understanding the interdependency of parameters affecting the cost performance of such projects can assist in managing complexity and substantial cost under/overruns. Developing learning-based cost performance evaluation models is of growing interest.

In this regard, the application of ANNs in evaluating the cost performance of LSR projects has been gaining popularity in recent years. El-Maaty et al. (2021) attempted to find the best-fitting ANN model based on four paradigms by applying the linear regression analysis method and statistical fuzzy theory to estimate road project delay and cost overrun percentages in Egypt. They demonstrated that the linear regression-based model performs better than the statistical fuzzy-based model. Tijanic et al. (2020) utilized three different ANNs for predicting road construction costs in Croatia using data from 57 road sections. They concluded that using ANNs can be a promising approach, especially when the sample size is small.

Naik and Radhika (2015) applied ANNs (Neural Network Fitting tool (NFtool) and Neural Network/Data Manager (NNtool)) to the time and cost performance of road construction projects. They obtained an accuracy of ± 8%, which was acceptable for estimating project duration and cost. Barros, Marcy, et al. (2018) utilized ANNs to develop a model for predicting road construction costs in Brazil. Different network structures with 10, 15, and 20 neurons were trained and tested. Their study demonstrated a favorable accuracy rate of 99%. El-Kholy (2021) and Tijanić, Car-Pušić et al. (2020) applied Radial Basis Function Neural Network (RBFNN) due to its simplicity in analyzing road construction projects' cost data. Both studies concluded that this model performs as a best-fitted model where the sample size is small.

Yet, studies on the use of ANNs on the cost performance of LSR projects are scattered, and there is still a lack of systematic research on the application of ANNs in road construction management. Developing models capable of capturing and analyzing interdependencies between the parameters affecting the cost performance of LSR projects will substantially improve the accuracy of cost estimation and, as a result, better allocation of resources and be more beneficial for society. However, the applications of such models are found to be limited in the literature.

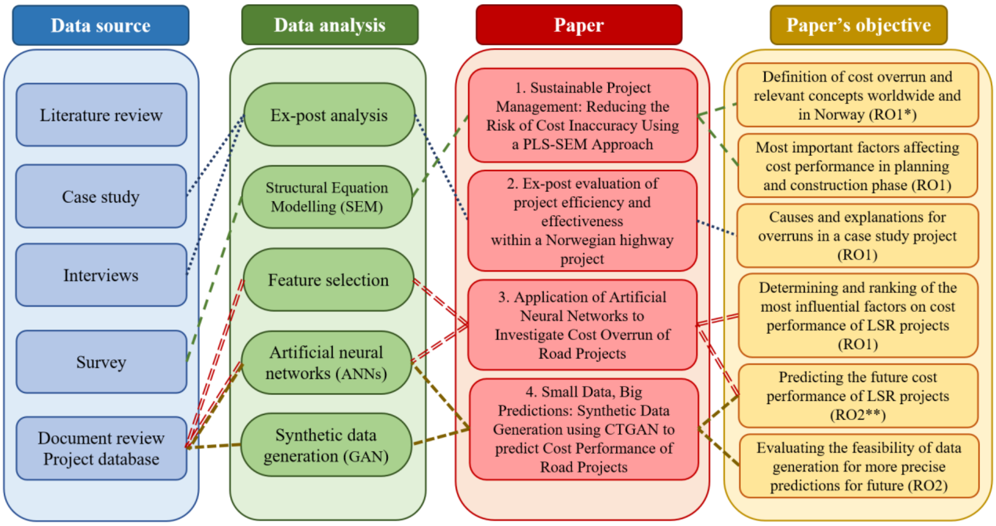
3. Methodology

This chapter presents the research design used in this study, including data sources/collection, analysis methods, and other methodological issues relevant to the scope of this thesis. Moreover, a brief discussion of the relevancy of the methods used in addressing the research objectives is also presented. A more detailed description of the methodologies used for the individual studies can be found in each paper.

3.1. Research design

Cost performance evaluation of LSR projects in Norway is a relatively new research area. The reason is that since the QA program (as described in section 1.2) was introduced in 2000 and expanded in 2005 with the introduction of QA1, the number of such projects completed under the program is limited. Planning and construction phases for such projects usually take several years. Moreover, at least two to three years is commonly needed after the project's completion for the project's cost data to be finalized, and a cost performance evaluation to be feasible. This means that data available for analysis is limited. Therefore, in situations with a lack of sufficient quantitative data or well-established theories, qualitative and inductive approaches could be utilized as assistive methods for data collection and further analysis (Samset 2003, Volden 2019). Thus, a combined quantitative/qualitative approach (i.e., survey, in-depth interviews, and project documentation) was used for data collection in addressing RO1. However, a complete quantitative analysis method was utilized to address RO2 in this study.

Fig. 12 illustrates the research design, including the data collection sources used and the different methods applied for each paper. Additionally, each paper is linked to its main objectives in order to give a better insight into the relevance of each paper's objective(s) to the main objectives of the thesis.



RO1: To further understand the concept of cost overrun and the influential parameters affecting cost inaccuracies in large-scale road projects in Norway.
****RO2: To predict the cost performance of large-scale road projects using past project data.***

Fig. 12. Research design: data sources, methodologies, and objectives

All the included studies, except Paper 1, were carried out in collaboration with at least one additional researcher(s). Research design, case study choice, survey questions guide, checklists for document review, interview guide and sampling, as well as analysis methods, interpretation, and discussion of the findings, were all done with feedback from relevant experts/researchers. These collaborations were beneficial, and their invaluable input notably improved the validity and reliability of the research. All the steps in the research process were developed by the author's assumptions and experiences.

This chapter provides an overview of the research design used in each paper, followed by a more thorough discussions of the data collections and methodologies. Even further explanation of the method can be found within each paper.

3.1.1. Paper 1

The first step to starting a research project is to conduct a literature review. Since the research area was open and broad, the starting point of this thesis was to conduct a thorough review of the literature on cost overrun. The literature review provided an overall perspective on the concept of cost overrun, methods of calculation, causes of cost overrun, explanations, relevant supporting theories, project governance frameworks, planning and construction phases, ex-post analysis, etc. From the review, it was understood that while the impact of the planning phase in the cost overrun estimation is high, it is often ignored in the literature. Within Paper 1, the knowledge gained from the literature review was used to develop a survey sent to experts with experience and involvement in LSR projects.

Additionally, several interviews were held as supplementary input to the survey development. The survey aimed to determine the most relevant factors affecting LSR projects' cost performance in the planning and construction/implementation phase within Norway in order to address RO1. The Relative Importance Index (RII) was used to rank the causes of cost overrun in both phases according to the survey results. Further, the parameters specific to the construction phase were categorized into four distinct constructs, and Partial Least Squares Structural Equation Modeling (PLS-SEM) was used to assess the importance of these constructs on the projects' cost performance. Categorizing the causes into four distinct constructs was assumed to provide a clearer insight into the types of causes affecting cost overruns in the construction phase, but it also provided indirect insights regarding the impact of the planning phase, as the planning phase was one of the constructs used in the analysis.

3.1.2. Paper 2

In conjunction with RO1, several meetings were held with NPRA where several potential projects with a considerable cost increase in the construction phase were discussed for further investigation within a case study. Project E6: Frya-Sjoa was chosen as the case study project as it was a project with significant cost increases (hence negative media attention). The objective of the case study was to assess the magnitude and the causes of cost overrun. To do so, several in-depth group and individual interviews were held, and project documentation was reviewed. As the research progressed, it became evident that with the project being completed and operational for over five years, there was an opportunity to assess the tactical success of the project. This was done using project documentation and simple analyses utilizing data from NPRA databases. Therefore, Paper 2 focuses on not only assessing cost performance as one criterion of operational success but also includes an ex-post evaluation of the tactical performance of the project.

3.1.3. Paper 3

As the research progressed, a new aspect of the knowledge gap became apparent: the literature's reliance on simple traditional analysis methods. A more profound perception of the cost performance of LSR projects requires advanced, updated analysis methods. Therefore, Paper 3 embarked on an exploration of the application of feature selection methods (ML tasks) for determining influential parameters causing inaccuracies in cost estimations. Given the fact that simple regression models (which the current literature is primarily based on) perform weakly when there are non-linear relationships and/or there is a desire to capture more complex patterns/dimensions, Paper 3 focuses on evaluating the feasibility of applying recently developed ANNs to i) predict the cost performance of future LSR projects, and ii) compare their performance with traditional regression models. This addresses RO2. Paper 3 considers two ANNs, which are able to utilize a large number of parameters as inputs and predicts the target parameter (here, PCO) based on the patterns found in the available data. To support the argument that using ANNs has clear advantages over the traditional models, two regression models (i.e., simple linear and fuzzy) were selected as competitive models to be evaluated. Standard evaluation criteria are used to compare the performance of the ANNs with the traditional models. Data used in Paper 3 was cost data of 52 LSR projects in Norway, in which, for each project, there are several documented independent explanatory variables as well as PCO as the dependent variable.

3.1.4. Paper 4

Continuing with a focus of using ML to further understand the cost performance of LSR projects, Paper 4 addresses a challenge seen within both the literature review and Paper 3, that of small sample size when considering country-specific analyses. Thus, Paper 4 applies generative modeling (Generative Adversarial Networks (GANs)) to generate synthetic data similar to the real (original) data to increase the size of the dataset used within cost performance analyses. With a larger dataset, it is possible to improve methodologies to predict future cost performance of LSR projects which can be used to further understand the causes of cost innaccuracy. Three ML classifiers (SVM, MLP, and XGBoost) are utilized within the study for prediction and model evaluation. The initial dataset used in Paper 4 is the same dataset used in Paper 3, which includes 52 LSR projects in Norway The dataset is then expanded to a total of 225 samples when 173 synthetic samples from the generative modelling are included.

3.2. Data Collection and Sources

As stated earlier, this thesis encompasses both qualitative and quantitative research designs, incorporating survey research, case study research, and the utilization of ML-based methods for quantitative data analysis. Consequently, multiple methods of data collection from various sources have been employed. This section provides a detailed explanation of the data collection sources utilized.

3.2.1. Literature review

As the first step for studying a new topic, one needs to conduct a literature review to understand the state-of-art, past research, and current challenges and problems. To this aim, great care should be taken to find all relevant studies within published and unpublished (gray) literature. Moreover, the relevance and methodology of the selected studies should be examined precisely before including them in the analysis. The reason for including unpublished studies is to avoid 'publication bias,' as Odeck (2019) believes some completed studies have not been published despite having well-accepted methodology and sound data, only because their results were not acceptable according to the reviewers' opinion. Guidelines provided by Cooper, Schindler et al. (2006), describe the literature search and review process as follows:

1. Building an information pool
2. Applying filters to reduce the pool size
3. A rough assessment of sources to a further reduction in the pool size

4. Analyzing the literature in the pool
5. Refining filters / stopping the search.

The literature search for this thesis was mainly electronic, and the terms cost overrun, cost escalations, cost overrun explanations, ex-post evaluation, Norwegian road planning, project management, quality assurance, as well as infrastructure, roads, and highways were the search terms in the initial stages of this study. Google Scholar and Google Scholar Advanced Search were the primary search engines, and other search engines, such as Yahoo, were used as complementary/verification. Moreover, a complementary search was conducted in the Concept research program archive, Norwegian libraries search engine (ORIA), Transportation Research Part A: Policy and Practice, Transportation Policy, Transportation, the Journal of Transportation Economics and Policy, The International Journal of Management Science, Transport Reviews, and several other journals that were considered to be particularly relevant.

The selection criteria for the collected studies to be included in the analysis were as follows: 1) they should address the issue of cost overrun by reporting either the magnitude, percentage, or other means of representing the values of cost overrun; 2) the main scope of the projects evaluated in the studies should be transport infrastructure projects, 3) sample size, project type, the region in which the projects are located in, and other individual parameters of the studied projects in the study should be indicated. Additionally, studies with a focus on the planning phase of the projects were of interest, as well as studies specific to the issue of cost overrun in large-scale infrastructure projects in Norway.

A review of the literature was continuously performed and expanded during the whole study period. At the later stages of the study, several additional keywords related to the methodologies were also added to the literature review. This included Structural Equation Modelling (SEM), Artificial Intelligence, Regression, Feature Selection, Classification, Neural Networks, Machine Learning, Data Generation, and Deep Learning.

The literature review provided a thorough introduction to the field and an identification of different researchers with specific experience and expertise, the methodologies they have used, and the current gaps in the literature.

3.2.2. Survey research

Surveys through questionnaires are among the best means of obtaining information from individuals about themselves or something they belong to or are involved in (Rossi, Wright et al. 1983). Three features characterize surveys:

1. The main objective is to describe the studied population quantitatively
2. Obtained and analyzed data are based on the responses to predetermined questions
3. Respondents are representatives of the studied population (Pinsonneault and Kraemer 1993)

The use of a questionnaire depends on several parameters, such as the purpose of the study, the type of data required, or the desired population to be studied. A structured questionnaire was utilized as an assistive approach for data collection and analysis in order to define the importance of factors affecting the cost increase in 1) the planning phase (planning factors: PF) and 2) the construction phase (construction factors: CF) (Paper 2). The planning phase involves problem determination, recognition of the concept, rough cost estimations, and initial planning until the moment of formal decision-making refers to the planning phase. Whereas the construction phase begins at the moment of decision-making and budget allocation and continues until the project is finished and is opened for service. Additionally, there were questions in the questionnaire to address demographics related to professional experience. The survey was distributed among owners, contractors, consultants, researchers, and project economists working within transport infrastructure throughout Norway. Respondents were asked to answer the survey only if they were involved in at least one LSR project in their career and could consider project-specific factors.

The survey also had an additional part in which the efficacy of the QA program was investigated. Since it was not within the framework of the thesis, the results are not presented in the main body of the thesis.

3.2.3. Interviews

One of the main benefits of using interviews within research is gaining a deeper understanding and broader insight from personal interaction. If open-ended questions are used, the opportunity for the respondents to share their ideas increases. This also allows the interviewer to probe further if a more detailed answer is desired (Qu and Dumay 2011). To compare to the previously described method, interviews collect qualitative data (some may include close-ended questions), while questionnaires gather quantitative data (some may consist of open-ended questions). Interviews were held at two different stages of this study, as described below.

- ✓ Preparation of the questionnaire

Several interviews were held with professors at the Department of Civil and Environmental Engineering at NTNU as well as experts at NPRA regarding the preparation of the previously described questionnaire. The interviews supplemented the literature review, and factors affecting cost overrun during the planning and construction phases were discussed, modified, and improved as a result of the interviews. Moreover, factors: *'different degrees of maturity before QA1'*, *'cost increases from QA1 to QA2 have no consequences'*, and '*value for money is of little importance'* were added to the list of influential factors in the planning phase.

- ✓ Case study research

In-depth interviews were also conducted to investigate the causes and explanations for the cost increase in the case study research. Interviewees were chosen among the key persons involved in the project, including project owners, managers, and economists. They were identified and appointed using NPRA public databases and the assistance of the author's contact person in NPRA/co-supervisor. Interviews were held after document reviews, which allowed discussion of critical points identified in the project documentation with the interviewees.

A two-hour group interview was held in a semi-formal environment and focused on reasons for cost increases during the construction phase that corresponded to the official project documentation (Fig. 13). After the group interview, five individual interviews were held to further supplement the understanding of the reasons for cost increases. This setting helped the respondents talk more informally about their ideas and opinions concerning cost increase and their possible causes. Another advantage of this interview format is that it allows the interviewer to learn about the terms, expressions, and even issues brought up by the respondents. These interviews resulted in the interviewer's ability to extract critical values from the project documentation regarding costs incurred during construction phases and identify the leading causes of cost under/overruns. It should be noted that only including interviewees from the NPRA (the project owner) may have a risk of bias, and it would be beneficial to have contractors involved in discussions as well. However, in the case study research (Paper 1), the interviews largely focused on the specific items of cost increase in the documentation on cost increases delivered to the Parliament for budget increase requests. Therefore, the bias is assumed to be low since the project owner (NPRA) and the contractors agreed with this documentation.

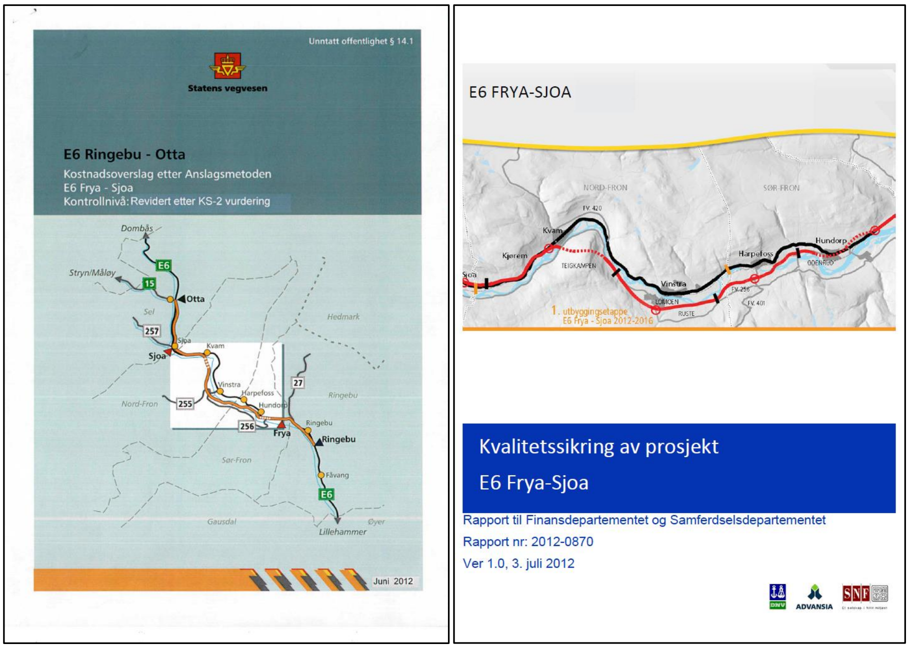
Fig. 13. Individual and group interviews with projects relevant people at NPRA, Lillehammer, Norway

3.2.4. Document reviews

Document review included collecting, analyzing, and interpreting data, and within this research is split into two different stages, as described below.

✓ *Case study documents*

A wide range of structured data of costs, expenses, contracts, deliveries, etc., of the case study was retrieved from NPRA databases, meetings, and with the assistance of contact persons at NPRA. This study used two main documents for deriving project cost data and estimations (Fig. 14). Fig. 14.a presents the official project document sent to the Parliament for budget allocation, including all the cost estimations for the project (Vegvesen 2012). This document was used as the basis for estimated costs for further comparisons in this study. The project's quality assurance (QA2) report (Fig. 14.b) was also used as a supplementary source. It consists of additional documentation, including the assurer's cost estimations and evaluation (e.g., cost-benefit analysis) of the project (Samferdselsdepartementet 2012). Moreover, project documentation includes a report sent to the Parliament explaining the magnitude and reasons leading to the cost increase (as part of the budget reallocation process) (Prosjektavdelingen 2013). The magnitudes of cost increase in this report were used in the analysis of cost overrun, and the in-depth interviews examined the underlying reasons for these increases, as discussed in the report.



(a) (b)

Fig. 14. Project documents: (a) official project document sent to Parliament for budget allocation (Vegvesen 2012), and (b) quality assurance (QA2) report made by external evaluators (Samferdselsdepartementet 2012)

✓ *Data on LSR projects in Norway*

An initial data set of 86 large-scale infrastructure projects, including 60 LSR projects, was provided through the Concept research program (funded by the Norwegian Ministry of Finance, which monitors and analyses data from projects under the quality assurance (QA) scheme). Because of data invalidity or insufficient information, 8 LSR projects were excluded from the dataset, leaving a sample size of 52 LSR projects containing reliable and valid data (presented in Papers 3 and 4). In addition to being an LSR project, at least three years must have passed since the project was completed, and the project should be in operation in order to be considered in the analysis.

The data was treated and supplemented later for further analysis corresponding to the objectives of Papers 3 and 4. In the analyzed dataset in Papers 3 and 4, each project has eleven specific independent explanatory parameters (features) as well as Percentage Cost Overrun (%PCO). The independent features are shown in Table 4.

Table 4. Description of the explanatory variables (features)

Feature	Description	Type
R	Region of construction	dummy
TL	Total road length in meters	continuous
CT	Construction time in year	continuous
year	Decision-making year	dummy
DQA2	The cost deviation percentage from the QA2 report	continuous
%T	Percentage of tunnel length to the total road length	continuous
%B	Percentage of bridge length to the total road length	continuous
NC	Number of contractors	discrete
YC	Year construction completed	dummy
TPC	Time lapse between the parliamentary decision and construction start	continuous
Final	Final cost	continuous

3.2.5. Case study research

As previously mentioned, interviews and document reviews were used within the context of a case study. Case study research design is widely accepted for addressing descriptive or explanatory research questions (Towne and Shavelson 2002). It can be described as an in-depth analysis of an individual, group, community, or other units to generalize about a larger sample (Gustafsson 2017). Case study research helps a better in-depth understanding of a real-life phenomenon within its context. Since it might be complicated to differentiate the phenomenon and the context, a case study investigates the potential minor data points by combining multiple sources of evidence (Yin and Davis 2007). These data sources might be qualitative, quantitative, or a combination of both, which can eventually provide a thorough understanding of the research question. Case study research is commonly used in research within cost overrun. Flyvbjerg (2006) believes that with a strategic choice of cases (e.g., maximum variation cases, paradigmatic cases, or critical cases), it is feasible to generalize conclusions from very few cases or a single case.

A single case study of an LSR project (E6: Frya-Sjoa) in Norway (Fig. 15) was selected to investigate the most important parameters affecting cost overruns in Norway (RO1). The use of this method is justified in several ways. First, by working within a Norway-specific context, the case study addresses the previously mentioned gap in existing literature where studying cost overrun within the context of a specific country will give a better understanding of the issue of cost overrun particular to that country. Such research can provide a proper insight into the problem of cost overrun by answering the questions 'how' and 'why' of the causes of cost overrun happening in the project. Additionally, the selected case study is one of a limited number of projects which went through QA2. Thus, many associated reports, official documents, and data that can be used within the study of this project are available. This allows for further research, which can give a better understanding of the QA program and planning process in the road planning system in Norway. Finally, the author's initial knowledge of the topic within the context of Norway was limited; the case study provided an opportunity to expand personal knowledge and develop insights into the problem of cost overrun in LSR projects in Norway and in general.

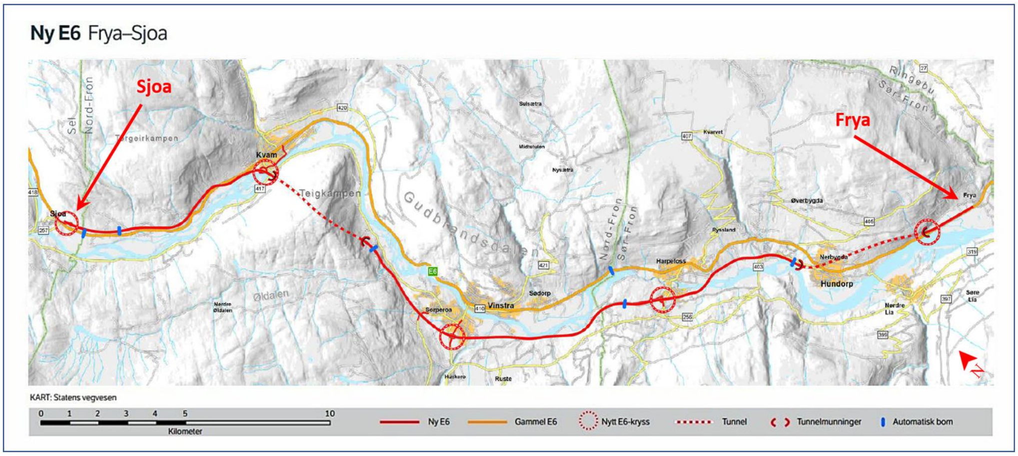


Fig. 15. Selected project for single case study research (E6: Frya-Sjoa)

3.3. Methods used: data analysis

Data analysis is an essential step in each study after data collection. For quantitative data (which this thesis largely utilizes), the data analysis process varies depending on several parameters, including data type and the type of analysis required. Generally, data management is the first step for data analysis. This step, also known as 'cleaning data,' involves choosing appropriate software, screening data, entering data into the program, and then eventually cleaning data. It is necessary to distinguish variables by cause and effect (e.g., dependent or independent) and their measurement classes (e.g., nominal, ordinal, interval, and ratio). Descriptive analysis, such as measures of central tendency (i.e., mean, mode, and median), dispersion (i.e., range quartile, variance, and standard deviation), and distribution (skewness and kurtosis), is a common primary step in analyzing quantitative data. Inferential analysis to draw initial conclusions based on the primary measures or predictive analysis to analyze current and historical data to make predictions can be the next steps in data analysis. Finally, statistical analysis can be used to ensure the findings are significant (not a coincidence). In each study/paper, the data analysis was performed separately following the corresponding objective of the paper. A brief description of the data analysis methods used in this research is presented below.

3.3.1. Ex-post evaluation

Ex-post evaluations are assessments conducted to determine whether a specific intervention has met or achieved its predetermined objectives (ex-ante) as expected or not (Fig. 16). In addition to presenting the performance of a project (to the public and policymakers) after completion, ex-post evaluations can also improve the accuracy of cost estimations over time (Odeck and Kjerkreit 2019). Depending on at which stage of the project's lifetime the evaluation is carried out, different approaches are used, and as a result, additional questions may be raised.

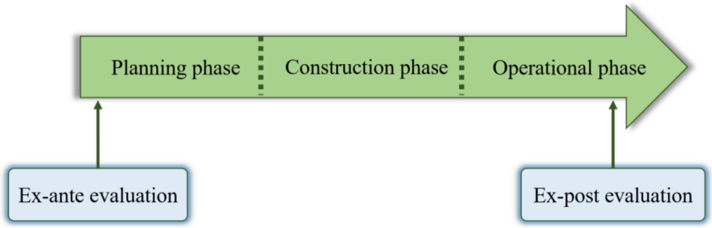


Fig. 16. Phases in project governance at which ex-ante and ex-post are performed

In the case study within this research (Paper 2), the project's cost performance was determined by investigating the accuracy of ex-ante analysis, or in simple terms, the difference between the final actual costs of the project and the estimated costs. It is a relatively simple calculation in which costs are all converted to NPV and compared. Cost overrun can be expressed in several ways, including Percentage Cost Overrun (PCO), or magnitude of cost overrun, described in the included study.

In addition to cost performance evaluation, the tactical success of the case study project was measured by quantitatively assessing to what extent the project has reached its technical objectives, which was designed and implemented for (within the case study: the reduction of fatal and severe injury accidents, and a reduction of travel time and traffic congestion). A before-after study using traffic accident and traffic volume data was used to carry out the ex-post analysis of tactical success for the case study project.

3.3.2. Partial Least Square – Structural Equation Modelling (PLS-SEM)

SEM has been found as a suitable method to analyze and interpret the raw data of surveys. The Partial Least Squares-based (PLS-SEM) method is a simplified version of SEMs that can be used to examine the relation (effect) of each construct (several variables which are grouped in distinct scopes) to the target variable (cost overrun in this thesis). PLS-SEM is a regression-based modeling approach using a component-based (similar to principal components factor analysis) technique in path models (Vinzi, Trinchera et al. 2010). One of the main advantages of PLS-SEM is its ability to handle complex models with a relatively small sample size. PLS path models comprise two sets of linear equations: the outer model, also called the measurement model, and the inner model, also called the structural model. The inner model specifies the relationships between unobserved or latent variables. Latent variables in (PLS-SEM) refer to underlying constructs that cannot be directly observed but are inferred from observed variables. In contrast, the outer model specifies the relationships between a latent variable and its observed variables (indicators or influential parameters) (Ringle, Sarstedt et al. 2010).

In this thesis, to evaluate the results obtained from the survey, Relative Importance Index (RII) was first calculated to rank the importance of the parameters stated in the survey on cost increase in both the planning and construction phases. In addition, the parameters affecting cost overrun in the construction phase were categorized into four different constructs (groups), including Contractor's Site Management (SM), Pre-construction phase (PC), External (EX), Project Management and Contractual Relationship (PM), in which each construct represent a group of relatively close parameters. Hence, the influence of each construct on cost overrun could be measured PLS-SEM analysis. The theoretical model used in this thesis is presented in Fig. 17. Indicators (each parameter affecting cost overrun) are shown in lime color and coded according to the abbreviation of their corresponding latent variable (construct) in dark green. More details can be found in the included study (Paper 2).

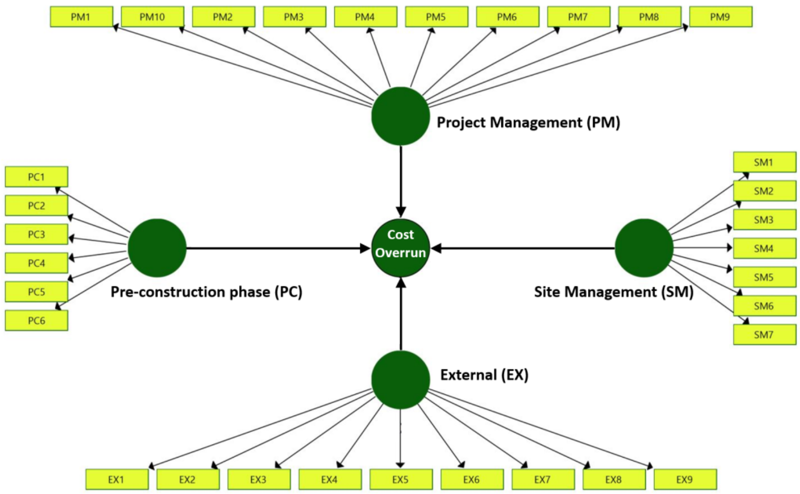


Fig. 17. Theoretical model for determining factors affecting cost overrun

3.3.3. Machine learning: Feature Selection

As described in Chapter 2, feature selection is a process of identifying a subset of relevant features or variables from a larger set of available features in a dataset. Feature selection methods aim to improve the performance of machine learning algorithms by reducing the dimensionality of the data and removing irrelevant or redundant features (Fig. 18). Within the context of this study, the features in the data set are the project-specific explanatory variables such as region, year completed, final cost, etc.

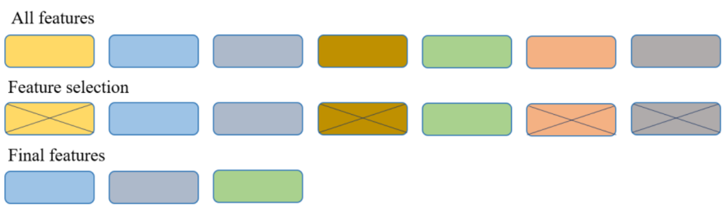


Fig. 18. Feature selection process

Correlation-based Feature Selection (CFS), which is a supervised feature selection method, was used in this research. As mentioned before, supervised feature selection methods use the information provided by the target variable (i.e., the class label or regression target) to evaluate the relevance of each feature. They aim to select a subset of most relevant features for predicting the target variable while discarding irrelevant or redundant features.

Within the scope of this study, CFS considers the correlation of each feature with the target variable (i.e., PCO), as well as the inter-correlation between features (see Paper 3). By doing so, it tries to select a subset of features that are highly correlated with the target variable but uncorrelated with each other. The outcome of CFS is a score given to each feature based on its importance on PCO.

3.3.4. Machine learning: Classification

As mentioned in Chapter 2, classification is the process of predicting the class of given data points or categorizing a given set of data into classes. Classification in ML and statistics is a supervised learning approach in which the computer program learns from the given data and makes new observations or classifications (Goodfellow, Pouget-Abadie et al. 2014, Rouhi and Nezamabadi-Pour 2020).

Classification predictive modeling has been used in Paper 4 when predicting the cost performance of future LSR projects. The developed model predicts the class of cost overrun (range of PCO) based on the real and synthetic (fake) data. The accuracy of the classifications is measured to ensure an acceptable prediction ability of the model.

3.3.5. Neural networks

As explained in Chapter 2, ANNs are tools that can analyze cause-effect relationships within a data framework. Within the context of this research, they can assist in exploring and recognizing the interdependence of the factors contributing to the cost inaccuracy in the existing project data of LSR projects. Moreover, the predictive performance of ANNs allows for the prediction of PCO for future projects given a set of project features. Paper 3 utilizes two ANN models, Multi-Layer

Perceptron (MLP) and Radial Basis Function Neural Networks with Gaussian Process (RBFNN-GP), as further described within the paper itself. The importance of a model with high generalization performance is that it can make accurate predictions on new, real-world data that it has not been trained on.

3.3.6. Data generation: Generative Adversarial Networks

As already stated in Chapter 2, GANs are a powerful class of machine learning models that can learn to generate new data samples that are similar to a given dataset. GAN-based data generation methods can be particularly useful for tabular datasets, as they can help to increase the size and diversity of the dataset, which can improve the performance of machine learning models trained on that data.

Among the various GAN-based data generation methods, CTGAN (Conditional Tabular GAN) is a popular choice because it is specifically designed to generate synthetic tabular data that preserves the statistical properties and dependencies of the real data. CTGAN method was utilized to generate synthetic data in Paper 4, and it is further elaborated within the paper itself.

3.4. Summary of the methodology

As discussed within this chapter, the methods for data collection and data analysis used in all four papers are briefly summarized in Table 5.

Table 5. An overview of the used methods for data collection and analysis

Paper	Data collection				
	Literature review	Case study	Interviews	Surveys	Document review
1. Sustainable Project Management: Reducing the Risk of Cost Inaccuracy Using a PLS-SEM Approach	X		X	X	
2. Explaining cost overrun in transportation projects: The case of a Norwegian highway	X	X	X		X
3. Application of Artificial Neural Networks to Investigate Cost Overrun of Road Projects	X				X
4. Small Data, Big Predictions: Synthetic Data Generation using CTGAN to predict Cost Performance of Road Projects	X				X

Paper	Data analysis					
	Ex-post	PLS-SEM	Feature selection	Neural networks	Classification	Data generation
1. Sustainable Project Management: Reducing the Risk of Cost Inaccuracy Using a PLS-SEM Approach		X				
2. Explaining cost overrun in transportation projects: The case of a Norwegian highway	X					
3. Application of Artificial Neural Networks to Investigate Cost Overrun of Road Projects			X	X		
4. Small Data, Big Predictions: Synthetic Data Generation using CTGAN to predict Cost Performance of Road Projects					X	X

4. Results and discussion: Understand the concept of cost overrun and the influential parameters affecting cost inaccuracies in Norway (RO1)

This chapter examines the first research objective by presenting the results from Papers 1 and 2 and a part of Paper 3. Then, the results are discussed, highlighting each study's most important results, and putting them into the context of the first research objective.

As explained in Chapter 3, several approaches were used to address RO1. The starting point of this study was to carry out a thorough literature review on the topic of cost overrun. It gave a broad perspective on cost overrun, what can cause overrun, its explanations, and the theories supporting each explanation, and was used within the subsequent study approaches. Paper 1 aims to understand experts' opinions regarding the most important influential parameters affecting cost overrun in planning and construction phases in Norway through a survey. Paper 2 evaluates the cost performance of a newly built roadway in Norway through a case study by focusing on the magnitude of cost overrun and relevant causes and explanations for the specific project using project documentation and interviews. The results of Papers 1 and 2 are presented in Sections 4.1. and 4.2., respectively. The results of the feature selection analysis (as a part of Paper 3) are presented in section 4.3., in which the most important individual project-specific parameters influencing PCO are determined using feature selection algorithms. The discussion of the results in light of RO1 is presented in section 4.4.

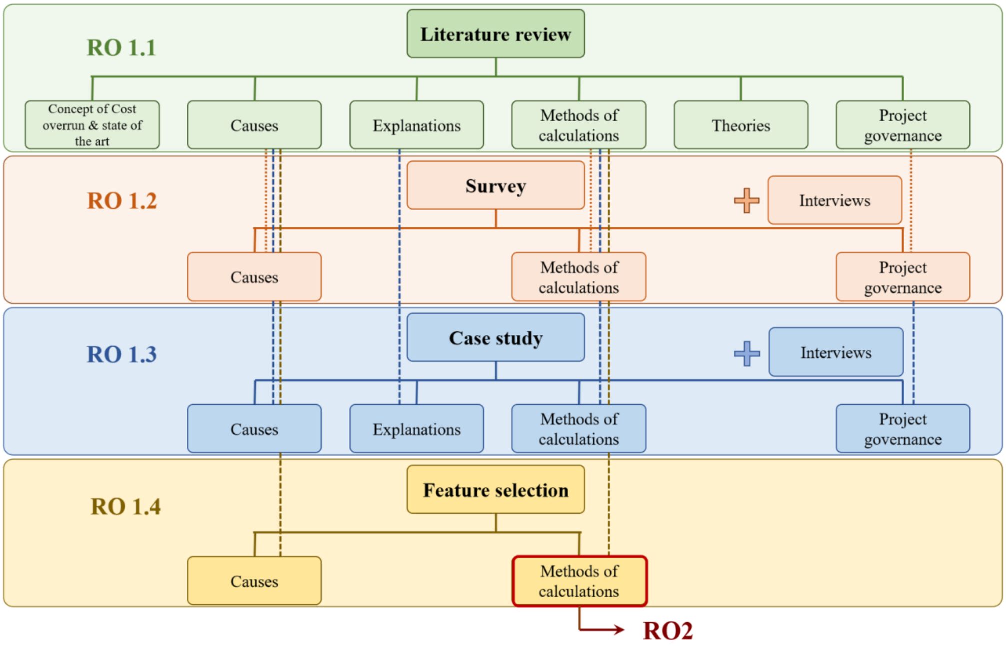


Fig. 19. Diagram of approaches addressing RO1

4.1. Determining the most important factors affecting cost overrun using a PLS-SEM Approach (Paper 1)

After performing a comprehensive review of the literature on cost overrun, the scope of this paper was formed based on the need to acquire a deeper understanding of the current challenges and causes of cost overrun in LSR projects in the context of Norway, not only in the construction phase (whereas existing literature primarily focuses on the construction phase) but also in the planning phase. The main objectives of this paper were as follows:

1. Determine the most important factors impacting cost overrun during the planning and construction phases.
2. Categorize the causes of cost overrun into four distinct constructs and evaluate their aggregated importance on project cost performance during the construction phase.

A survey of those involved in LSR projects was used to gather data on perceived factors (causes) affecting cost performance in both the planning and the construction phase. For each phase, the factors were ranked according to their Relative Importance Index (RII) value. The results for the planning phase are seen in Table 6.

Table 6. Ranking of factors affecting cost inaccuracy in the planning phase

Rank	Factor	RII	Mean	Std. Deviation
1	Local wishes without cost responsibility	0.818	4.0606	0.7044
2	Defective estimation	0.794	3.9697	1.1035
3	Long processing time	0.727	3.5455	1.1481
4	Those who get the benefit are not the ones who pay	0.709	3.5455	1.0335
4	Changes in rules and regulations	0.709	3.4545	1.0335
5	Project optimism	0.697	3.4242	0.9364
5	Poor project management	0.697	3.4242	1.1734
5	Lack of follow-up	0.697	3.3939	1.1163
6	Changes in society's expectations	0.661	3.2121	1.0828
7	City projects are detailed and costly to estimate	0.655	3.1818	1.2613
8	Different degrees of maturity before projects become the subject of QA1	0.642	3.1515	0.8704
9	Cost increases from QA1 to QA2 have no consequences	0.588	2.9091	0.9139
9	Technological development	0.588	2.8485	1.0642
10	Weak incentives to reduce planning time	0.576	2.8485	0.7124
11	Little transparency	0.558	2.7879	0.8572
12	Socio-economic profitability is of little importance	0.552	2.7576	0.8671
12	Increased funding hides cost growth	0.552	2.6970	0.9838
13	Changed/different staffing	0.473	2.3333	0.8165

For the planning phase, '*local wishes without cost responsibility'* was determined to be the most influential cause of cost overrun. This parameter was also mentioned as a recurring challenge in the Norwegian road planning system in the interviews before the survey and is related to the fourth-ranked cause, *'those who get the benefit are not the ones who pay.'* Both originate from a lack of cost accountability and responsibility within the project and are also often connected to the second-ranked cause, *'defective estimation,'* where local authorities sometimes intervene in planning to increase the chance of their desired project through low (i.e., inaccurate/defective) cost estimations. When the wrong project is chosen, the chance of scope change and higher cost escalations during the planning and construction phases is even higher (Welde and Odeck 2017). Introducing liabilities and incentives for cost control at early planning stages to avoid cost increases may be a practical solution to minimize the impact of this cause.

'Long processing time' was also ranked highly as an important cause of cost overrun in the planning phase. Project planning in Norway is a communicative process that requires all stakeholders to be consulted. Given that local authorities must grant planning permission before

the government can approve a final budget, there is a risk of misalignment of incentives, and the process may take longer than planned. Additionally, as the process prolongs, the expectations of society increase and acceptance of adverse environmental and social effects decreases. As a result, the risk of unwanted cost growth increases as the planning phase stretches out.

The importance of each parameter affecting cost performance in the construction phase was also evaluated and is shown in Table 7.

Table 7. Ranking of factors affecting cost inaccuracy in the construction phase

Rank	Factor	Description	RII	Mean	Std. Deviation
1	PM2	Scope changes	0.842	4.212	0.820
2	EX4	Market conditions	0.818	4.091	1.011
3	EX3	Unforeseen ground conditions	0.806	4.030	0.847
4	PM10	Conflicts between the contractor and the owner	0.752	3.758	0.751
5	PC1	Forecasting errors (e.g., increasing prices)	0.739	3.697	0.810
6	PM9	Contractual claims (cost or time extension)	0.697	3.485	0.939
7	PC2	Delays in decision-making	0.691	3.455	0.938
7	PC5	Inadequate planning process	0.691	3.455	0.971
8	SM1	Insufficient site management and inspection	0.648	3.242	0.969
8	EX9	Project size	0.648	3.242	1.032
9	PM3	Improper scheduling	0.636	3.182	0.882
10	PM6	Poor project management	0.624	2.758	0.663
10	PM8	Lack of/slow communication between parties	0.624	3.121	0.960
10	EX7	Terrain condition	0.624	3.121	0.960
11	SM2	Lack of experience (in handling such projects)	0.600	3.000	0.559
12	EX8	Length of the road	0.588	2.939	1.171
13	SM7	Lack of incentives	0.582	2.909	0.843
13	PC6	Land and property acquisition challenges	0.582	2.909	0.980
14	SM5	Inefficient organizational structure	0.570	2.848	0.870
15	SM6	Rework due to poor material quality	0.558	2.788	0.992
16	PM1	Poor project design	0.552	2.758	0.663
16	PM5	Changes in materials types and specifications	0.552	2.758	1.119
17	EX2	Effect of bad weather (climate)	0.527	2.636	1.113
18	EX1	Labor unavailability or lack of skilled labor	0.521	2.606	0.704
19	SM3	Poor on-site financial control	0.515	2.576	0.936
19	EX5	Lack of resources	0.515	2.576	1.062
20	SM5	Inefficient use of resources	0.503	2.515	0.870
21	PC3	Strategic behavior (deliberate behavior)	0.497	2.485	1.004
22	SM4	Low labor productivity	0.485	2.424	1.062
23	EX6	Monopolization of special equipment	0.455	2.273	1.008
24	PC4	Deliberate underestimation of costs	0.442	2.212	1.193
25	PM4	Delay in progress payment by the owner	0.412	2.061	0.827

The first three most important parameters, '*scope change*', *'market conditions'*, and '*unforeseen ground conditions',* are well in line with the literature. Notably, *'conflicts between the contractor and the owner'* was ranked fourth. Norway is a country with egalitarian and independent working culture, giving people freedom and flexibility in the areas of their responsibility. However, according to a recent study by Sabri, Lædre et al. (2019), conflicts and disputes in the construction industry in Norway have been increasing in recent years, which may explain the prominence of this parameter in the ranking.

The parameters of *project size* and *length of the road* ranked eighth and twelfth, thus a mid-range level of influence. The results of the past studies in the literature are not conclusive regarding the project size (which is often directly related to road length), and the responses within this survey are also varied between respondents. Using simple linear regression, Welde (2017) considered the impact of project size on cost overrun for about 78 LSR projects in Norway, yet did not find any clear correlation. Thus, when evaluating a data set of projects with several projects' individual characteristics (features), more advanced analysis methods would provide a better insight into correlations and interdependence of the features and the target factor (here: cost overrun). One of the main ideas taken forward out of this study was to improve and further develop the analysis methods currently used in the studies of cost overrun and inaccuracy (i.e., in RO2).

The causes of cost overrun considered within the construction phase were then categorized into four distinct constructs to evaluate their importance on project cost performance. The four constructs were: external (EX), contractor's site management (SM), pre-construction (PC), and project management and contractual relationships (PM). While these causes affect cost during construction, some have origins within the planning phase and are thus categorized within the PC construct. Categorizing the factors to separate constructs is not seen much within the existing literature. Still, it is beneficial because it allows for evaluating the impact of each group of factors in an aggregated way, which can give a better understanding of the larger issues of cost overrun in the construction phase, thus identifying areas for further study.

Fig. 20 presents the impact of each construct on the final cost overrun, retrieved from PLS-SEM analysis. The number on each arrow indicates the importance of the corresponding construct, the higher the value is, the higher the impact on cost overrun.

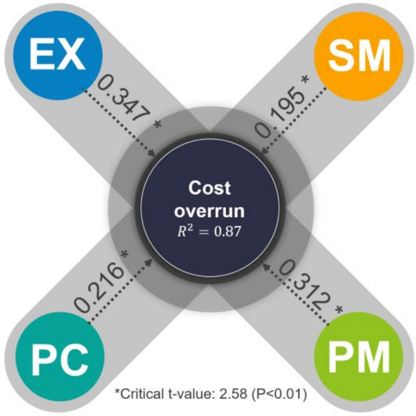


Fig. 20. Results obtained from the structural model using PLS-SEM

External factors (EX) were determined to have the highest impact on cost overrun. Factors including labor unavailability or lack of skilled labor, bad weather (climate), unforeseen ground conditions, market conditions, lack of resources, monopolization of special equipment, terrain condition, length of the road, and project size. Complete control over these factors is impossible (e.g., weather conditions). However, it may be possible to minimize the risk of overrun originating from some of them (e.g., market instability or lack of enough resource/labor) by proper planning, effective management, continuous monitoring and communication strategies, and also the use of technology and data (e.g., real-time data).

Considering the planning phase, the effect of the pre-construction factors (PC) on the total overrun was determined to be the third most important among the four constructs investigated. However, it should be noted there is a distinct gap between the PC factors where three of the factors were ranked as rather influential: *forecasting errors* (PC1), *delays in decision-making* (PC2), and *inadequate planning process* (PC5) were ranked fifth, seventh, and seventh respectively, while two other PC factors: *strategic behavior (deliberate behavior* (PC3)*,* and *deliberate underestimation of costs* (PC4) were ranked as 21st and 24th among the 25 factors investigated. Thus, the latter factors reduced the overall effect of the construct, but this may have been inadvertently due to the wording used to explain factors. Norwegian working culture is often characterized as being based on trust and equality, with a focus on collaboration and cooperation rather than competition or deception. Yet, the wording of PC3 and PC4 might have been found to imply deliberate ways of inaccurately presenting the project's costs and benefits and may have given an impression to the respondents that the factors involved disloyalty or deception. Instead, the factors were meant to imply that the path and decisions taken by an authority in the early stages to influence a project can have a lasting impact on the project idea's trajectory and growth, such as explained earlier within the discussion of factors within the planning phase. This incongruity within the survey was influential on the overall importance of the PC construct, indicating the planning phase factors have a greater impact on the cost increase in the construction phase than found in these results.

4.2. Examining cost inaccuracy through a case study of a Norwegian highway project (Paper 2)

The second paper, which addresses RO1 evaluates the cost performance of a case study project (E6 Frya-Sjoa) to provide a deeper and more detailed insight (compared to Paper 1) into the challenges such a large-scale project face in the construction phase within Norway. Given that the case study was conducted more than three years after the project opening, it was also possible to assess several tactical success criteria. Thus, the study presents a two-level success evaluation of a Norwegian highway that examines project efficiency and effectiveness, i.e., operational and tactical success. The main objectives of this paper were as follows:

1. Evaluating the cost performance (operational success) of the case study project Frya-Sjoa in the construction phase, i.e., determining the existence and the magnitude of cost under/overrun,
2. Identifying causes and explanations which led to the project cost increase,
3. Evaluating the tactical success of the project through assessment of project goals.

4.2.1. Evaluating cost performance

Based on analysis of the project documentation and obtained estimated and actual costs, project E6: Frya to Sjoa revealed a cost increase of NOK 1,583M (+28.15% higher than the estimated costs at the time of decision-making). However, as seen in Fig. 21, the values for P(50) and P(85) were increased during the course of the project, resulting in a final value for P(85) of NOK 7,390M. Given the Norwegian conceptualization of cost overrun, which is based on absolute values of P(85), this cost increase is not interpreted as a cost overrun for the project but instead an underrun of 2.48%. This highlights the importance of understanding the definition of cost overrun specific to the context (country) of study, particularly how to calculate cost overrun, as cost overrun is interpreted differently globally.

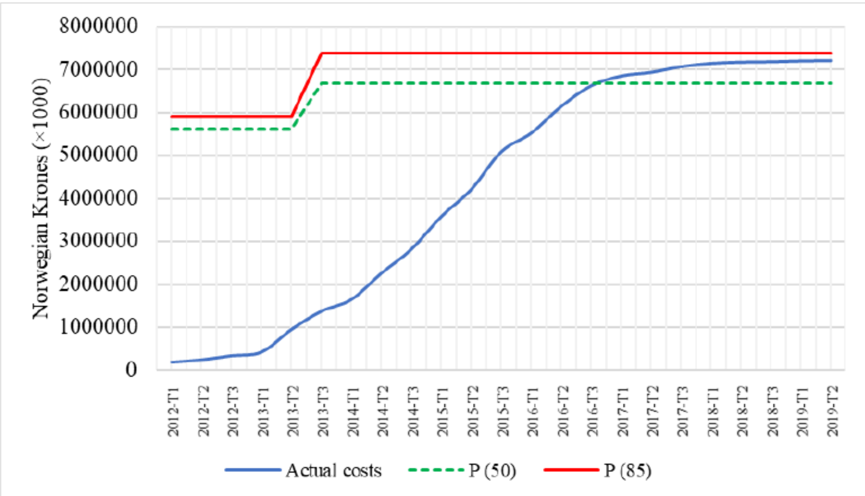


Fig. 21. Costs and frameworks for E6: Frya-Sjoa

4.2.2. Causes and Explanation of cost increase

Once it was established that there was a significant cost increase despite not having an official cost overrun, the in-depth interviews gave insight into the causes of these increases. Five specific causes were identified: market situation, new rules and regulations, design change, removing landfill, and land acquisition, along with a sixth cause, 'additional costs,' which includes other costs which could not be easily identified. The causes were categorized into four explanations (technical, political, economical, and psychological) based on several leading pieces of research in the literature on cost overrun (Morris 1990, Flyvbjerg, Skamris Holm et al. 2003, Odeck 2004, Cantarelli, Flyvbjerg et al. 2008, Love, Edwards et al. 2011). Explanations are more general categorizations and might include several causes. Hence, the main reason for categorizing the causes was to gain a broader understanding of the causes (similar to concepts of the constructs used in the first paper). As Morris (1990) concludes in his study that a general explanation can help better understand planning failures. Table 8 presents an overview of the causes and explanations for the cost increase in the studied project.

Table 8. Causes and explanations of cost increase

Cause	Explanation (supporting theory)	Amount of increase (NOK M) *	% of total cost increase
Market situation	Technical (forecasting)	611	39%
New rules and regulations	Technical (forecasting)	165	10%
Design change	Political (Machiavellianism)	65	4%
Removing landfill	Political (ethical)	60	4%
Land acquisition	Technical (forecasting)	60	4%
Additional costs	Technical / Economical (rational choice)	623	39%
Total (cost final cost increase)		1583	100%

*All prices are presented in 2018 Norwegian *Krones*

Much of the cost increases within the project are explained by technical explanation. In general, technical explanations imply challenges regarding forecasting the future. Cantarelli (Cantarelli 2011) also refers to it as *'honest errors'* associated with difficulties and complexities of predicting the future. For example, the interviewees used the term *'hot market'* to explain fluctuations in the construction market and the associated complications with the market situation.

Two of the technical explanations, *market conditions,* which caused the largest increase within the project, and *land acquisition,* are causes that are connected to and could be addressed during the planning phase of the project. Although the prediction of the market is a very complex task, a greater emphasis on uncertainty analysis in the very early stages of planning can improve the understanding of the impact of potential market shift on cost estimates. This may then affect the conceptual solutions ranking and project selection (note, this is a general conclusion and does not apply to this project specifically since it had not been through QA1). Similarly, costs increases during the construction phase due to *land acquisition* are a result of poor initial estimations of land needed due to limited/incomplete project details during the planning phase, as well as a potential lack of experience in early phase estimations. Using reference projects and experience-based cost information is an effective way to improve land acquisition estimations. The final technical explanation involved *new rules and regulations*, specifically in the case study, regarding water resource security, flood and erosion protection, climate requirements, and frost protection layers for the pavement. These upcoming regulations had been unclear or uncertain during the project budget development and not considered as an uncertainty, thus were characterized as related to inappropriate organizational structure.

Political explanations were also seen within the cost increases. A design change in the early stages of construction is believed to have occurred due to either lack of discipline or organizational/political pressure. There was also the need to remove a previously undisclosed (by the municipalities or local politicians) landfill, indicating a lack of local responsibility within the project. While only 8% of the cost increase occurred because of political interventions, this does not necessarily reflect the actual political impact on the overall cost increase. Politicians are involved earlier in the planning process, before the parliamentary decision. They may change/influence the direction of the project during the planning phase, which can consequently pose cost increases/decreases, affecting the accuracy of the initial cost estimations or project cost performance.

4.2.3. Tactical success evaluation of the project

Given that the case study project has been completed since 2017, it was also possible to consider tactical success of the project by evaluating the extent to which the project has reached the intended goals through an ex-post analysis. Specifically for the case study project, this includes a reduction in traffic accidents to improve traffic safety, better accessibility and reduced travel time for both local and through-traffic users.

Using historical data from NPRA databases, specifically Vegkart[2], it is possible to compare accident data from comparable length periods (70 months) before and after the roadway construction. Doing so showed a reduction from 61 accidents (light damage, severe damage, and fatality accidents) in the before period to 9 accidents in the after period, indicating a rather significant reduction in traffic accidents. While simplistic, this implies that the project has

[2] https://vegkart.atlas.vegvesen.no/

successfully reached the intended safety-related objective by reducing traffic accidents and improving traffic safety.

The project aimed to reduce the traffic volume on old E6, which varied between 5000 and 6500 on different segment stretches, to 1000-2000 for daily traffic users. According to Fig. 22, which presents the traffic volumes on both the old E6 and E6 Frya-Sjoa, before and after the project implementation, it can be inferred that traffic volume is distributed on E6 Frya-Sjoa and the old E6 as it was intended to improve accessibility. Moreover, travel time on this stretch is also reduced by 13 minutes from 38 to 25 minutes (Samferdselsdepartementet 2012).

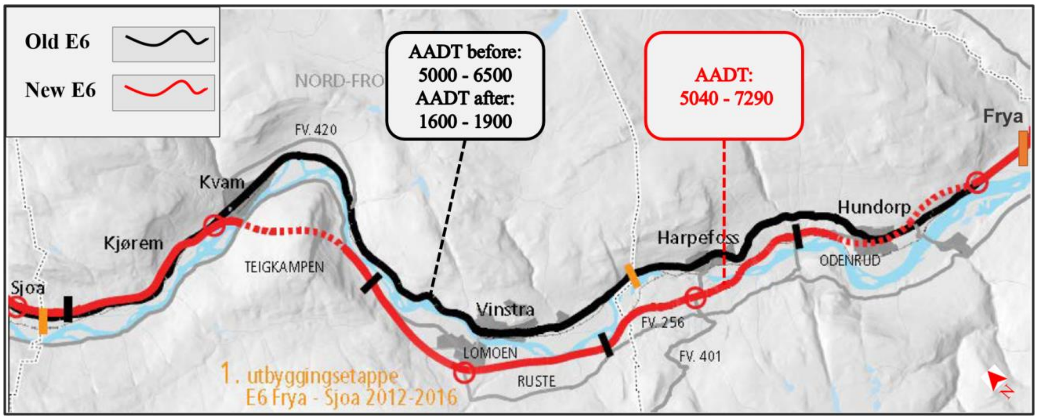


Fig. 22. Comparison of traffic volume on E6 Frya-Sjoa and the two parallel local municipality roads per November 2022, adopted from (Samferdselsdepartementet 2012)

While the tactical success evaluation is simplistic, through an ex-post lens, it shows that that project evaluation should not be limited to the construction phase and operational success evaluation. Cost efficiency is necessary; however, as described in the first paper does not necessarily guarantee the project's success. A project with significant cost increases might be a successful project with regards to addressing society's needs. For example, within this case study, the ex-post evaluation indicates the project's strategic success despite having substantial cost overruns. Thus, a broader perspective on the concept of success can help better understand how the project fulfills societal needs.

4.3. Determining the most influential factors on cost inaccuracies using feature selection (Paper 3)

As explained in chapter 3, the main application of feature selection methods is to eliminate irrelevant features (parameters/variables) within a dataset of several different features in which each feature's importance to an output target is unclear. Consequently, the results are more accurate and representative than simple linear regressions. Within RO1.4, a correlation-based feature selection method (CFS) was used as a part of data analysis in Paper 3 to determine the most important features affecting cost inaccuracies (underruns and overruns). Correlation is an important criterion, and numerous feature selection methods utilize correlation in their algorithms. If two features are highly correlated, one is considered redundant and can be removed from the feature subset. For example, within the feature selection process in this study, year of construction (YC) was eliminated due to its high correlation with decision making year (DMY).

Additionally, the algorithm used in CFS assigns a score to each feature, and then the features are ranked according to their importance. Based on the project dataset used within RO2 (see Paper 3 and 3.2.4 for details), the results of the feature selection analysis are presented in Fig. 23. The final (actual) cost was determined to be the most influential parameter affecting PCO, followed by the number of contractors (NC) and length of construction (CT). Moreover, the percentage of bridge (%B) in the project's length was seen to be the least influential parameter and was removed from the features for further analysis (within RO2). It can be concluded that while classic regression models include all variables in the calculations, the results of feature selection by eliminating redundant features can improve the accuracy of the results.

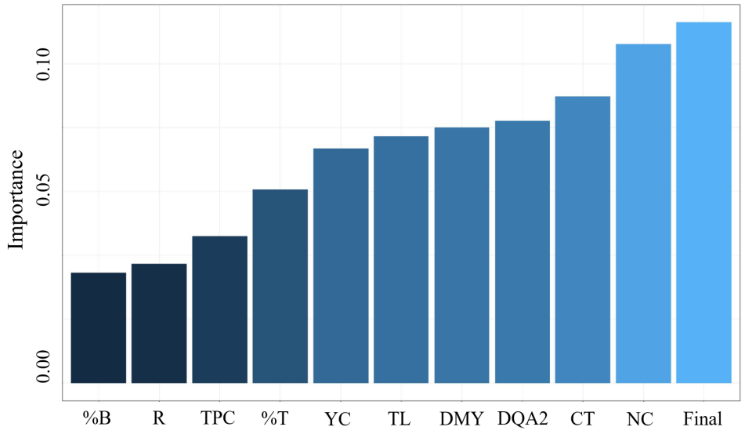


Fig. 23. Feature importance visualization

4.4. Discussion

This section discusses and synthesizes the results presented in the three previous sections. The discussion is structured based on the three main findings of the study: the important parameters affecting cost overrun, the importance of the planning phase, and the use of new methodologies.

4.4.1. Important parameters affecting cost overrun

Causes of cost overrun were investigated through a survey and a case study and considered through a feature selection algorithm. The survey investigated factors affecting cost overrun in both the planning and the construction phase, while the case study focused on the construction phase. Examining the results of studies collectively, the following three factors were commonly ranked highly influential in both: scope change, market conditions, and unforeseen ground conditions. The first two factors are among the most common reasons for the cost increase in the existing literature.

Scope change occurs when there are alterations to the project scope, design, or requirements after the project construction has begun. These changes can be initiated by the client (in the example of E6 Frya-Sjoa), stakeholders, or even the project team. The changes may be due to several reasons, including unforeseen site conditions, regulatory requirements, changes in the client's needs (again, E6 Frya-Sjoa) or preferences, or changes in technology.

To minimize the risk of scope changes, it is essential to have a well-defined project scope and communicate it clearly to all stakeholders involved in the project. This ensures that everyone has a common understanding of the project's objectives, deliverables, timelines, and budget. The project team should also work closely with the client to identify any potential changes in requirements, which should be incorporated into the project scope and design early on. Another way to minimize the risk of scope change is to conduct a thorough risk analysis and identify potential risks and their impacts on the project. This analysis should be done at the beginning of the project and updated regularly throughout the project's lifecycle. This will help the project team to be prepared for any potential changes and to have contingency plans in place.

Additionally, a change management process should be established to manage any scope changes that may arise during the project's execution. This process should include a clear procedure for requesting and approving changes, assessing their impact on the project schedule, budget, and resources, and communicating any changes to all stakeholders. This will help to minimize the impact of scope changes on the project's overall cost and schedule.

Market conditions refer to the state of the market at the time of the project, such as changes in the price of materials, fluctuations in currency exchange rates, and the availability of labor and equipment. These factors can significantly impact project costs, especially in the long term. In Norway, the economy has traditionally been heavily dependent on the oil and gas industry. This dependence can create uncertainty in the market and impact the availability and cost of resources needed for road construction projects. For example, changes in oil prices can affect the value of the Norwegian krone, which can impact the cost of imported materials and equipment.

To minimize the risk of cost increase due to market conditions, project teams should monitor market conditions closely and be prepared to adjust project plans and budgets as necessary. Additionally, they should consider local sourcing of materials and equipment to minimize the impact of fluctuations in currency exchange rates. Collaboration with suppliers, subcontractors, and other stakeholders can help ensure that the project team is aware of any potential changes in the market and can adapt to them in a timely manner.

Although not as prevalent in the existing research, ‘unforeseen ground conditions’ can be a significant cause of cost increases in road construction projects. These conditions refer to unexpected challenges encountered during excavation and construction due to unforeseen soil or rock formations, buried debris (in E6 Frya - Sjoa), groundwater, or other issues. In Norway, the topography and geology of the land can make it difficult to anticipate ground conditions accurately, which can result in additional costs for road construction projects. Norway is known for its mountainous terrain, and building roads through these rugged landscapes can be challenging. Additionally, Norway’s extensive coastline, proximity to the Arctic Circle, and climate change can lead to unpredictable weather conditions, which can also impact ground conditions.

To minimize the risk of unforeseen ground conditions causing cost increases in road construction projects, it is crucial to conduct thorough geological and geotechnical investigations before starting construction. This can involve drilling, soil sampling, and other techniques to gather data about the soil and rock formations beneath the surface. This information can help the project team anticipate potential issues and plan accordingly. Additionally, it is essential to have a contingency plan in place to address any unexpected challenges that may arise during construction. By proactively addressing potential issues and having contingency plans in place, the project team can minimize the risk of cost overruns due to unforeseen ground conditions.

Feature selection method (discussed more at the end of the discussion section) was also used in this thesis to address the same objective (e.g., determining the most important parameters affecting cost overrun) within RO1. The parameters evaluated in the feature selection method were different than those in the survey and case study, not allowing for direct comparison, yet this use of three methods, i.e., mixed methods, to consider the same objective seems to be a very effective approach.

Quantitative methods, such as surveys, can provide a large amount of data that can be analyzed using statistical techniques. This can help identify trends and patterns in the data, as well as measure the strength of relationships between variables. In this research, the survey allowed us to gather data from the potential respondents (n=33), which can provide statistical power to the analysis.

Qualitative methods, such as case studies and interviews, can provide a more in-depth and nuanced understanding of the topic being studied. This can help to uncover underlying reasons for certain trends and patterns in the data, as well as provide insights that cannot be captured through quantitative data alone. In this thesis, the case study led to gathering detailed information about a specific road project and the factors that contributed to the cost increase.

Feature selection analysis can be a useful tool to help identify the most important factors affecting cost overrun in road projects. By using this technique and eliminating redundant features, one can identify the most important variables in the dataset and prioritize them in the analysis. This can help to focus the analysis on the most relevant factors and improve the accuracy of the results.

Overall, using a mixed methods approach with feature selection analysis is believed to provide a more comprehensive and accurate understanding of the important parameters affecting cost overrun in road projects in Norway.

4.4.2. The importance of the planning phase

The importance of the planning phase became apparent at the very beginning of this research while carrying out the literature review and interviews. It plays a crucial role in the Norwegian road project governance framework to minimize cost overruns. This phase is critical for defining a project’s scope, objectives, and deliverables, as well as assessing its feasibility and potential risks, which ultimately impact the project’s cost performance.

During the planning phase, road projects in Norway undergo a thorough analysis of various factors such as environmental impact, societal needs, and maybe the most important for this study: cost estimates. This comprehensive approach helps identify and mitigate potential issues before the construction phase begins. The involvement of various stakeholders, such as government agencies, contractors, and communities in the planning phase ensures that the project meets the expectations of all parties, reducing the likelihood of cost overruns due to scope creep or changes in requirements. Moreover, by carefully analyzing the scope of the project, its feasibility, and potential risks, the project managers can identify and address potential cost drivers before they become actual problems. Therefore, giving proper attention and resources to the planning phase in road project governance frameworks is essential to ensure successful project delivery and avoid significant cost increases.

In addition, increasing transparency in this phase can also play a crucial role in limiting future cost increases. Transparency can be achieved through open communication and information sharing between all parties involved in the planning phase, including project sponsors, designers, contractors, and stakeholders. By doing so, potential issues or challenges can be identified and addressed early in the process before they become major cost drivers. Additionally, transparency can help to build trust and accountability among all parties involved, leading to more efficient and effective decision-making throughout the project lifecycle. Moreover, increasing transparency can also be interpreted as providing systematic logging of cost estimation development, which can lead to more accurate cost estimations. Overall, increasing transparency in the planning phase can help to mitigate risk and prevent cost increases, ultimately leading to more successful road projects in Norway.

Within the evaluation of operational success, the final actual cost is the criterion in the calculations, while both the early cost estimates in the planning phase and budget increases during the construction phase are ignored. Referring to Frya-Sjoa, the budget was increased by almost NOK 1,5B during the construction, yet this budget increase is not reflected within the overrun determination. Thus, it is suggested that determinations for cost overrun may be revised to consider both cost growth during the planning phase, and of adjustments to the budget. It was mentioned and discussed in almost every interview that increased transparency (before example, registering all CA phase interventions) and a cost track record system will improve the efficient use of resources. Also, Welde and Odeck (Welde and Odeck 2017) demonstrated that cost growths at the early stages of planning are considerably more than cost overruns during the construction phase.

In conclusion, the planning phase plays a crucial role in the estimation of cost overruns in road projects in Norway. It provides an opportunity for the identification and mitigation of potential risks and uncertainties, including those associated with the intervention of local authorities. Additionally, increasing transparency during the planning phase can improve the accuracy of cost estimates, thereby reducing the likelihood of cost increase. Without considering the planning phase and the whole project governance framework, evaluating the causes of cost overrun in only the construction phase does not seem to provide a profound insight into the cost performance of a project.

4.4.3. New Methodologies

While new ML methodologies will be more thoroughly investigated within RO2, they are also considered in RO1. The feature selection method in Paper 3 provides, theoretically, a more accurate overview of the importance of the parameters (features) affecting cost overrun. The advantage of these learning-based models, which can learn from the input data, and find patterns and interdependencies among all the variables over the traditional regression models, has already been demonstrated in the literature in various fields of transportation economics (travel demand modeling, pricing analysis, freight transportation analysis, and mode choice analysis) (Bray, Caggiani et al. 2014, Cheng, Lai et al. 2020). Finding patterns and interdependencies among the variables will lead to reduced complexity of the analysis by identifying the most important factors and eliminating irrelevant or redundant variables. Another advantage is that feature selection can improve the accuracy of the analysis by reducing the risk of overfitting the model. Still, there may be some challenges with respect to the small sample size, which could be addressed using deep learning methods (discussed further in the next chapter).

In a well-functioning project governance framework, the existence of advanced analysis methods applicable to any data set is not only able to provide a deep understanding of the existing data for the user but also assist the user in predicting the future based on the lessons learned from currently available data is necessary. The next chapter will elaborate more on further progress in the development of analysis methods in this study.

4.4.4. Diverse methodologies and their implications

The utilization of diverse methodologies across Papers 1-3 in this thesis serves as a deliberate strength of the research that aligns with the overarching research objectives. While the inherent variation in these methodologies gives the potential for differing findings, the inclusion of different method parameters can enrich the breadth of perspective and contextual understanding. In this research, the conscious variation of parameters not only underscores the complexity of the subject matter but also contributes to a more comprehensive grasp of the topic. It is worth noting that despite variations in both parameters and outcomes, there is also a degree of convergence among the findings, which serves to strengthen their credibility.

Each paper addresses a unique facet of the complex issue of cost overruns in LSR projects, culminating in a comprehensive understanding of the topic. Paper 1, for instance, uses a literature review and empirical data collection through expert surveys to examine the topic. The survey methodology gathers real-world insights from practitioners and employs techniques such as the RII and PLS-SEM to identify and prioritize influential factors contributing to cost overruns in both the planning and construction phases of LSR projects. This foundational paper sets the stage for subsequent research and informs the design of further empirical analyses. Paper 2 offers a comprehensive two-level evaluation of project success (i.e., operational and tactical) for a case study project, highlighting a thorough exploration of causes and challenges leading to cost increase/inaccuracy in the project. Building upon the insights gained from Papers 1 and 2, Paper 3 advances the research by exploring the application of ML methods, specifically focusing on feature selection to uncover the most important parameters affecting cost inaccuracies. This represents a significant progression in our methodology, enabling us to capture complex patterns and relationships within the data that might be overlooked by traditional linear regression methods.

While variations in findings are expected due to differing methodologies and objectives, the collective insights from these papers significantly deepen the understanding of the complex issue of cost overruns. The distinct findings are incorporated into a broader discussion that highlights the strengths and limitations of various approaches, enriching the validity and depth of the research conclusions related to understanding cost overruns in LSR projects which is ultimately aligned with the broader goal of improving cost performance prediction models and decision-making in the transportation sector.

5. Results and discussion: prediction of cost performance for future projects (RO2)

The second objective of this study is to explore the utilization of (machine) learning-based models to assess the feasibility of predicting the cost performance of future LSR projects based on existing datasets of completed projects. In addressing RO2, PCO is the dependent target variable (feature), and independent variables (features) affecting PCO, regardless of the PCO being negative (underrun) or positive (overrun), are considered in all the analyses. Therefore, the term 'cost inaccuracy' is used more often in addressing RO2 since both negative and positive PCOs are indications of inaccuracy in cost estimations. The data sets used in these studies are described in section 3.2.4. Similar to Chapter 4, this chapter presents the results from Papers 3 and 4 in the first two sections and discusses the findings in Section 5.3.

The first part of Paper 3 (feature selection) was presented and discussed within RO1. Related to RO2, the main body of Paper 3 presents two Artificial Neural Network models, one of which (RBFNN-GP) has been recently developed in data science literature for application on small datasets. RBFNN-GP, along with MLP, are used to predict the PCO given a set of project variables. These models are then evaluated and compared with the two traditional regression models commonly used in this field to understand their performance. To follow this, Paper 4 presents a unique GAN-based method, recently developed for generating data based on the available patterns found in existing datasets to enlarge the dataset size and improve the precision of the prediction models. This approach was applied to the small sample size in this study, and the prediction performance of the models trained and tested on the generated data was evaluated to assess its applicability. Thus, the studies within RO2 address the current issues regarding small sample sizes for country-specific cost performance analysis.

5.1. Use of artificial neural networks for predicting cost performance of future projects (Paper 3)

Paper 3 considers the possibilities of using ML methods to learn from past projects' features to predict the cost performance of future LSR projects, in comparison to current modelling methods. Therefore, the main objectives of this paper were as follows:

1. Apply MLP and RBFNN-GP on the dataset of LSR projects to predict PCO.
2. Evaluate and compare the performance of the two ANNs with two traditional models (classic regression and fuzzy regression).

A comprehensive description of the utilized models and dataset is given in Chapter 3. A challenge with the studied dataset was missing data (Fig. 24), which needed to be addressed before applying the models. Unlike common practices to estimate missing data, this paper utilized a Correlation Based Regression Imputation (CBRI) (ÜRESİN 2021) method, in which the parameter with the highest correlation and the parameter that has the missing observations were considered for the prediction of the missing observations. Scaling of data, as a part of data preprocessing, was also performed before moving to feature selection (as described in section 4.3).

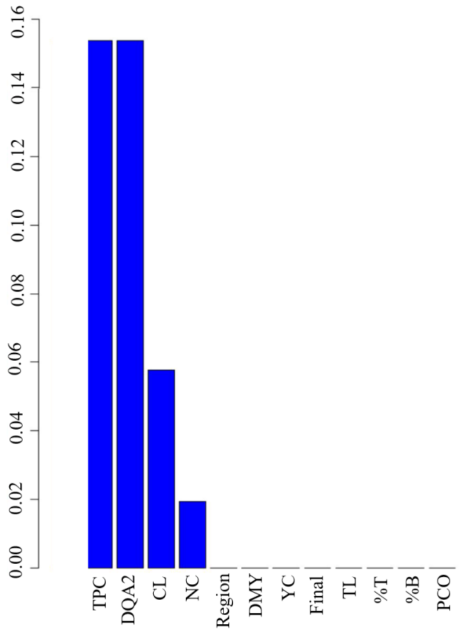


Fig. 24. The visualization of missing data

For MLP and RBFNN-GP, the following model considerations were used. Five-fold cross-validation was performed. The entire set of 11 features was considered inputs and weighted randomly. The number of hidden layers was set to 3. The activation function for hidden and output layers is Tanh. Based on the relevant literature, the learning rate for RBFNN-GP was set equal to 0.003 (Yang, Wang et al. 2022). The learning rate is a hyperparameter that defines how much the model is altered in response to the predicted error whenever the model weights are updated.

Table 9 presents the model evaluation results for the four proposed models in this paper using the main three criteria of Mean Absolute Percentage Error (MAPE), Root Mean Squared Error (RMSE), and Mean Squared Error (MSE).

Table 9. Model evaluation for the utilized and developed models

Model	MAPE (%)	RMSE	MSE
	Training set		
Linear regression	36.12	0.425	0.214
Fuzzy regression	41.63	0.487	0.245
MLP	12.11	0.243	0.081
RBFNN-GP	**8.65**	**0.147**	**0.021**
	Test set		
Linear regression	44.10	0.493	0.251
Fuzzy regression	48.23	0.583	0.334
MLP	15.01	0.34	0.12
RBFNN-GP	**9.81**	**0.213**	**0.035**

The results show that MAPE for RBFNN-GP in training and test sets was determined to be 8.65% and 9.81%, respectively, demonstrating that this model is significantly more accurate than the traditional regression models (with MAPE values varying between 36 and 48%). These results align with Tijanić, Car-Pušić et al. (2020), finding that RBFNNs have a good performance for predicting the cost performance of road projects. Additionally, in this study, RBFNN-GP was utilized. Compared to normal RBFNN, RBFNN-GP uses Gaussian Processes (GP) to provide probabilistic predictions and uncertainty estimates, which leads to considerably higher generalization accuracy. The same performance results are seen when considering RMSE and MSE, i.e., RBFNN-GP performs better than the other considered models. This is followed by MLP, which for all metrics, is closer to RBFNN-GP than the two other traditional models.

The obtained results from the application of ML methods in this study were promising and reasonable, implying that both RBFNN-GP and MLP outperform the classic and fuzzy regression models in the context of this study, i.e., prediction of cost performance. The novel ANN approach proposed in this paper was specifically selected for its ability to consider small sample sizes better to understand the cost performance evaluation of LSR projects. Yet, the accuracy of the models will be improved as more projects are added to the sample.

5.2. Improving the accuracy of cost performance prediction using data generation networks (Paper 4)

The results of Paper 3 were promising, and the high accuracy of ANNs (considerably higher than traditional regression models) was observed. Yet, although the proposed ANNs (RBFNN-GP and MLP) are specifically developed for small sample sizes, small size of data remains a challenge. A low number of samples may affect the accuracy and, as a result, the model's credibility. This can be more critical where the number of features is also limited. Therefore, Paper 4 attempts to address this issue by utilizing a recently developed data generation model, which produces synthetic data based on the patterns found in the available data. Accordingly, the main objective of paper 4 is to 'assess the feasibility of using data generation models to improve prediction models' performance.'

The novel methodology used in Paper 4 consists of data generation and performance evaluation of the prediction models built on generated and real data within the context of the cost performance of LSR projects. First, data is generated using a GAN-based method. GAN algorithms are learning-based neural networks that produce synthetic (fake) data based on the patterns learned in the available data (see 2.5.3).

In the second part of this paper, the PCO prediction model (classifier) is built and evaluated based on the generated synthetic data. Classification analysis was performed using three ML classifiers: XGBoost, MLP, and SVM. Based on the input feature data, the predictive model determines the class or range of percentage cost overrun. The model was trained and tested in two different steps to obtain higher validity and credibility of the analysis. First, the classifiers were trained with the synthetic data and then validated by the real data. Then the real and synthetic data were combined, and the performance of the classifiers was then evaluated.

5.1.1. Qualitative evaluation of generated data

Two different plots are used to present a qualitative (visual) comparison of the real and generated synthetic data. Cumulative sums (cumsum) plots of eleven features of the data set, together with that of the dependent feature (PCO), are a useful tool for evaluating the effects of data generation on the distribution of a dataset and ensuring that it remains balanced and representative of the real data. The plots shown in Fig. 25 suggest that the generated data has similar properties as the real data. This can indicate that the generative model is performing well and is able to capture the underlying structure of the real data.

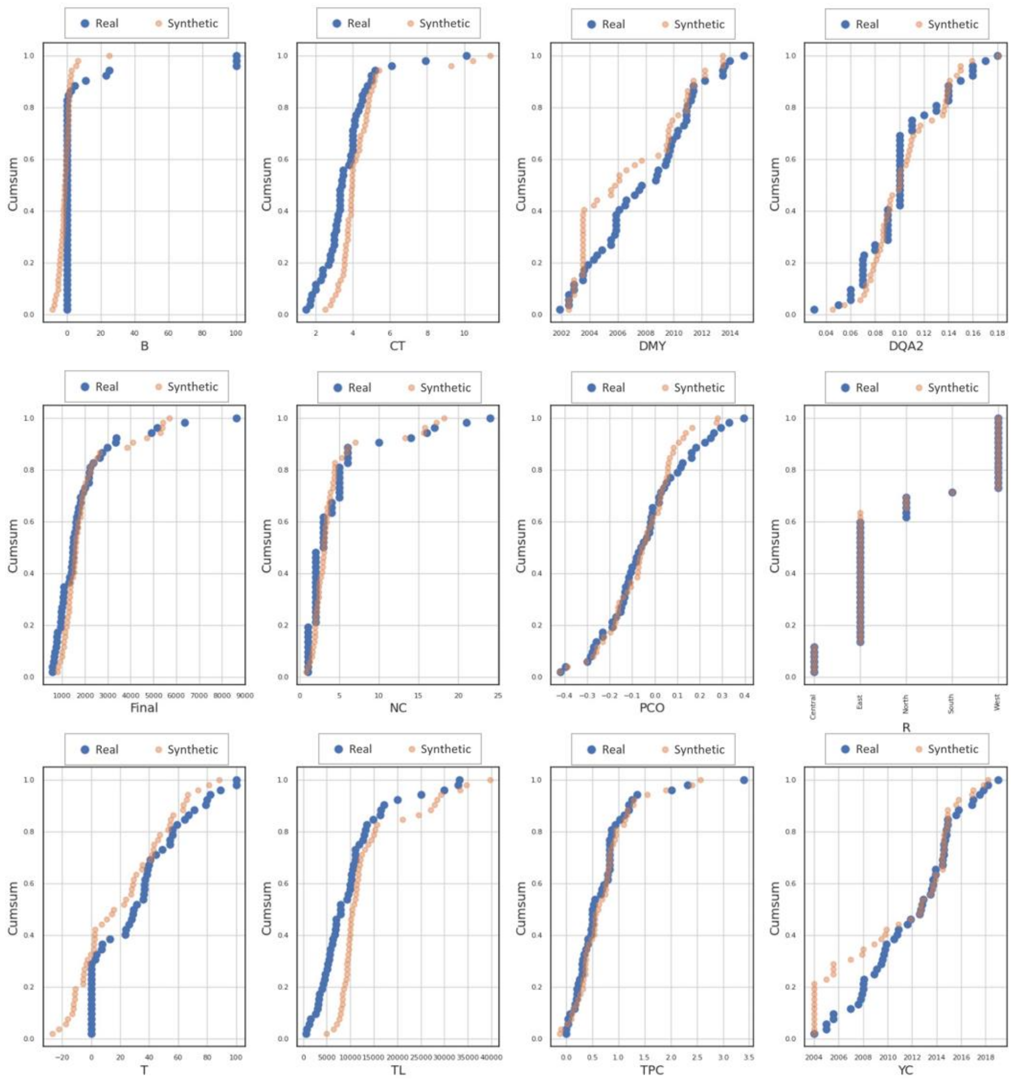


Fig. 25. Cumulative sums per feature

For further visually inspecting the synthetic data, Fig. 26 illustrates a comparison of the distribution diagram of each feature for the real and the synthetic data. Central tendency, spread, skewness, and outliers are the main information that distribution diagrams can provide. Considering the above-mentioned parameters, the distribution of synthetic data generated by the proposed algorithm is found to be very similar to that of the real data.

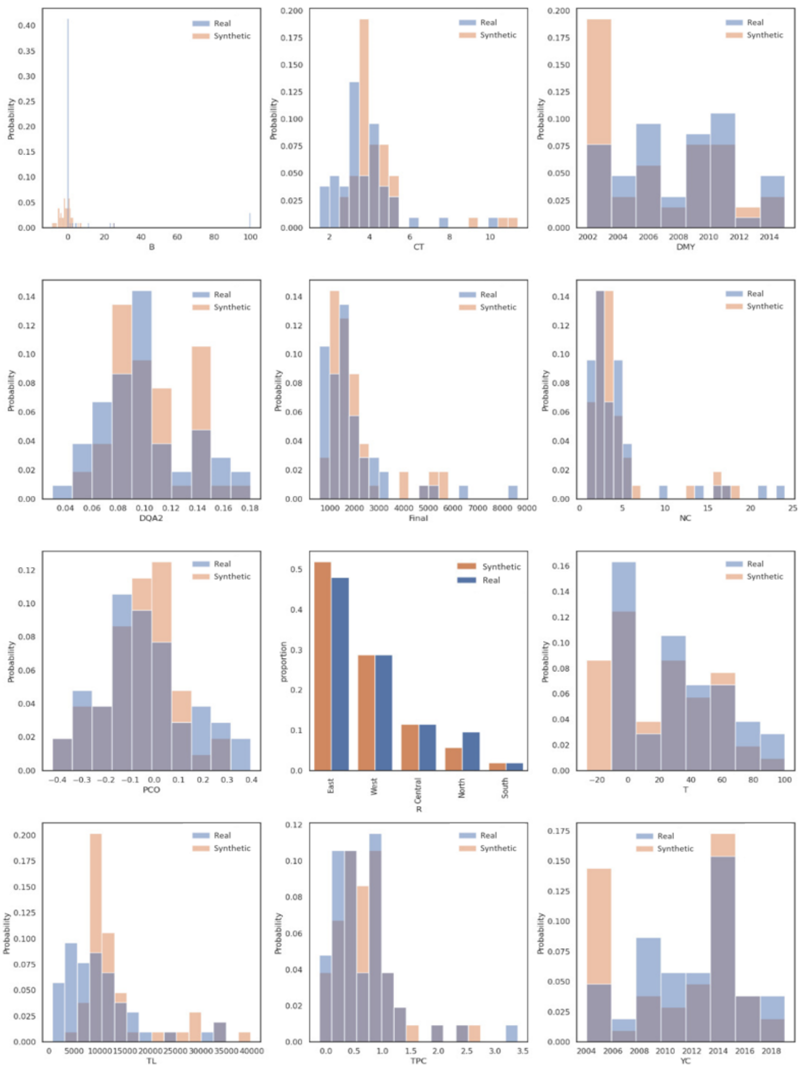


Fig. 26. Distribution comparison of real and synthetic data per feature

Based on the cumulative sum plots and the distribution diagrams, the generated synthetic data appears to largely follow the pattern of the real data, indicating that it can be further considered for use in supplementing small data sets. However, in order to quantitatively assess the degree of similarity of the generated synthetic data to that of the real data, they will be applied and tested on classifiers (i.e., prediction models).

5.1.2. Quantitative evaluation of synthetic data

In order to quantitatively assess the similarity of real and synthetic data and evaluating the performance of the prediction models, the model setup and evaluation in this study are conducted in two different stages utilizing three different ML classifiers, XGBOOST, SVM, and MLP. It is to be noted that in this study, the data samples are classified into six different classes according to the PCO prediction (within the range of -45% to +45%) as shown in Table 10.

Table 10. Classes and correspondent PCO ranges.

Class	A	B	C	D	E	F
Range (%)	$-45 \leq PCO < -30$	$-30 \leq PCO < -15$	$-15 \leq PCO < 0$	$0 \leq PCO < 15$	$15 \leq PCO < 30$	$30 \leq PCO < 45$

In the first stage, the classifiers were trained with the synthetic data and then validated by the real data. The results are presented in Table 11, indicating that the trained classifiers were approximately 75% accurate in predicting the PCO of the real data, where accuracy represents the percentage of correct predictions made by the classifier out of the total number of predictions. Moreover, the three classifiers obtained an average F1 score of 0.73, with MLP showing the best performance with an accuracy of 0.76 and an F1 score equal to 0.78. The F1 score is a single metric that combines precision and recall into a balanced measure of a model's overall performance (Lipton, Elkan et al. 2014)

Table 11. Performance evaluation of classifiers on real data

Classifier	Accuracy	F1 Score
XGBOOST	0.76	0.74
SVM	0.75	0.67
MLP	0.76	0.78

The results indicate that data generation algorithm used in this study has an acceptable performance, i.e., the synthetically generated data are similar to real data. The three employed classifiers performed encouraging, where MLP and XGBoost performed only slightly better than SVM.

5.1.3. Prediction performance evaluation

Upon confirming the similarity between the generated synthetic data and the real data, a larger dataset was formed by combining 173 synthetic samples with 52 real samples. This combined dataset was utilized for training and evaluating the prediction model using a five-fold cross-validation approach.

In the five-fold cross-validation process, the dataset was divided into five subsets of roughly equal size. The classifiers were trained and tested five times, with each subset serving as the test set once while the remaining four subsets were used as the training set. This procedure was repeated until each subset had been used as the test set, ensuring comprehensive coverage of the entire dataset during both training and testing.

Performance evaluation results of the classifiers, using the combined set of real and synthetic data, were obtained through the five-fold cross-validation approach. The reported accuracies represent the average performance across the multiple iterations, providing a robust assessment of the prediction model's effectiveness. According to Table 12 and considering the problem and the size of the dataset, the three classifiers have performed accurately, with slight differences in performance, where again, MLP performed better than the others.

Table 12. Performance evaluation of classifiers on the combined data set

Classifier	Accuracy	F1 Score
XGBOOST	0.75	0.74
SVM	0.73	0.72
MLP	0.76	0.79

The results obtained from the model evaluation are promising, indicating the possibility of generating synthetic data to match small samples of real data. Here, acceptable performance of the classifiers was achieved with a real dataset of only 52 samples, each with eleven features. This addresses one of the main challenges identified within this study, the lack of sufficient data.

5.3. Discussion

The findings of Chapter 4 demonstrated that improvements in the cost performance of LSR projects could be made by giving consideration to the early planning phase. Increasing transparency and accountability, as well as documentation of the changes in cost estimates from very early planning stages, contribute to better control and overviews on the cost escalations and, as a result, the cost performance of a project. While poor or incomplete pre-project planning is at the root of failures of LSR projects' cost performance, the successful cost delivery of such projects is complex, particularly due to its dependence on a wide variety of parameters and interdependencies between these parameters. Thus, additional considerations must be taken into account in the planning phase.

As already mentioned, literature on cost overrun predominately uses traditional methods (e.g., linear regression) for investigating the causes of cost overrun or assessing the cost performance of the LSR projects. Although linear regression has the important advantage of being straightforward to understand and explain, it performs poorly when there are non-linear relationships. Linear regressions are not naturally flexible enough to capture more complex patterns/dimensions. Moreover, the additional use of proper interaction terms or polynomials in linear regressions can be tricky and time-consuming.

Given this, and motivated by the substantial capabilities of AI, RO2 of this thesis was addressed by investigating the use of several types of ML applications in order to improve cost performance modeling. Such cost estimation models can be helpful to the decision-makers and other stakeholders in the early stages of project governance to retain better control of projects.

I. Comparison of ANNs within predictive modeling

ANNs are supervised learning tasks for modeling and predicting continuous, numeric variables in various applications, including, as seen here, cost performance evaluation. New architectures and variations of ANNs are constantly being developed and researched, and determining the best

ANN for a particular problem often requires expertise and experimentation. Both ANNs (RBFNN-GP and MLP) examined within this research are commonly used for regression and classification. RBFNN-GP is a type of ANNs that uses Radial Basis Function (RBF) as its activation function and Gaussian process (GP) as its learning algorithm. MLP, on the other hand, is a type of ANNs that uses multiple layers of nodes with non-linear activation functions.

RBFNN uses RBFs as activation functions in the hidden layer. The key advantage of RBFNNs is that they are able to model complex non-linear relationships between the input and output variables without requiring a large number of hidden units. This is because the RBF units in the hidden layer act as localized non-linear functions that can capture complex patterns in the data. Overall, RBFNNs can be a powerful tool for modeling complex relationships, particularly in cases where the relationships are non-linear. Yet, they may require careful tuning of hyperparameters, such as the number and placement of the RBF units, and may not perform as well on all types of data.

The advantage of RBFNN-GP is an improvement over traditional RBFNN as it is able to automatically learn the hyperparameters of the RBFs, such as the width and amplitude, through the use of GP regression, making the model less susceptible to overfitting and leading to better performance and reduced complexity. Overfitting occurs when the network becomes too complex and is able to fit the training data too closely, leading to poor performance on new or unseen data. In other words, the model becomes too good at fitting the training data, to the point where it starts to memorize the training examples rather than learning to generalize to new, unseen examples. Reducing the likelihood of overfitting is favorable for studies such as this one with a small sample size. However, RBFNN-GP can be computationally expensive and may result in models that are difficult to interpret compared to simpler models like linear regression. This is because the structure of the network is determined by the algorithm rather than by human intuition or prior knowledge about the data. In some cases with high dimensionality (e.g., hundreds or thousands of features) and complex interdependencies, this may make it harder to understand how the model is making its predictions or to diagnose problems with the model. However, in the context of this thesis it is less of a concern since one of the objectives of this study is to evaluate the accuracy of RBFNN-GP compared to linear regression.

The other ANN used within the study was MLP, which also has the ability to model complex non-linear relationships between the input and output variables. This is because the non-linear activation functions used in the hidden layers of the network allow it to capture and represent complex patterns and relationships in the data. MLP is generally more complex than RBFNN-GP, as it has more layers and nodes, which may result in longer training times and potentially overfitting if not carefully tuned. Comparatively, MLP can be harder to interpret due to its complex architecture and nonlinearity. Whereas RBFNN-GP uses Gaussian processes, which allow for probabilistic predictions and uncertainty estimates.

The performance of both models may vary depending on the specific dataset and problem you are trying to solve. MAPE, MSE, and RMSE are the best means to compare their performance, which is done in Paper 3. As shown in Table 9, both models outperformed the traditional regression models used as competitive models in this study, and the performance results of RBFNN-GP showed higher accuracy than that of MLP. Yet, it should be noted that the performance of ANNs may vary significantly depending on the context and the type of data.

II. Data generation to address small sample size:

The main challenge with the dataset used in this study has been the small sample size of the dataset to be used within model development, which is also a general challenge within country-specific cost performance studies. Data generation using GANs is a powerful technique that can be used to enhance the quality and quantity of data (i.e., to address the issue of small sample size), leading to better performance in ML modeling, particularly given the need for data to be used within training processes. Compared to other data generation methods (such as PCA, decision tree-based methods, and systematic or stratified sampling), GANs can generate a large amount of data quickly and efficiently, where the data generated is visually similar to real data (Gulrajani, Ahmed et al. 2017), as seen in Figures 25 and 26.

CTGAN (Conditional Tabular GAN) was used in this study, as one of the key features is that it can handle the conditional generation of tabular data (including categorical, continuous, and ordinal data), which means that the synthetic data can be generated to match specific conditions or constraints. CTGAN produces synthetic data that is statistically similar to the real data, including preserving the correlations between variables in the real data, which is important for maintaining the integrity of the data and ensuring that the generated data is representative of the real data (Xu, Skoularidou et al. 2019, Lee and Lee 2021, Abedi, Hempel et al. 2022). Thus, given the type of data utilized within cost performance analysis (i.e., tabular data where the aim is to identify relationships between variables in order to predict PCO), CTGAN was an appropriate choice of data generation method to enlarge the dataset.

Based on the results provided in Paper 4, the effectiveness of CTGAN in generating additional data that proved useful for training and validating ML models is evident. All three classifiers demonstrated relatively high accuracy scores while being trained on the synthetic data and tested on real data, with XGBoost achieving an accuracy of 0.76, SVM achieving 0.75, and MLP achieving 0.76.

Furthermore, when combining the generated data with the real data, the classifiers continued to perform well, albeit with slightly lower accuracy scores. XGBoost attained an accuracy of 0.75, SVM achieved 0.73, and MLP achieved 0.76. These results suggest that the combination of real and generated data further enhanced the classifiers' ability to generalize and make accurate predictions.

It is worth noting that the F1 scores, which provide a measure of the models' overall performance by considering both precision and recall, were consistently higher when the classifiers used the combination of the real and synthetic data than being trained on the synthetic and tested on the real data. The improvement in F1 scores can be attributed to the larger and more diverse dataset resulting from the combination of real and generated data. By incorporating a greater variety of instances and patterns from the real data, the models were able to learn more effectively and make better predictions, leading to an enhanced balance between precision and recall.

While there is still room for improvement, the results are pretty promising, especially considering the size of the original (real) dataset. However, it's important to keep in mind that there are limitations to using synthetic data, such as lack of variability and potential for replication of biased data. Thus, it's beneficial to validate the models using real-world data whenever possible.

Thus, in addressing RO2, as seen within the results of the studies completed and the further discussions of the methodologies, ML techniques were found to be promising within cost performance modeling, both as competitive alternatives to traditional techniques and as a way to address issues of small size within existing data. At the same time, there is a need for further study to continue to develop and understand the use of ML within transport economics to ensure the methods and techniques are being used appropriately.

6. Reflections and conclusions

This thesis highlights the critical importance of projects' cost performance evaluation in the Norwegian road projects' governance framework. Despite efforts to manage project costs, cost inaccuracy remains a persistent problem in road construction projects. This study identifies the most important factors contributing to cost inaccuracy in Norwegian road projects, providing critical insights into where cost management efforts should focus. Additionally, this research shows that traditional methods, which rely on simple regression models, can be improved upon using more advanced methods to accurately predict and manage costs in complex large-scale road (LSR) projects. Specifically, this research demonstrates that new Machine Learning (ML) technologies, such as Artificial Neural Networks (ANNs) and generative adversarial networks (GANs), offer promising avenues for improving cost performance evaluation. This final chapter summarizes the key findings of this study, discusses their implications, specifies the study's limitations, and suggests areas for future research in this field.

Two broad research objectives have guided the research process for this thesis:

RO1. *To further understand the concept of cost overrun and the influential parameters affecting cost inaccuracies in Norway.*

RO2. *To predict the cost performance of large-scale infrastructure projects using past project data.*

The primary motivation behind the thesis was to address the recurring problem of cost overruns in Norwegian road construction projects by understanding the most important parameters affecting cost overrun. The research revealed that traditional cost estimation models were often inadequate for capturing the complex and dynamic nature of road projects. However, it was recognized that new ML methods (e.g., ANNs and GANs) had shown promise in addressing similar challenges in other fields. The research was expanded to explore the potential benefits of using these new and more sophisticated algorithms to predict and manage costs in Norwegian LSR projects. Through the analysis, it was found that the use of these methods can be very beneficial in overcoming the challenges of cost estimation and management in the Norwegian road construction industry, and further study is warranted. Overall, the thesis provided an excellent opportunity to explore an important and challenging problem in the Norwegian road sector while utilizing new and innovative techniques and provided valuable experience and opportunities for further research and collaboration in the field of cost estimation and management.

6.1. Main findings

The first research objective, RO1 – *To further understand the concept of cost overrun and the influential parameters affecting cost inaccuracies in Norway* – is addressed in Papers 1, 2, and a part of Paper 3, through a variety of methods. A survey of relevant experts in LSR projects and several interviews were the methods used in Paper 1. Paper 2 studied a case study project (E6 Frya-Sjoa) and utilized documentation review and group/individual interviews. Feature selection was the method used to address RO1 in Paper 3.

The second research objective, RO2 – *To predict the cost performance of large-scale road projects using past project data* – is addressed in Papers 3 and 4. A dataset of 52 LSR projects, in which each project has several independent project-specific variables, was used for analysis in Papers 3 and 4. Newly developed ANNs and a recently developed data generation algorithm for tabular data (i.e., CTGAN) were primarily used as the analysis methods in Papers 3 and 4, respectively.

The main findings and the corresponding reflections are summarized below:

6.1.1. Factors affecting cost overrun (RO1)

Based on this research, the three main reasons identified for cost overrun in road projects during the construction phase in Norway are scope changes, market conditions, and unforeseen ground conditions. This conclusion was reached by analyzing both survey and case study research, where results largely agreed. These factors can significantly impact the project's budget and timeline, and it is important to consider them during the planning phase to minimize the risk of cost overruns.

In Norway, well-defined project scope, open communication, collaboration, and thorough risk analysis can help reduce the risk of scope changes leading to cost overruns in LSR projects. Additionally, monitoring market conditions, local sourcing of materials and equipment, and collaboration with suppliers, subcontractors, and stakeholders can help minimize the risk of cost overrun due to market conditions. To minimize the risk of unforeseen ground conditions causing cost overruns, it is crucial to conduct thorough geological and geotechnical investigations before starting construction and have a contingency plan in place.

The case study project revealed a cost increase of NOK 1,5B during the construction phase, which it is not interpreted as a cost overrun due to a budget increase. This indicates that the overrun calculation method used in Norway may not be a reflection of the actual cost performance of a project. The final actual cost is the criterion for operational success but changes in early cost estimates and budget increases during construction are often ignored. Thus, it may be suggested that revisions to the calculation method should be considered in order to account for cost increases in the planning phase (the importance of which is described below) and/or budget increases during the construction phase.

The results also suggest including ex-post evaluations in project governance systems to assess tactical and long-term strategic success. The Frya-Sjoa case study is an example where ex-post evaluation showed the effectiveness of the project despite the project's negative reputation due to a significant cost increase. Thus, it's important to evaluate success several years after project completion, in addition to considering operational success to consider all aspects of success.

6.1.2. The importance of the planning phase (RO1)

While addressing RO1, it became apparent that it is essential to consider not only the construction phase but also the planning phase. This is because many factors that can cause cost overruns, such as inadequate planning, design changes, and scope creep, often originate from decisions made during the planning phase. Neglecting to evaluate the planning phase can result in incomplete and misleading information, which can lead to ineffective cost management strategies and ultimately impact the success of the project. It was seen through the preparation and analysis of the survey results that a thorough analysis of the planning phase, in addition to the construction phase, is necessary to identify and address the factors contributing to cost overruns in an LSR project.

The planning phase is acknowledged as a critical phase in minimizing cost overruns, and a key contributor to the success of LSR projects in Norway. It helps to define the project scope, assess the feasibility and potential risks, and involve various stakeholders to ensure project expectations are met. A thorough analysis of factors such as environmental impact, needs, available possibilities, traffic demand, market evaluation, etc., can help identify potential issues and mitigate them early on. Increasing transparency in the planning phase through open communication and sharing of information can also help to limit future cost overruns by identifying and addressing potential issues early on. Proper attention and resources should be given to the planning phase in road project governance frameworks to ensure successful project delivery and avoid significant cost overruns. Early prediction of the performance of an LSR project is critical for project stakeholders to make decisions that could influence project success, and a well-functioning planning phase can provide the basis for more accurate early predictions.

6.1.3. New methodologies (RO1 and RO2)

While the advent of ML algorithms as a subset of AI has resulted in an exponential rise in the accuracy and development of data science, its use in the transportation economy has been limited. As in most fields of study, experts in transportation economy and project management are typically not data scientists, thus there is a need to bridge between the two disciplines. This thesis provides an opportunity to do just that.

The use of ML was seen to improve the accuracy of analysis and feature selection, which identifies important factors contributing to cost overrun, while eliminating irrelevant or redundant variables. The findings highlight the advantages of learning-based feature selection algorithms over traditional regression models (RO1), and the potential for deep learning methods to address small sample size challenges (RO2), further summarized in the following subsections. The inclusion of advanced analysis methods in cost performance evaluation can provide a deeper understanding of data and result in better predictions of the future.

6.1.4. Investigation of ANNs to build prediction models (RO2)

One significant advantage of artificial intelligence and machine learning in today’s world is their ability to process and analyze vast amounts of data quickly and accurately, enabling us to gain insights, make predictions, and automate complex tasks with greater efficiency and effectiveness than ever before. This has significant implications for a wide range of fields, including transportation economics and project management, where data-driven decision-making and optimization can lead to improved cost management, risk mitigation, and project outcomes.

The use of recently developed ANNs, such as RBFNN-GP, is novel and beneficial in the field of cost overrun in transportation economics because these models can learn from data and identify complex patterns and interdependencies among variables that may be difficult for traditional statistical models to detect. This can lead to more accurate predictions of cost overruns and identification of critical risk factors, which can help project managers make more informed decisions and take appropriate action to mitigate potential cost overruns. Additionally, RBFNN-GP models have the ability to handle both continuous and categorical variables, making them versatile tools for analyzing transportation data.

In this thesis, two ANNs (i.e., RBFNN-GP and MLP), together with two traditional regression models (i.e., linear and fuzzy regression), were applied to a dataset of 52 LSR projects, and their performances were compared. The value of Mean Absolute Percentage Error (MAPE, %) for the testing set was determined to be 9.81 and 15.01 for RBFNN-GP and MLP, while it was observed to be 48.23 and 44.10 for fuzzy regression and linear regression, respectively. Likewise, Mean Squared Error (MSE) was calculated to be 0.035 and 0.12 for RBFNN-GP and MLP, this value for fuzzy regression and linear regression was 0.334 and 0.251, respectively. The results indicate that new ML technologies such as RBFNN-GP and MLP can lead to significantly better performance in predicting the cost performance of LSR projects compared to traditional regression models like linear and fuzzy regression. Yet, while both models outperformed traditional regression models in the study, but their performance may vary depending on the context and type of data.

6.1.5. Data generation using CTGAN to address the issue of small sample size (RO2)

ML techniques were employed to address the challenge of small sample size in developing prediction models by leveraging data generation techniques, specifically Conditional Tabular GAN (CTGAN), to generate synthetic tabular data. CTGAN has advantages over traditional data generation techniques, such as handling conditional generation, generating high-quality synthetic data, preserving correlations between variables, supporting diverse data types, and reducing the need for data collection. In this study, 173 synthetic samples were generated based on 52 real examples. In the first stage, the classifiers (XGBoost, SVM, and MLP) were trained on the synthetic data and validated using the original data, resulting in accuracy scores of 0.76, 0.75, and 0.76, respectively, indicating the similarity between the generated and real data. Additionally, the F1 scores for XGBoost, SVM, and MLP in the first stage were 0.74, 0.67, and 0.78, respectively. When the real and synthetic data were combined in the second stage, the proposed predictive model achieved accuracy scores of 0.75, 0.73, and 0.76 for XGBoost, SVM, and MLP, respectively, along with F1 scores of 0.74, 0.72, and 0.79, respectively. These findings highlight the success of utilizing CTGAN for data generation, with all three classifiers exhibiting relatively high accuracy and F1 scores.

In specialized contexts like cost performance prediction for LSR projects, addressing small sample size challenges necessitates innovative approaches such as the utilization of ML techniques for synthetic data generation, as demonstrated in this study. However, it's important to acknowledge the potential risk of generalization error that arises from limited data availability. Yet, the results of this study offer promising insights, suggesting that the employed technique has effectively minimized the generalization error. Training classifiers on the combined real and synthetic data resulted in high accuracy scores and F1 scores for multiple models (XGBoost, SVM, and MLP), indicating a notable alignment between the synthetic and real data. This finding underscores the methodology's capability to mitigate generalization risks in the examined specialized domain.

6.2. Policy implications

The results of this research effort can inform policy implications that address the multifaceted challenges of cost inaccuracies in LSR projects. These policy implications, structured into two distinct categories, are specifically tailored to align with the findings from Papers 1-2 and Papers 3-4. Through the integration of empirical insights and cutting-edge analytical methods, this study establishes a foundation for well-informed policy recommendations. These recommendations have the potential to bolster the efficiency, cost management, and overall success of road infrastructure projects.

6.2.1. Enhancing Cost Management and Project Planning Policies:

This group of policy implications is primarily derived from Papers 1 and 2 and focuses on improving cost management, planning, and project coordination policies:

- *Alignment of local wishes and cost responsibility:* Given the significance of 'local wishes without cost responsibility' as a major factor affecting cost overrun in the planning phase, policymakers should emphasize mechanisms that align local stakeholder interests with financial responsibilities. Introducing mandatory local contributions or involving local stakeholders in the cost estimation process can help mitigate this risk.
- *Integrated cost estimation and risk management:* Policymakers should prioritize the integration of advanced cost estimation methodologies with robust risk management practices. For instance, to address the challenge of 'defective estimation,' it is essential to enhance cost estimation methodologies that capture the inherent uncertainties and risks associated with LSR projects. This includes enhancing estimation techniques to capture uncertainties and risks and implementing comprehensive risk assessment throughout the project lifecycle. An integrated approach ensures more accurate initial cost projections and better preparedness for potential cost overruns.
- *Streamlined processing time:* Recognizing the impact of 'long processing time' on cost overrun, policymakers may implement measures to streamline the approval and decision-making processes related to project planning. Reducing bureaucratic delays can contribute to improved cost performance.
- *Accountability for benefits and costs:* To address the issue of 'those who get the benefit are not the ones who pay,' a clear framework should be established to ensure that the beneficiaries of a project share the responsibility for its costs. This could involve mechanisms for cost sharing or benefit-based funding arrangements.
- *Regulatory stability:* 'Changes in rules and regulations' emerged as a significant factor affecting cost overrun. Policymakers should work to provide regulatory stability and avoid frequent changes that can disrupt project planning and execution.
- *Robust scope management:* Recognizing the impact of 'scope changes' on cost overrun during the construction phase, project managers and policymakers should focus on robust

scope management practices. Well-defined and controlled scope changes can help mitigate unexpected cost increases.

- *Adaptive risk management:* Fluctuating market conditions and unforeseen events can impact project costs. Policymakers should encourage adaptive risk management strategies that account for external factors and adjust project plans accordingly.
- *Effective conflict resolution:* Given the significance of ‘conflicts between contractor and the owner,’ policymakers should encourage effective conflict resolution mechanisms between project stakeholders. Clear guidelines and dispute resolution procedures can prevent disputes from escalating and causing cost overruns.
- *Enhanced transparency and communication:* Effective communication and transparency between stakeholders, as highlighted by factors like ‘project optimism,’ ‘poor project management,’ and ‘lack of follow-up,’ are crucial. Policymakers should promote transparent reporting, regular updates, and open communication channels to ensure alignment and avoid misunderstandings. Also, Paper 2 highlights instances where poor coordination and communication among different stakeholders led to cost increases. This suggests a policy focus on promoting better collaboration and information sharing among relevant parties, such as project managers, local authorities, and decision-makers, to ensure that potential challenges are identified and addressed in a timely manner.
- *Improved cost management, resource allocation and prioritization:* the insights gained from this part of the study can aid policymakers and government agencies in prioritizing and allocating resources to road projects. By understanding the key factors contributing to cost inaccuracies, authorities can focus on addressing those factors early in the planning and construction stages, thereby reducing the likelihood of financial setbacks.
- *Integration of Ex-post analysis:* The study underscores the value of integrating tactical evaluation into project assessments, which considers the longer-term impacts of a project’s goals and outcomes. Policymakers could consider incorporating post-project evaluation periods to assess the effectiveness of a project in achieving its intended goals, such as safety improvements, accessibility enhancements, and overall societal benefits.

6.2.2. Leveraging Advanced Analytical Methods and Data-Driven Policies:

This group of policy implications draws from Papers 3 and 4 and emphasizes the adoption of advanced analytical methods, data-driven decision-making, and continuous learning to enhance cost prediction and resource allocation policies:

- *Integration of advanced analytical methods:* the successful application of advanced analytical methods, such as artificial neural networks (ANNs) and generative modeling, highlights the potential for integrating cutting-edge technologies into road project management. Policymakers and practitioners should explore the adoption of these methods to enhance accuracy in cost performance prediction and resource allocation.
- *Data-driven decision-making culture:* to promote effective decision-making in road infrastructure projects, there is a need to foster a data-driven culture among stakeholders. Governments, project owners, and industry players should prioritize data collection, sharing, and analysis, leveraging modern analytical tools for evidence-based planning and execution.
- *Capacity building and training, continuous learning and improvement:* the use of advanced methods calls for continuous learning and improvement. Governments and organizations should establish mechanisms for knowledge exchange, encourage the sharing of best practices, and support ongoing research to refine predictive models and enhance cost estimation accuracy.
- *Adoption of synthetic data generation:* the use of synthetic data to augment small datasets offers a practical solution for improving predictive modeling. Policymakers should explore the integration of synthetic data generation techniques into project planning processes, especially in contexts with limited data availability.
- *Long-term planning with predictive models:* the predictive models developed in the studies offer a valuable tool for long-term infrastructure planning. Policymakers can incorporate these models into their planning processes to ensure that future road projects are designed, funded, and executed with a focus on minimizing cost overruns.
- *Continued research and data collection:* this study emphasizes the importance of data quality and quantity for accurate predictions. Governments and organizations can invest

in ongoing data collection, sharing, and analysis to continually improve the accuracy and reliability of predictive models for cost performance.

6.3. Limitations

It is essential to be careful when generalizing findings from a study within a given context to other situations and contexts. This thesis is focused specifically on LSR projects in Norway, which means that the results should be applied with caution to such large-scale government-funded projects in other sectors, such as defense, construction, major public ICT projects, etc., or in other countries. More research should be done to examine project governance frameworks in other circumstances, such as smaller projects, projects in different countries or sectors, and under different governance schemes.

Some other potential limitations of this research include the following:

Limited data availability: There were challenges in obtaining access to all relevant data required for accurate cost performance prediction, which could limit the effectiveness of machine learning algorithms (in addition to previously discussed small sample size challenges).

Complex project dependencies: LSR projects often involve numerous stakeholders and interdependencies, making it difficult to predict costs accurately. While ML is believed to model complex relationships more accurately, it may still be that the methodologies may not fully capture all these complexities, potentially limiting the accuracy of predictions.

Within ML there is a concept known as ‘No Free Lunch’ theorem, wherein no absolute algorithm is found that works best for every problem. This means that in the context of this thesis, cost performance prediction for LSR projects in Norway, no single model or approach can be expected to provide optimal results in every situation. Therefore, it is important to consider a variety of factors such as the specific characteristics of the project, the available data, and the goals of the prediction model when selecting an appropriate approach.

While this research utilizes ML techniques which is a fast-growing and quickly evolving field, it is important to acknowledge that the author’s background is primarily in civil engineering, with limited but growing experience in computer science. Therefore, while the methodological decisions made in this study are grounded in a solid understanding of the underlying theory, there may still be limitations arising from a lack of extensive experience in applying these methods in practice.

6.4. Future work

Some potential directions for future work could include:

- Replicate this study on a more extensive and diverse sample of infrastructure projects in different contexts/countries to validate the findings and expand the generalizability of the model.
- Explore the potential of other machine learning algorithms and models, such as deep learning, convolutional neural networks, and support vector machines, for predicting the outcomes of infrastructure projects and comparing their performance to RBFNN-GP. This could also involve a review of current literature on the topic (as the literature is updating quickly) and further testing different models to determine which ones are most effective.
- Investigate the impact of external factors, such as political and economic instability, technological advancements, and social and environmental factors, on the performance of LSR projects, and incorporate these variables in the predictive models.
- • Examine techniques to minimize and improve the generalization performance, such as advanced transfer learning approaches that leverage knowledge from related fields or larger datasets to fine-tune models for specific contexts.
- Apply the insights gained from this study to develop further specific practical recommendations and guidelines for project managers, policymakers, and other stakeholders to improve the governance and management of infrastructure projects and enhance their economic, social, and environmental benefits.

6.5. Final remarks

Cost overruns and inefficient resource allocation are significant challenges faced by LSR projects. ML technologies can potentially improve cost performance prediction and cost management, especially for complex projects such as those found in Norway. However, caution should always be exercised when applying findings from case studies to other contexts, and more research is needed to explore the implementation of ML algorithms (e.g., RBFNN-GP, CTGAN, MLP) in different circumstances.

Overall, this study provides a valuable contribution to the field of road construction project management and provides insights for project managers and policymakers in the road infrastructure sector, by helping to improve cost estimation and management practices to ultimately deliver better outcomes for taxpayers, communities, and other stakeholders.

References

Abedi, M., et al. (2022). "GAN-Based Approaches for Generating Structured Data in the Medical Domain." Applied Sciences **12**(14): 7075.

Afzal, F., et al. (2021). "A review of artificial intelligence based risk assessment methods for capturing complexity-risk interdependencies: Cost overrun in construction projects." International Journal of Managing Projects in Business **14**(2): 300-328.

Al-Hazim, N. and Z. A. Salem (2015). "Delay and cost overrun in road construction projects in Jordan." International Journal of Engineering & Technology **4**(2): 288.

Anguera, R. (2006). "The Channel Tunnel—an ex post economic evaluation." Transportation Research Part A: Policy and Practice **40**(4): 291-315.

Barros, L. B., et al. (2018). "Construction cost estimation of Brazilian highways using artificial neural networks." International Journal of Structural and Civil Engineering Research **7**(3): 283-289.

Berechman, J. and Q. Wu (2006). Cost overruns risk analysis in transportation infrastructure investments, Phelps Centre for the Study of Government and Business, Sauder School of ….

Blanc-Brude, F., et al. (2006). "Ex ante construction costs in the European road sector: a comparison of public-private partnerships and traditional public procurement."

Blanc-Brude, F., et al. (2009). "A comparison of construction contract prices for traditionally procured roads and public–private partnerships." Review of Industrial Organization **35**(1): 19-40.

Bordat, C., et al. (2004). "An analysis of cost overruns and time delays of INDOT projects."

Bray, S., et al. (2014). "Features selection based on fuzzy entropy for Data Envelopment Analysis applied to transport systems." Transportation research procedia **3**: 602-610.

Bruzelius, N., et al. (2002). "Big decisions, big risks. Improving accountability in mega projects." Transport policy **9**(2): 143-154.

Cantarelli, C. C. (2011). "Cost overruns in large-scale transport infrastructure projects: A theoretical and empirical exploration for the Netherlands and worldwide."

Cantarelli, C. C., et al. (2012). "Geographical variation in project cost performance: the Netherlands versus worldwide." Journal of Transport Geography **24**: 324-331.

Cantarelli, C. C., et al. (2008). Cost overruns in large-scale transportation infrastructure projects: Which explanations can be given? 2008 First International Conference on Infrastructure Systems and Services: Building Networks for a Brighter Future (INFRA), IEEE.

Cantarelli, C. C., et al. (2012). "Characteristics of cost overruns for Dutch transport infrastructure projects and the importance of the decision to build and project phases." Transport policy **22**: 49-56.

Chapulut, J., et al. (2005). "The new ex-post evaluation methods for large projects in France." PROCEEDINGS OF ETC 2005, STRASBOURG, FRANCE 18-20 SEPTEMBER 2005-RESEARCH TO INFORM DECISION-MAKING IN TRANSPORT INNOVATIVE METHODS IN TRANSPORT ANALYSIS-PLANNING AND APPRAISAL-APPRAISAL I.

Cheng, L., et al. (2020). "Applying an ensemble-based model to travel choice behavior in travel demand forecasting under uncertainties." Transportation Letters **12**(6): 375-385.

CHEVROULET, T. and C. REYNAUD (2010). "Assessment of high speed rail projects: selection of European cases and recommendations from EVA-TREN research." Notes **4015**(4338): 8.

Chollet, F. (2017). Deep learning with Python, Simon and Schuster.

Cooper, D. R., et al. (2006). Business research methods, Mcgraw-hill New York.

Creedy, G. D., et al. (2010). "Evaluation of risk factors leading to cost overrun in delivery of highway construction projects." Journal of Construction Engineering and Management **136**(5): 528-537.

El-Kholy, A. (2021). "Exploring the best ANN model based on four paradigms to predict delay and cost overrun percentages of highway projects." International Journal of Construction Management **21**(7): 694-712.

Ellis Jr, R. D., et al. (2007). "Evaluation of alternative contracting techniques on FDOT construction projects."

Faludi, A. (1973). "The “systems view” and planning theory." Socio-Economic Planning Sciences **7**(1): 67-77.

Flyvbjerg, B. (2006). "Five misunderstandings about case-study research." Qualitative inquiry **12**(2): 219-245.

Flyvbjerg, B., et al. (2003). Megaprojects and risk: An anatomy of ambition, Cambridge university press.

Flyvbjerg, B., et al. (2003). "How common and how large are cost overruns in transport infrastructure projects?" Transport Reviews **23**(1): 71-88.

Fouracre, P., et al. (1990). The performance and impact of rail mass transit in developing countries.

Goodfellow, I., et al. (2014). "Generative adversarial nets." Advances in neural information processing systems **27**.

Gulrajani, I., et al. (2017). "Improved training of wasserstein gans." Advances in neural information processing systems **30**.

Gustafsson, J. (2017). Single case studies vs. multiple case studies: A comparative study.

Hall, P. (1982). Great planning disasters, University of California press.

Kahneman, D. and D. Lovallo (1993). "Timid choices and bold forecasts: A cognitive perspective on risk taking." Management science **39**(1): 17-31.

Kaliba, C., et al. (2009). "Cost escalation and schedule delays in road construction projects in Zambia." International journal of project management **27**(5): 522-531.

Klakegg, O. J. and G. H. Volden (2016). "Governance in public projects: the Norwegian case." Governance and governmentality for projects: Enablers, practices and consequences.

Larsen, J. K., et al. (2016). "Factors affecting schedule delay, cost overrun, and quality level in public construction projects." Journal of management in engineering **32**(1): 04015032.

Lee, J.-K. (2008). "Cost overrun and cause in Korean social overhead capital projects: Roads, rails, airports, and ports." Journal of Urban Planning and Development **134**(2): 59-62.

Lee, J. and O. Lee (2021). "Ctgan vs tgan? which one is more suitable for generating synthetic eeg data." Journal of Theoretical and Applied Information Technology **99**(10).

Lin, D. and X. Tang (2006). Conditional infomax learning: An integrated framework for feature extraction and fusion. European conference on computer vision, Springer.

Lipton, Z. C., et al. (2014). "Thresholding classifiers to maximize F1 score." arXiv preprint arXiv:1402.1892.

Love, P. E. and D. D. Ahiaga-Dagbui (2018). "Debunking fake news in a post-truth era: The plausible untruths of cost underestimation in transport infrastructure projects." Transportation Research Part A: Policy and Practice **113**: 357-368.

Love, P. E., et al. (2016). "Cost overruns in transportation infrastructure projects: Sowing the seeds for a probabilistic theory of causation." Transportation Research Part A: Policy and Practice **92**: 184-194.

Love, P. E., et al. (2011). "Moving beyond optimism bias and strategic misrepresentation: An explanation for social infrastructure project cost overruns." IEEE transactions on engineering management **59**(4): 560-571.

Lundberg, M., et al. (2011). Cost overruns in Swedish transport projects, Centre for Transport Studies Stockholm, Swedish National Road & Transport ….

Mahmud, A. T., et al. (2021). "Key driving factors of cost overrun in highway infrastructure projects in Nigeria: a context-based perspective." Journal of Engineering, Design and Technology.

Makovšek, D., et al. (2012). "A cost performance analysis of transport infrastructure construction in Slovenia." Transportation **39**(1): 197-214.

Memon, A. H., et al. (2011). "Preliminary study on causative factors leading to construction cost overrun." International Journal of Sustainable Construction Engineering and Technology **2**(1).

Merewitz, L. (1973). Cost overruns in public works, Institute of Urban & Regional Development, University of California.

Morris, P. (2013). "Reconstructing project management reprised: A knowledge perspective." Project Management Journal **44**(5): 6-23.

Morris, P. W. and J. Geraldi (2011). "Managing the institutional context for projects." Project Management Journal **42**(6): 20-32.

Morris, S. (1990). "Cost and time overruns in public sector projects." Economic and Political Weekly: M154-M168.

Müller, R., et al. (2016). Organizational enablers for project governance, Project Management Institute.

Naik, M. G. and V. Radhika (2015). "Time and cost analysis for highway road construction project using artificial neural networks." Journal of Construction Engineering and Project Management **5**(1): 26-31.

Nicolaisen, M. S. (2012). "Forecasts: fact or fiction?: Uncertainty and inaccuracy in transport project evaluation."

Nijkamp, P. and B. Ubbels (1999). "How reliable are estimates of infrastructure costs? A comparative analysis." International Journal of Transport Economics/Rivista internazionale di economia dei trasporti: 23-53.

Odeck, J. (2004). "Cost overruns in road construction—what are their sizes and determinants?" Transport policy **11**(1): 43-53.

Odeck, J. (2014). "Do reforms reduce the magnitudes of cost overruns in road projects? Statistical evidence from Norway." Transportation Research Part A: Policy and Practice **65**: 68-79.

Odeck, J. (2019). "Variation in cost overruns of transportation projects: An econometric meta-regression analysis of studies reported in the literature." Transportation **46**(4): 1345-1368.

Odeck, J., et al. (2010). "Economic appraisal of universal design in transport: Experiences from Norway." Research in Transportation Economics **29**(1): 304-311.

Odeck, J. and A. Kjerkreit (2019). "The accuracy of benefit-cost analyses (BCAs) in transportation: An ex-post evaluation of road projects." Transportation Research Part A: Policy and Practice **120**: 277-294.

Odeck, J. and T. Skjeseth (1995). "Assessing Norwegian toll roads." Transportation Quarterly **49**(2).

Odeck, J., et al. (2015). "The impact of external quality assurance of costs estimates on cost overruns: empirical evidence from the Norwegian road sector."

OECD, D. (2002). Evaluation and Aid Effectiveness, Glossary of Key Terms in Evaluation and Results Based Management, OECD, Development Assistance Committee.

Office, U. N. A. (2007). Estimating and monitoring the costs of building roads in England. Department for Transport. Audit report.

Park, Y. I. and T. C. Papadopoulou (2012). "Causes of cost overruns in transport infrastructure projects in Asia: their significance and relationship with project size." Built Environment Project and Asset Management.

Pickrell, D. H. (1992). "A desire named streetcar fantasy and fact in rail transit planning." Journal of the American Planning Association **58**(2): 158-176.

Pinheiro Catalão, F., et al. (2019). "Exogenous determinants of cost deviations and overruns in local infrastructure projects." Construction management and economics **37**(12): 697-711.

Pinsonneault, A. and K. Kraemer (1993). "Survey research methodology in management information systems: an assessment." Journal of management information systems **10**(2): 75-105.

Pinto, J. K. and D. P. Slevin (1988). Project success: definitions and measurement techniques, Project Management Institute Newton Square, PA.

PMI (2017). A guide to the project management body of knowledge (PMBOK® Guide). 6th ed.

Qu, S. Q. and J. Dumay (2011). "The qualitative research interview." Qualitative research in accounting & management.

Rajakumar, A. (2016). "Analysis of cost overrun in road construction activities–a critical." International Research Journal of Engineering and Technology (IRJET) **3**.

Rajan, T. A., et al. (2014). "PPPs and project overruns: evidence from road projects in India." Journal of Construction Engineering and Management **140**(5): 04013070.

Riksrevisionsverket (1994). Infrastrukturinvesteringar- en kostnadsjamforelse mellan plan och utfall i storre projekt inom Vagverket och Banverket. **23**.

Ringle, C. M., et al. (2010). Response-based segmentation using finite mixture partial least squares. Data Mining, Springer.

Rossi, P. H., et al. (1983). "Sample surveys: History, current practice, and future prospects." Handbook of survey research: 1-20.

Rouhi, A. and H. Nezamabadi-Pour (2020). "Feature selection in high-dimensional data." Optimization, Learning, and Control for Interdependent Complex Networks **1123**: 85.

Roxas, N. R. and S. Chalermpong (2008). Forecasting inaccuracies in transportation projects in selected South East Asian countries. Proceedings of the 16th Annual Conference of the Transportation Science Society of the Philippines, Pasay City, Philippines.

Rwakarehe, E. E. and D. A. Mfinanga (2014). "Effect of inadequate design on cost and time overrun of road construction projects in Tanzania." Journal of Construction Engineering and Project Management **4**(1): 15-28.

Sabri, O. K., et al. (2019). "Why conflicts occur in roads and tunnels projects in Norway." Journal of Civil Engineering and Management **25**(3): 252-264.

Samarghandi, H., et al. (2016). "Studying the Reasons for Delay and Cost Overrun in Construction Projects: The Case of Iran."

Samferdselsdepartementet (2012). Kvalitetssikring av prosjekt E6 Frya-Sjoa.

Samset, K. (2003). "Project evaluation." Making investments succeed, Trondheim, Tapir Akademisk Forlag.

Samset, K. and G. H. Volden (2017). "Quality Assurance in Megaproject Management: The Norwegian Way."

Samset, K. F. and G. H. Volden (2014). "Front end Governance of Major Public Projects-Lessons with a Norwegian Quality Assurance Scheme."

Siemiatycki, M. (2009). "Academics and auditors: Comparing perspectives on transportation project cost overruns." Journal of Planning Education and Research **29**(2): 142-156.

Siemiatycki, M. (2016). Cost overruns on infrastructure projects: Patterns, causes, and cures, Institute on Municipal Finance and Governance.

Singh, R. (2010). "Delays and cost overruns in infrastructure projects: extent, causes and remedies." Economic and Political Weekly: 43-54.

Situ, H. (2022). The Costs of Megaprojects: An Analysis of the Hong Kong-Zhuhai-Macau Bridge. Viterbi Conversations in Ethics, USC Viterbi School of Engineering. **6**.

Skamris, M. K. and B. Flyvbjerg (1997). "Inaccuracy of traffic forecasts and cost estimates on large transport projects." Transport policy **4**(3): 141-146.

Tijanić, K., et al. (2020). "Cost estimation in road construction using artificial neural network." Neural Computing and Applications **32**(13): 9343-9355.

Towne, L. and R. J. Shavelson (2002). Scientific research in education, National Academy Press Publications Sales Office.

ÜRESİN, U. (2021). "Correlation Based Regression Imputation (CBRI) Method for Missing Data Imputation." Turkish Journal of Science and Technology **16**(1): 39-46.

Van Wee, B. (2007). "Large infrastructure projects: a review of the quality of demand forecasts and cost estimations." Environment and Planning B: planning and design **34**(4): 611-625.

Vartabedian, R. (2021). Years of Delays, Billions in Overruns: The Dismal History of Big Infrastructure. The new York Times.

Vegvesen, S. (2012). E6 Ringebu - Otta kostnadsoverslag etter anslagsmetoden.

Vinzi, V. E., et al. (2010). PLS path modeling: from foundations to recent developments and open issues for model assessment and improvement. Handbook of partial least squares, Springer**:** 47-82.

Volden, G. H. (2018). "Public project success as seen in a broad perspective.: Lessons from a meta-evaluation of 20 infrastructure projects in Norway." Evaluation and program planning **69**: 109-117.

Volden, G. H. (2019). "Up-Front Governance of Major Public Investment Projects."

Wachs, M. (1982). "Ethical Dilemmas in Forecasting for Public Policy." Public Administration Review(42): 557-562.

Welde, M. (2017). Kostnadskontroll i store statlige investeringer underlagt ordningen med ekstern kvalitetssikring, Ex ante akademisk forlag.

Welde, M. (2018). "In search of success: Ex-post evaluation of a Norwegian motorway project." Case Studies on Transport Policy **6**(4): 475-482.

Welde, M. and J. Odeck (2017). "Cost escalations in the front-end of projects–empirical evidence from Norwegian road projects." Transport Reviews **37**(5): 612-630.

Wu, Q. (2006). Transportation infrastructure project cost overrun risk analysis: risk factor analysis models, University of British Columbia.

Xu, L., et al. (2019). "Modeling tabular data using conditional gan." arXiv preprint arXiv:1907.00503.

Yang, Y., et al. (2022). "A novel radial basis function neural network with high generalization performance for nonlinear process modelling." Processes **10**(1): 140.

Yin, R. K. and D. Davis (2007). "Adding new dimensions to case study evaluations: The case of evaluating comprehensive reforms." New directions for evaluation **2007**(113): 75-93.

Appendices

Appendix A:

Paper 1

sustainability

MDPI

Article

Sustainable Project Management: Reducing the Risk of Cost Inaccuracy Using a PLS-SEM Approach

Ali Foroutan Mirhosseini [1,2,*], Kelly Pitera [1], James Odeck [1,3] and Morten Welde [1]

1 Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, 7491 Trondheim, Norway; kelly.pitera@ntnu.no (K.P.); James.odeck@ntnu.no (J.O.); Morten.welde@ntnu.no (M.W.)
2 Norwegian Public Roads Administration, 7075 Tiller, Norway
3 Norwegian Public Roads Administration, 0609 Oslo, Norway
* Correspondence: Ali.mirhosseini@ntnu.no; Tel.: +47-45869767

Abstract: Determining the factors leading to cost inaccuracy in infrastructure projects relates to sustainability by improving the cost performance of the projects (economic sustainability) and reducing the waste of available resources (environmental sustainability). This study investigates the effects of various factors affecting the cost performance of large-scale road projects in Norway in both the planning and construction phases. To this aim, a quantitative approach using a questionnaire survey was employed to understand the attitude of practitioners towards various factors causing cost increases. An advanced multivariate statistical approach of Partial Least Square Structural Equation Modeling (PLS-SEM) and Relative Importance Index (RII) was utilized to analyze the questionnaire responses. The results of the RII analysis show that local wishes, defective estimations, and long processing times had the most impact on the cost increase during the planning phase. At the same time, scope changes, market conditions, and unforeseen ground conditions were the most influential parameters in the construction phase. Moreover, the results obtained from PLS-SEM reveal that external related factors had the most influence among the other grouped factors (i.e., pre-construction, project management and contractual relationship, contractor's site management, and external) on cost overrun during the construction phase. Increasing the knowledge of these factors will allow for developing relevant project management approaches targeted at improving economic and environmental sustainability within both the planning and construction phases.

Keywords: cost overrun; PLS-SEM; project management; sustainability; Norway

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1. Introduction

Transportation infrastructure is a key element in the development of countries, and the demand for such infrastructure is increasing, while the economic and material resources available are diminishing. Recently, increased attention has been paid to needs analysis, planning procedures, budget allocation, and the performance of projects to make sure that the right projects are selected for implementation, and that the projects are delivered in a sustainable and efficient way.

1.1. Problem Statement

Sustainability continues to attract considerable attention in many domains, including project management. Sustainability stands on the three pillars (i.e., social, environmental, economic) of the well-known "three P" concept (People, Planet, Profit), which are interrelated and affect each other [1]. To relate sustainability to project management, one should consider aspects that can be addressed by sustainability considerations, including human resources management, procurement, communications, and risk management [1]. As sustainability in the field of project management has developed, economic sustainability is now being interpreted as a success factor in projects [1,2].

While economic sustainability is a concern within infrastructure project management, most transportation projects are not monetarily profitable alone, and are often undertaken for additional political and/or social reasons [3]. In addition, many large infrastructure projects around the world are not completed within their cost- or timeframe, further exacerbating cost efficiency problems. The weak cost performance of a project can be considered as a failure in project management, since traditionally project success has been linked to high efficiency in the three main aspects of scope, time, and cost, known as *the golden triangle* [4]. Therefore, determining and eliminating the risk factors that reduce efficiency in any of the mentioned aspects (risk factors) can significantly improve the level of project success [5,6], and thus improve economic sustainability.

1.2. Knowledge Gap

The literature in the field of cost overrun/cost performance of infrastructure projects has been primarily focused on the construction phase and on project-specific factors, which can affect the cost performance of the project during the construction phase, including project size, project type (e.g., road, rail, etc.), project completion time length, the geographical area in which project is constructed, etc. [1–5,7–9]. However, while less studied, aspects of the planning phase are also suggested to significantly affect cost inaccuracies in project governance [4]. During the planning phase, many factors can affect the project idea, and the direction in which the project concept evolves. Consequently, initial scope and cost estimations may change and escalate, respectively. Odeck believes cost escalation during the planning phase can be even higher than that of the construction phase [9]. Moreover, factors affecting cost performance during the planning phase may indirectly affect the construction phase. Thus, further research into planning phase factors and their relevance to the overall cost performance of the infrastructure projects contributes to the body of literature on cost efficiency and economic sustainability within project governance.

1.3. Research Aim

Cost inaccuracy poses a risk to the sustainable implementation of infrastructure projects. Therefore, determining the parameters affecting cost accuracy will not only improve the cost performance of the project and result in economically sustainable project management, but can also result in the better use of resources and thus further preservation of the environment [1,5,6].

The aim of this paper, therefore, can be expressed in two main research questions:

1. What are the main factors affecting cost inaccuracy during the planning and construction phases?
2. How can different groups of risk factors (constructs) affect cost inaccuracies during the construction phase?

The importance of this study is that the Norwegian Public Roads Administration (NPRA) has reformed and revised the structure of planning and surveillance in the planning process of the large-scale road projects from 2000 in order to curb cost overruns. Hence, this study gives insight into the current challenges in the planning and construction of large-scale road projects, and helps the NPRA to both evaluate the efficiency of the modified program and improve the current system. This is particularly relevant given that recently, the sustainable development of projects has become one of the top goals of the NPRA [7]. The data were gathered via questionnaires, and based on the obtained results, factors in both planning and construction stages were ranked according to their importance. The influential factors in the construction phase were categorized into four main constructs (i.e., external, contractor's site management, pre-planning, and project management and contractual relationship). A full model for cost increase was constructed and empirically validated using the PLS-SEM approach. Studies that have examined the causes of cost increase using the PLS-SEM methodology are scant in the literature. Evaluating these factors can present the current challenges in cost performance evaluation in a larger aggregated picture. It is important to note that this type of study should be done in individual countries, as using international results may create the risk of fallacies in the interpretation of statistical data. However, the methodology used in this study is still valid for similar studies worldwide, and the results can inform the development of other studies.

1.4. Organization of the Paper

The rest of this paper is organized as follows: Section 2 gives an overview on the concept of cost overrun and the relevant studies; Section 3 describes the methodology of the paper, including the main factors affecting cost increase and overrun in the planning and construction phases, respectively, as well as data collection, and describes the concept and the methods used to analyze and interpret the data; Section 4 presents and synthesizes the results. Section 5 discusses the obtained results, and finally, Section 6 summarizes the study's conclusions within the context of the field.

2. Literature Review

The positive difference between actual costs minus estimated costs (in net present value) within the construction phase is called cost overrun. The difference between actual costs and estimated costs can be expressed as a percentage of estimated costs, and is called percentage cost overrun [8–11]. There is a variety of research addressing the issue of cost overruns. Early studies concentrated on the prevalence, magnitude, and percentage of cost overrun [12–15]. Despite differences in their findings, which could be attributed to several factors including geographical area, type of the project, sample size, use of nominal or real prices, methods of calculation, and considering different moments for estimated and actual costs, almost all the studies agree that cost overrun is prevalent, but the magnitude varies from one project to another [8]. Later, studies aimed to focus on the causes and explanations of cost overrun, in addition to the magnitude and the percentage of cost overrun [16–19]. A study within this group by Cantarelli et al. [20] categorized the explanations for cost overrun into four main categories: technical, economical, psychological, and political. Other research has evaluated the causes of/factors affecting cost overrun using questionnaires or surveys. These studies are primarily case-specific/individual, and are limited to a specific country/region [21,22]. However, there is a lack of studies on the identification of root causes of overruns within specific countries. As mentioned, most of the studies have either evaluated cost overrun in large sample sizes around the world, or focused on the magnitude and determinants of cost overrun. Evaluating the causes of cost overrun within specific countries can give a better understanding of the current situation of the project governance and cost performance of the projects. Moreover, since the results of one specific country may not be applicable for other countries, carrying out case study research within specific countries may provide valuable knowledge for organizations responsible for the planning, estimation, and delivery of large projects.

On the other hand, the literature indicates that significant cost increases often occur during the planning phase; thus, to gain a better understanding of a project's cost performance, early planning phases must be taken into consideration [19,20,23]. Cost overrun in the planning phase is commonly considered a "cost increase" or "cost escalation". When the cost estimates are not precise, the wrong project may be decided upon, and later managing the project, especially large-scale projects, will be difficult, likely leading to cost overruns [24]. However, if estimations are accurate and the actual costs are known to the decision-makers, they may choose more profitable projects, modify the current proposal, or invest the budget elsewhere [15]. For instance, Welde and Odeck [23] found that cost estimates used in final investment decisions have gotten more accurate in the past decade in Norway. However, the estimates in the planning stages have been significantly underestimated. They largely suggest that project governance and the role of project ownership should be improved, cost–benefit and ex-post evaluations should be increased, and in general, cost estimations in the planning stages should be further investigated. Therefore, it can be inferred that unlike cost overrun during the construction phase, research on the most important causes of cost increase in the planning phase is scant.

3. Methodology

3.1. Identifying the Causes of Cost Overrun in the Construction Phase

Within this study, it was necessary to identify potential causes of both cost increase and cost overrun, to be used within the questionnaire. A comprehensive literature review was carried out to identify the major factors affecting cost overrun during the construction phase. The thirty most common and frequently occurring causes are presented in Table 1. In addition, the two additional factors of project size (budget) and length of the road were added to the initial factors, according to the author's experience and previous studies, resulting in 32 factors considered in the study.

3.2. Identifying the Causes of Cost Increase in the Planning Phase

As there is less existing research on overruns within the planning phase, the identification of potential causes affecting cost increase was carried out through both literature reviews and also two explorative semi-structured interviews with two project teams responsible for implementing two large-scale (budgets more than EUR 75 million) road projects in Norway. The semi-structured interviews identified 18 different causes affecting cost increase during the planning phase, as presented in Table 2. QA1 and QA2 (as seen in the table) indicate two different steps in the Quality Assurance regime introduced and financed by the Ministry of Finance for planning, financing, and implementing large public projects. The main goals of the QA process are to ensure that projects result in more benefits, lower overruns, and improved performance [23].

Table 1. Thirty factors affecting cost overrun in the construction phase (from literature review, without two additional complementary parameters).

Factor	Study														
	[25]	[26]	[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]	[35]	[36]	[37]	[38]	[39]
1- Insufficient site management and inspection	•	•		•				•	•		•	•	•		
2- Forecasting erx7rors (e.g. increasing prices)		•												•	
3- Poor project design	•	•		•				•		•		•	•		•
4- Scope changes			•	•	•		•	•	•				•	•	•
5- Labor Unavailability or lack of skilled labor		•	•	•			•		•		•				
6- Improper scheduling	•	•	•	•											
7- Lack of experience (in handling such projects)	•	•	•			•		•		•	•	•	•	•	•
8- Effect of bad weather (climate)	•	•	•	•	•	•			•	•	•	•	•	•	•
9- Unforeseen ground conditions	•							•	•		•				
10- Delay in progress payment by the owner	•	•			•		•	•	•	•	•		•	•	
11- Poor in-site financial control			•									•	•		
12- Low labor productivity		•			•					•	•	•		•	
13- Changes in material types and specifications	•	•				•	•		•	•		•			•
14- Poor project management	•		•	•	•						•		•		
15- Delays in decision-making	•	•				•	•	•	•	•	•	•	•		•
16- Market conditions		•	•		•	•	•	•		•			•	•	•
17- Inefficient use of resources		•		•	•				•			•			
18- Rework due to poor material quality	•		•	•	•	•	•			•	•	•			•
19- Strategic behavior (deliberate behavior)	•	•		•			•		•			•			•
20- Deliberate underestimation of costs	•		•	•				•				•			•
21- Lack of incentives			•				•	•	•					•	
22- Inadequate planning process	•	•	•	•	•		•		•	•	•	•	•		•

Table 1. *Cont.*

Factor	Study														
	[25]	[26]	[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]	[35]	[36]	[37]	[38]	[39]
23- Lack of resources	•				•										
24- Inefficient organizational structure			•			•		•		•	•	•	•		•
25- Monopolization of special equipment		•			•				•		•			•	
26- Lack of/Slow communication between parties	•			•	•	•	•	•		•	•	•	•		•
27- Contractual claims (cost or time extension)			•	•							•				•
28- Terrain condition	•	•				•	•			•		•	•	•	
29- Land and property acquisition challenges		•	•					•			•				•
30- Conflicts between contractor and the owner	•		•	•	•	•		•	•	•	•	•	•	•	•

Table 2. Factors affecting cost increase in the planning phase.

Num.	Factor
1	Local wishes without cost responsibility
2	Defective estimation
3	Long processing time
4	Those who get the benefit are not the ones who pay
5	Changes in rules and regulations
6	Project optimism
7	Poor project management
8	Lack of follow-up
9	Changes in the society expectations
10	City projects are detailed and costly to estimate
11	Different degrees of maturity before QA1
12	Cost increases from QA1 to QA2 have no consequences
13	Technological development
14	Weak incentives to reduce planning time
15	Little transparency
16	"Value for money" is of little importance
17	Increased funding hides cost growth
18	Changed/different staffing

3.3. Data Collection

Questionnaire surveys are among the best means of obtaining information from individuals about themselves or something they belong to or are involved in [40]. In this study, a structured questionnaire survey was utilized for data collection, including three main parts: (1) demographics related to professional experience, (2) defining the importance of factors affecting the cost increase in the planning phase (planning factors (PF)), and (3) defining the importance of factors affecting the cost overrun in the construction phase (construction factors (CF)). The early stages of planning (i.e., the planning phase) include problem determination, recognition of the concept, rough cost estimations, and initial planning until the moment of formal decision-making. The construction phase is from the moment of decision-making and budget allocation until the project is finished and is opened for service. The survey was distributed among owners, contractors, consultants, researchers, and project economists working within the transport infrastructure throughout Norway. Respondents were asked to answer the survey only if they were involved in at least one large-scale road project in their career and were able to consider project-specific factors. A total of 119 surveys were sent by e-mail, and 33 completed survey sets were received back and considered for further analysis, indicating a response rate of 28%.

Figure 1 presents the valid responses according to sector, region, years of experience, and profession. As seen, 62% of the respondents were from the public sector, which owns and maintains the roads in the whole road network in Norway. Half of the respondents are from the East region of the country, which together with the West constitute 67% of the responses. This was expected, since these two regions are densely populated and comprise almost 70% of the population. All the respondents have had more than 5 years' experience, and 63% have more than 15 years. Finally, consultants, researchers, and project leaders were the main three groups of respondents, while no contractors or project economists responded to the survey.

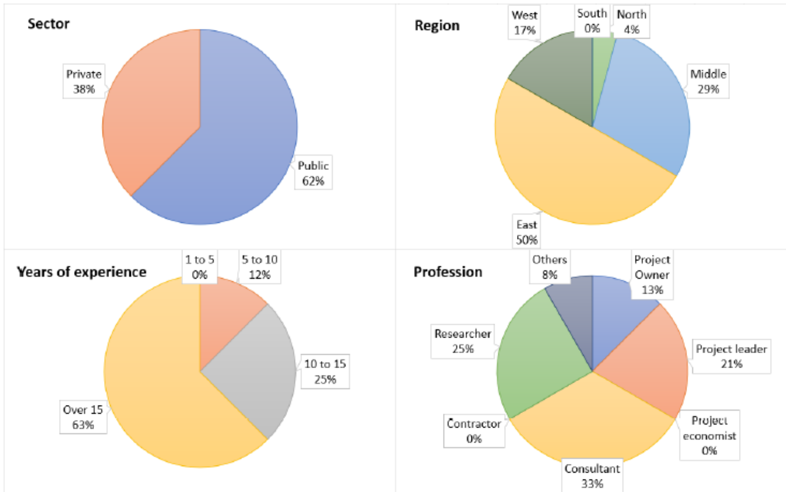

Figure 1. Categorization of respondents (N = 33) by sector, region, years of experience, and profession.

3.4. Data Analysis

As mentioned before, the survey considers cost increase/overrun factors for both planning and construction phases (18 and 32 factors, respectively), which were collected from a literature review and in-depth interviews. The respondents were asked to give their opinion regarding the impact of each factor on cost increase/overrun by choosing the correspondent number from a five-point Likert scale, where 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, and 5 = strongly agree (that the factor impacted project increases/overruns).

In order to analyze the data obtained from the received surveys, SPSS version 25.0 was first utilized to process the descriptive statistics and perform a reliability analysis on the collected data, and to examine the internal consistency of the survey (e.g., PFs and CFs). Internal consistency reliability is a means to assess how well a survey is designed and thus measures what is intended. Cronbach's coefficient α, which is explained below, is one of the most accepted measures for determining the consistency level of the survey [41]. After measuring the consistency of the survey to be acceptable, the Relative Importance Index (RII) was utilized to determine the importance of PFs and CFs in a range of 0.0–1.0, where an RII value closer to 1 indicates higher importance [30]. The RII is calculated as follows:

$$RII = \frac{\sum_{i=1}^{5} W_i}{A \times N} \quad (1)$$

where W is the weight given to each factor by respondents, A is the highest weight (5), and N is the total number of respondents.

After this, the construction phase was analyzed in more detail. Construction factors or factors affecting cost increase during the construction phase (CFs) were categorized into four main constructs, including Contractor's Site Management (SM), Pre-construction Phase (PC), External (EX), Project Management and Contractual Relationship (PM), as seen in Table 3. They were then coded for further analysis [41,42]. The main reason for doing so was to evaluate the impact of each group of factors in an aggregated way, which can give a better understanding of the larger issues of cost overrun in the construction phase, thus identifying areas for further study. Categorization of the factors was carried out based on the literature review and the author's knowledge.

Table 3. Causes of cost overrun during the construction phase.

Construct	Abbreviation	Description
External	EX1	Labor unavailability or lack of skilled labor
	EX2	Effect of bad weather (climate)
	EX3	Unforeseen ground conditions
	EX4	Market conditions
	EX5	Lack of resources
	EX6	Monopolization of special equipment
	EX7	Terrain condition
	EX8	Length of the road
	EX9	Project size
Pre-construction Phase	PC1	Forecasting errors (e.g., increasing prices)
	PC2	Delays in decision-making
	PC3	Strategic behavior (deliberate behavior)
	PC4	Deliberate underestimation of costs
	PC5	Inadequate planning process
	PC6	Land and property acquisition challenges
Project Management and Contractual Relationship	PM1	Poor project design
	PM2	Scope changes
	PM3	Improper scheduling
	PM4	Delay in progress payment by the owner
	PM5	Changes in material types and specifications
	PM6	Poor project management
	PM8	Lack of/slow communication between parties
	PM9	Contractual claims (cost or time extension)
	PM10	Conflicts between contractor and the owner
Contractor's Site Management	SM1	Insufficient site management and inspection
	SM2	Lack of experience (in handling such projects)
	SM3	Poor on-site financial control
	SM4	Low labor productivity
	SM5	Inefficient organizational structure
	SM5	Inefficient use of resources
	SM6	Rework due to poor material quality
	SM7	Lack of incentives

Within the further consideration of the construction phase, Convergent Validity (CV), which is a measure for determining the internal consistency of the CFs' constructs, was determined using Cronbach's coefficient α, Composite Reliability (CR) scores, and Average Variance Extracted (AVE) [41,43,44]. Cronbach's α is a reliability measure for the data, and CR is a measure that determines to what extent a construct is measured by its assigned indicators. They both are used to determine the internal consistency of the constructs, and the difference is that Cronbach's α does not consider factor loading and weighs all the items equally. In contrast, CR considers the item loadings within the theoretical model [41]. It is usually recommended that both Cronbach's α and CR be higher than 0.7 for a highly internally consistent construct. AVE is another measure for determining internal consistency, which is a measure of the amount of variance that is captured by a construct in relation to the amount of variance due to measurement error. As a rule of thumb, AVE should be higher than 0.5 [41,42,45]. This indicates that the latent variables capture more than 50% of measurement variance.

Structural Equation Modeling (SEM) was first considered to determine the perceived impact of CF constructs on cost overrun [41,46]. Thus, prior to the application of SEM, a theoretical model is required to determine the relationship of the CF constructs to the cost overrun. The theoretical model is presented in Figure 2, showing both the factors and associated constructs. Each factor in each construct is coded and identified as an indicator that relates to the correspondent construct or "latent variable" with an arrow. The direction of the arrow being outwards from the constructs indicates that they are reflective, since a change in one single indicator (factor) does not affect other indicators, and they (indicators) are highly correlated and essentially interchangeable. At the same time, constructs (latent variables) are essential to cost overrun, since omitting one indicator means omitting one part of the construct, while they are all contributing to cost overrun [47]. This means that the contribution of each of the constructs to the total overrun will be determined, and the reflection (loading) of the four main constructs will be assigned to the corresponding factors. The model presented in Figure 2 measures the direct and indirect relationships between the four constructs and the overall cost overrun.

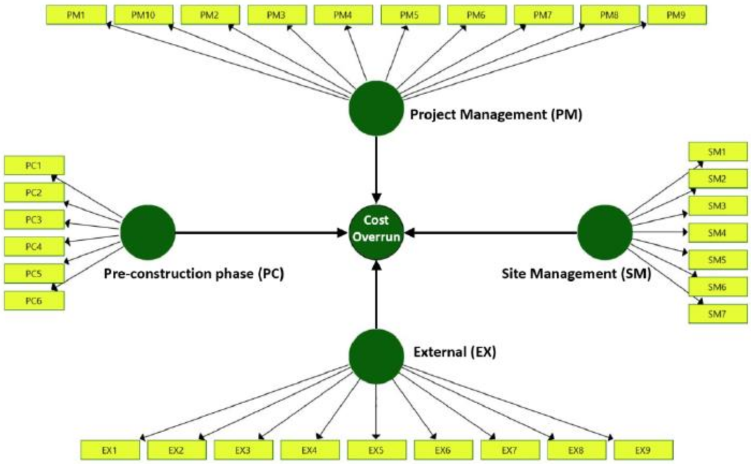

Figure 2. Theoretical model for determining factors affecting cost overrun.

Due to the small sample size and simplicity of the model, the Partial Least Squares method (PLS-SEM) was selected to analyze the data using SmartPLS version 3.0. PLS is a widely used method for estimating path coefficients in structural models, and is becoming significantly popular in management in recent years. Adopting a PLS approach to SEM has been recently recommended, and considered the most suitable method for examining causal relationships in the presence of constructs [41,45]. In addition, it has been demonstrated that SEM has better functionality than other multivariate techniques, including multiple regression, path analysis, and factor analysis [41,45,46]. One of the main advantages of PLS is its modeling ability for latent constructs under conditions of non-normality, and that it is practical for small to medium sample sizes [46,48].

4. Results

4.1. Ranking of the Factors Affecting Cost Increase in the Planning Phase (PFs)

This section presents the analysis of the results obtained from the respondents' attitudes towards the most influential parameters affecting cost increase in the planning phase. Prior to the RII analysis, reliability analysis was carried out, and Cronbach's α was determined to be 0.76, indicating acceptable consistency. In addition, the Mahalanobis test identified no potential outliers. Table 4 shows the results obtained from RII analysis, as well as the mean and standard deviation. The factors are ranked according to RII, which gives the same ranking as if sorted by mean. However, RII, which is simply a scaled mean score for an item, is a more precise criterion to evaluate the importance of the factors.

Table 4. Ranking of the most important parameters affecting cost increase in the planning phase (PFs).

Rank	Factor	RII	Mean	Std. Deviation
1	Local wishes without cost responsibility	0.818	4.0606	0.7044
2	Defective estimation	0.794	3.9697	1.1035
3	Long processing time	0.727	3.5455	1.1481
4	Those who get the benefit are not the ones who pay	0.709	3.5455	1.0335
4	Changes in rules and regulations	0.709	3.4545	1.0335
5	Project optimism	0.697	3.4242	0.9364
5	Poor project management	0.697	3.4242	1.1734
5	Lack of follow-up	0.697	3.3939	1.1163
6	Changes in the society expectations	0.661	3.2121	1.0828
7	City projects are detailed and costly to estimate	0.655	3.1818	1.2613
8	Different degrees of maturity before projects become the subject of QA1	0.642	3.1515	0.8704
9	Cost increases from QA1 to QA2 have no consequences	0.588	2.9091	0.9139
9	Technological development	0.588	2.8485	1.0642
10	Weak incentives to reduce planning time	0.576	2.8485	0.7124
11	Little transparency	0.558	2.7879	0.8572
12	Socio-economic profitability is of little importance	0.552	2.7576	0.8671
12	Increased funding hides cost growth	0.552	2.6970	0.9838
13	Changed/different staffing	0.473	2.3333	0.8165

The results show that the parameter *local wishes without cost responsibility* was ranked as the most important cost increase factor, with the RII value of 0.818. Next, *defective estimation* and *long processing time* are placed as the second and third, with RII values of 0.794 and 0.727, respectively. These are followed by *those who get the benefit are not the ones who pay* and *changes in rules and regulations* as the fourth most important factors, with an RII value of 0.709.

Project optimism together with *poor project management* and *lack of follow-up* were ranked as the fifth factor, with an RII value of 0.697, and *changes in society expectations* was ranked as the sixth factor.

The factors *changed/different staffing*, *increased funding hides cost growth*, *more value for money is of little importance*, and *little transparency* were determined to be the four least influential factors, with the RII values of 0.473, 0.552, 0.552 and 0.558, respectively. This is perhaps reflective of adjustments to quality assurance protocols since 'increasing the socio-economic profitability' and 'increasing transparency' were among the main objectives of the quality assurance regime in Norway.

4.2. Ranking of the Factors in the Construction Phase (CFs)

Similar to the planning phase, respondents' attitudes towards the most influential parameters affecting cost overrun in the construction phase were analyzed. Considering the reliability of the factors, Cronbach's α was measured to be 0.93. Data were assessed for multivariate outliers using a Mahalanobis Distance Test, and no multivariate outliers were identified [49]. The results of RII analysis for the CFs are presented in Table 5. *Scope changes* was determined to be the most important factor affecting cost overrun during the construction phase, with an RII value of 0.842. The value of RII for *market conditions* was calculated to be 0.818, as the second most important factor, followed by *unforeseen ground conditions* with an RII value of 0.806.

On the contrary, *delay in progress payment by the owner*, *deliberate underestimation of costs*, and *monopolization of special equipment* were listed as the least influential factors on cost overrun, with RII values of 0.412, 0.442, and 0.455 respectively.

Table 5. Ranking of the most important parameters affecting cost overrun in the construction phase (CFs).

Rank	Factor	Description	RII	Mean	Std. Deviation
1	PM2	Scope changes	0.842	4.212	0.820
2	EX4	Market conditions	0.818	4.091	1.011
3	EX3	Unforeseen ground conditions	0.806	4.030	0.847
4	PM10	Conflicts between contractor and the owner	0.752	3.758	0.751
5	PC1	Forecasting errors (e.g., increasing prices)	0.739	3.697	0.810
6	PM9	Contractual claims (cost or time extension)	0.697	3.485	0.939
7	PC2	Delays in decision-making	0.691	3.455	0.938
7	PC5	Inadequate planning process	0.691	3.455	0.971
8	SM1	Insufficient site management and inspection	0.648	3.242	0.969
8	EX9	Project size	0.648	3.242	1.032
9	PM3	Improper scheduling	0.636	3.182	0.882
10	PM6	Poor project management	0.624	2.758	0.663
10	PM8	Lack of/slow communication between parties	0.624	3.121	0.960
10	EX7	Terrain condition	0.624	3.121	0.960
11	SM2	Lack of experience (in handling such projects)	0.600	3.000	0.559
12	EX8	Length of the road	0.588	2.939	1.171
13	SM7	Lack of incentives	0.582	2.909	0.843
13	PC6	Land and property acquisition challenges	0.582	2.909	0.980
14	SM5	Inefficient organizational structure	0.570	2.848	0.870
15	SM6	Rework due to poor material quality	0.558	2.788	0.992
16	PM1	Poor project design	0.552	2.758	0.663
16	PM5	Changes in materials types and specifications	0.552	2.758	1.119
17	EX2	Effect of bad weather (climate)	0.527	2.636	1.113
18	EX1	Labor unavailability or lack of skilled labor	0.521	2.606	0.704
19	SM3	Poor on-site financial control	0.515	2.576	0.936
19	EX5	Lack of resources	0.515	2.576	1.062
20	SM5	Inefficient use of resources	0.503	2.515	0.870
21	PC3	Strategic behavior (deliberate behavior)	0.497	2.485	1.004
22	SM4	Low labor productivity	0.485	2.424	1.062
23	EX6	Monopolization of special equipment	0.455	2.273	1.008
24	PC4	Deliberate underestimation of costs	0.442	2.212	1.193
25	PM4	Delay in progress payment by the owner	0.412	2.061	0.827

4.3. Structural Relationship Model for CF Constructs

The theoretical model (SEM-based), which was developed to determine the relevance of each of the main constructs (categorized CFs) to cost overrun, and the results are presented in this section. As stated before, the CFs were categorized into four main constructs:

(i) External—factors that are not under full control of project organization, such as the effect of bad weather and market conditions;

(ii) Pre-construction—factors mainly related to the planning or, more generally speaking, pre-construction phase, but their impact is revealed in the construction phase and affects the project's cost performance;

(iii) Project Management and Contractual Relationship—human-related factors that can barricade the smooth and stable process of the project;

(iiii) Contractor's Site Management—challenges related to financing, scheduling, supervising, or the problems derived from changing requirements.

The above-mentioned constructs were modeled in SmartPLS, and their relationship with cost overrun was measured. First, the internal consistency reliability of the model was tested by measuring Cronbach's alpha and Composite Reliability (CR). In addition, the convergent validity of the model was tested through assessing factor loadings and Average Variance Extracted (AVE). Item loadings for all the 32 factors are presented in Table 6. The minimum values of item loading range between 0.5 and 0.7. A value of 0.6 was used as the threshold, and only EX4, SM2, and SM7 had loading factors lower than 0.6 (0.583, 0.469, and 0.353, respectively) [41,45,48]. EX4 was kept since the loading factor was very close to 0.6, and SM7, with the lowest loading factor, was deleted from further analysis. In the second round, it was observed that the deletion of SM7 resulted in a negligible increase in SM2′s loading factor. However, as this was still below the threshold, SM2 was also removed from further analysis.

Table 6. Reliability and convergent validity of the constructs.

Factor	Iteration 1				Iteration 2				Iteration 3			
	Loading	Alpha	CR	AVE	Loading	Alpha	CR	AVE	Loading	Alpha	CR	AVE
EX1	0.735	0.785	0.834	0.581	0.735	0.785	0.834	0.581	0.735	0.785	0.834	0.581
EX2	0.83				0.83				0.83			
EX3	0.802				0.802				0.802			
EX4	0.583				0.583				0.583			
EX5	0.688				0.688				0.688			
EX6	0.774				0.774				0.774			
EX7	0.787				0.787				0.787			
EX8	0.726				0.726				0.726			
EX9	0.866				0.866				0.866			
PC1	0.877	0.82	0.87	0.729	0.877	0.82	0.87	0.729	0.877	0.82	0.87	0.729
PC2	0.751				0.751				0.751			
PC3	0.763				0.763				0.763			
PC4	0.697				0.697				0.697			
PC5	0.781				0.781				0.781			
PC6	0.726				0.726				0.726			
PM1	0.725	0.784	0.839	0.556	0.725	0.784	0.839	0.556	0.725	0.784	0.839	0.556
PM10	0.679				0.679				0.679			
PM2	0.694				0.694				0.694			
PM3	0.791				0.791				0.791			
PM4	0.811				0.811				0.811			
PM5	0.808				0.808				0.808			
PM6	0.826				0.826				0.826			
PM7	0.788				0.788				0.788			
PM8	0.762				0.762				0.762			
PM9	0.732				0.732				0.732			
SM1	0.813	0.671	0.794	0.452	0.804	0.728	0.812	0.502	0.826	0.742	0.828	0.568
SM2	0.469				0.493				Omitted			
SM3	0.874				0.896				0.869			
SM4	0.755				0.791				0.784			
SM5	0.727				0.786				0.831			
SM6	0.722				0.757				0.845			
SM7	0.353				Omitted				Omitted			

Regarding Table 6, it can be observed that all AVE values, which are used to measure the common variance in a given construct, are higher than the recommended value of 0.5, ranging from 0.556 to 0.729 [48]. Moreover, CR values, which describe the degree to which the construct factors indicate the latent construct, were observed to be higher than the recommended value of 0.7 [46,48]. Thereafter, discriminant validity was checked, and the AVE value of each construct was found to be larger than its corresponding correlation coefficients [46,50].

The structural relationship model determines the direct and indirect relationships of each construct to cost overrun using regression coefficients R^2 and β, as presented in Figure 3. Moreover, the bootstrap procedure examined the significance of β values in indirect relationships among the constructs. However, due to the simplicity of the model used in this study and given that the constructs are directly related to the overall cost overrun, only direct relationships were measured in the model fit [41,46]. According to previous studies [45,46,48], the path relationships are assumed to be significant at

10%, 5%, and 1% significance levels, while the *t*-values are higher than 1.65, 1.96, and 2.57, respectively. In particular, the percentage of model variance extraction is shown by R^2, while path coefficients (β) indicate the strength of the relationships between the constructs [41,45]. This means that the values of path coefficients shown in Figure 3 indicate the impact of each construct on cost overrun.

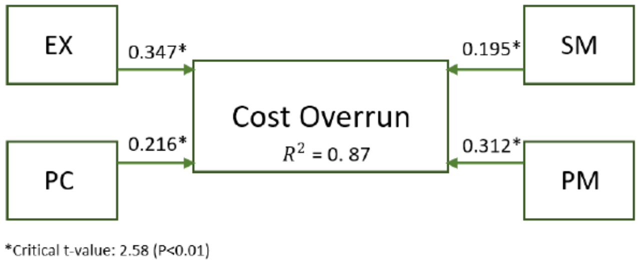

Figure 3. Results of the structural model.

As shown in Figure 3, R^2 is determined to be 0.87—higher than 0.26, which Cohen [51] believes indicates substantial explaining power. Regarding the path coefficients, it can be observed that all the constructs positively affected cost overrun, but they share different variance values. For instance, the construct EX has β = 0.347, which means this construct significantly affects cost overrun compared to the others by explaining 34.7% of the variance in cost overrun. Second, PM shares 31.2% of the variance (β = 0.312) with respect to cost overrun. The value of β was observed to be 0.216 and 0.195 for PC and SM constructs, respectively.

5. Discussion

This section discusses the results presented in the previous section, mainly the ranking of the most important factors affecting the cost inaccuracy in the planning and construction phases, and elaborates on the results obtained from PLS-SEM.

5.1. Factors Affecting Cost Increase in the Planning Phase (PFs)

Local wishes without cost responsibility was ranked as the most important factor, with an RII value of 0.818. A good example of this type of factor is the case of St Olav's Hospital in Trondheim, Norway (while not a transport project, this is still a state-funded project). The initiators and eventual owners of the project at the county level assumed that the state government would take responsibility for funding, and the cost increases would not stop the project based on previous state-funded hospital projects. However, within a few years, costs were increased from NOK 1 billion to NOK 12 billion, and if the state government had not curbed the cost increase through extensive hospital reform measures, the cost increases could have been much more [4,52]. Liabilities and incentives for cost control should be introduced at the early stages of planning to avoid cost escalations. The public sector relies on transparency in order to strengthen accountability. Therefore, government-funded projects should be selected based on high-quality information about the needs, benefits, costs, and risks.

Considering the factors of *local wishes without cost responsibility* (first), *defective estimation* (second), *those who get the benefit are not the ones who pay* (fourth), together with *project optimism* (fifth), it can be inferred that generally, inaccurate estimations in the phase of planning, together with local wishes and lack of responsibility, are the main reasons for cost increases in the planning phase. Sometimes, local promoters deliberately provide low-cost estimates to make it easier to gain acceptance for the project. Estimations are normally unrealistic, and on the contrary, benefits for the users and society are overestimated. As a result of underestimating the costs and overestimating the benefits, the chance of the project being accepted increases, and the project initiatives, which might have been reasonable and beneficial in the first place, grow in costs and become over-dimensioned, due to the requirements additionally introduced after the initial approval of the project. In contrast, if the actual costs are presented, the project may be rejected at the early stages [52,53].

These results agree with previous studies, which state that politicians play a role in the planning process. Road administrations in some regions are more politicized than others, which can also result in misleading cost information being given to Parliament, which eventually leads to cost increase. In addition, competition exists between different parties in some regions to keep their policies at the forefront [23]. As another example, Volden [53] evaluated nine large-scale projects' planning stages, and found that substantial resources were spent just on lobbying.

The fifth-place ranking belonged to *project optimism*, together with *poor project management* and *lack of follow-up,* with an RII value of 0.697. Although these three parameters are still among the most important in the respondents' opinions, project handling in the planning phase in Norway has been significantly improved since the quality assurance regime was introduced in 2000 and expanded in 2005. This implies that both the economic appraisals and cost estimates of large government projects must be scrutinized by external consultants before projects are allowed to proceed to the next planning phase [54]. This governance regime ensures that plans and estimates are subjected to an outside view, which may reduce the risk of over-optimism and strategic behavior.

Project planning in Norway is an open and communicative process that requires that all stakeholders must be consulted. Local authorities must grant planning permission before the government can approve a final budget. This increases the risk of both a misalignment of incentives and that the process may take longer than planned. As time passes, the expectations of society increase, and our acceptance of adverse environmental and social effects decreases. In addition to the fact that it may stretch the planning phase out, it may cause unwanted cost increases [55].

5.2. Factors Affecting Cost Overrun in the Construction Phase (CFs)

Ranked first in this study, *changes in the scope* of the projects has been listed among the main reasons for cost overrun indicated within the literature. Ascher [56] found that about 40-90% of the total cost overrun can be explained by three factors alone: scope change, impact of inflation, and delay. In a more recent study done by Lee in 2008, the author concluded that changes in scope, delays during construction, unreasonable estimations, and adjustments of project costs are the main reasons of cost overrun [57].

One of the main reasons that *market conditions* is ranked second is that Norway has experienced three different periods of high market volatility since 2000 (i.e., inflation, and as a result increases in materials prices, in 2004–2005; the world crisis in 2008–2009, and the oil price drop in 2015–2016). Norway's economy is highly dependent on the oil market, and fluctuations in the price of oil can result in an unstable and volatile market. This has also been investigated by Dahl et al. [58], who found a clear relationship between the increase in oil prices and cost overruns.

Unforeseen ground conditions was observed to be the third most important factor, and has been among the most important factors in the literature, but its importance is even higher in Norway. Fjord and mountain landscapes in the western and eastern regions, and to a lesser extent the central region, make the topography of Norway challenging for infrastructure construction. Most of the population is located in areas with large marine deposits, making road construction vulnerable to quick clay and unstable geological conditions. Therefore, it can be deduced that the first three factors should be considered as serious uncertainties in the early planning phases, which may lead to unwanted time or cost overruns.

In the opinion of Norwegian experts, *conflicts between contractor and the owner* was ranked as fourth, with an RII value of 0.752. Generally, Norwegian work culture is egalitarian and independent, meaning that people are given enough freedom to work in the areas of their responsibility. The system is also based on trust, and people usually prefer not to be told in detail how to do their job. However, conflicts and disputes in the construction industry in Norway have been increasing in recent years. According to a study carried out by Sabri et al. [59], tender specification and contract understanding, final settlement payment, low-priced contracts, and changes in the project were the most influencing parameters resulting in conflicts and disputes. Among them, tender specifications and contract understanding were the most influential causes of conflicts in Norway, followed by disagreements on final settlements, usually issued by the public owner. They recommend introducing a clear dispute management pattern for investments in large-scale Norwegian infrastructure projects [59].

Forecasting errors is another factor, similar to market conditions, that should be considered in uncertainty analysis from the early planning phases. This is a factor that stems from underestimation during the planning phase, affecting the cost overrun in the construction phase. In such a case, the government has two options: either finance the project for the additional requested budget, or stop the project. However, if the estimations were more precise, the government could make another decision, such as project modification. Increasing transparency and logging all project cost estimations from the early stages of planning could be a solution for increasing the precision of the estimation and reducing the risk of forecasting errors. Nevertheless, the analysis methods in this study could not measure these effects, which could be a potential area for further research.

Project size and *length of the road* were evaluated in this study, and were ranked as eighth and twelfth. Previous studies showed that project size, which is defined according to the budget allocated for the project, might have an impact on the magnitude of cost overrun, as the larger the project, the higher amount of cost overrun. However, the findings are inconclusive, but it can be regarded as an important parameter according to the obtained results.

Delay in progress payment by the owner, *deliberate underestimation of costs*, and *monopolization of special equipment* were listed as the least influential factors on cost overrun. It was expected that monopolization of equipment can be more influential in developing countries, in countries with lower GDP, or in places where the management and governance of the public projects is not transparent, and there might be a risk of corruption. *Deliberate underestimation of costs* and *strategic behavior (deliberate behavior)* were also among the lower-ranked factors. This indicates that in contrast to some of the available research, including that by Cantarelli et al. [20], who categorized them as economical explanations for cost overrun, these factors do not play an important role in Norway.

5.3. CF Constructs

Concerning the SEM analysis and model result in Figure 3, and with regard to the second research question, it can be inferred that external factors have the largest impact on cost overrun within this study. As previously stated, external factors are not entirely under the control of humans, such as the effect of bad weather or market conditions. However, it is possible to consider uncertainties that originate from external factors in the planning process. As of now, cost estimations, particular to Norway, are calculated based on stochastic (probability-based) estimations in the early planning phases. Carrying out stochastic estimations, either through mathematical analytical methods or simulation tools, results in a cumulative probability distribution of investment costs. The estimation process produces a tornado diagram that ranks different uncertainties according to their impact on total costs, which can then result in further oversight during the construction phase.

The *project management and contractual relationship* construct was determined to be the second most important group of factors affecting cost overrun. As mentioned previously and discussed in Section 5.2, this construct primarily includes human-related factors that can directly affect smooth and stable project governance. Risk factors in this construct mostly originate from tender specification and contract misunderstanding, improper scheduling/delayed final settlement/payment, low-priced contracts, and changes in the project's scope. For example, *conflicts between contractor and the owner* and *contractual claims* *(cost or time extension)* were ranked as fourth and sixth among the CFs, respectively. Therefore, improving and better clarifying tender specifications and contract understanding may reduce conflicts and disputes, which have been recently increasing in Norway.

Site management factors have the least impact on cost overrun. This means that contractors are performing justifiably in Norway, according to the respondents, who notably did not include contractors themselves.

According to the model results, pre-construction factors have the second lowest impact on cost overrun. These are factors that reveal themselves during the construction phase, but stem from the planning phase. Considering the previous rankings (in Table 5), some of the factors, including *forecasting errors (e.g., increasing prices), delays in decision-making*, and *inadequate planning process*, rank rather highly (fifth, seventh and seventh, respectively). While others, specifically *strategic behavior (deliberate behavior)* and *deliberate underestimation of costs*, are listed among the least important factors. Thus, there is not necessarily a consistent trend among the factors within this construct, and the low-ranking factors can reduce the overall impact of the construct as a whole.

6. Conclusions

Cost performance, specifically cost overrun, is an important topic within transportation economy and project management. It is essential to realize what factors affect cost overrun during both construction and planning phases. Determining these factors will not only improve the cost performance and improve the success level of the project, but also helps to manage and ensure the proper use of resources.

Considering sustainability, the main focus of this study was on the economic aspect of sustainability, focusing on risk factors that can affect the cost performance of large-scale road projects in order to curb cost overrun risks. Thus, increased knowledge of factors affecting cost performance is important to attain economically sustainable project management. Moreover, it can also result in the better use of resources, and thus the further preservation of the environment.

This study investigated the most important factors affecting cost overrun in the planning and construction phases using data from Norway. Using data from one country, where projects are planned and implemented in a consistent manner, ensures a more robust assessment of causes than studies based on data collected from different countries and from different time periods. This paper enhances the past research by introducing a new set of factors that may occur during the planning phase and affect the final cost performance of the project, as well as the most influential factors in the construction phase affecting cost overrun in Norway. Projects go through different stages in their development and delivery, and the causes of cost increase and overrun may differ as time proceeds. To identify root causes, studies should therefore distinguish between projects' front-end and delivery. To this aim, a questionnaire survey was distributed to various relevant people who have been involved in at least in one large-scale road project in Norway. The main findings of the study can be summarized as follows:

- *Local wishes without cost responsibility, defective estimation, long processing time, those who benefit are not the ones who pay*, and *changes in rules and regulations* are the main factors that can result in cost overrun in the planning phase. This suggests that from a political perspective, there may be arguments for better aligning the interests of project owners and local stakeholders, for example, through a mechanism for mandatory local contribution. Furthermore, despite progress in improving the quality of project front-end management over the last two decades, there is still potential for improving efficiency by improving cost estimation methodologies that better capture the risks in the early stages of appraisal and planning. Likewise, *changed/different staffing, increased funding hides cost growth*, and *socio-economic profitability is of little importance* are among the least influential factors, indicating that the planning process in some of the regions might be politicized. In addition, long processing time should be considered as a serious uncertainty even in the planning phase, which may result in an increase in cost estimations;

- *Scope changes, market conditions,* and *unforeseen ground conditions* are the most influential factors on cost overrun in the construction phase, according to the experts' opinions in Norway. This is in agreement with previous studies, as these three factors have been among the most critical uncertainties in large infrastructure projects worldwide. In addition, within the construction phase, *delay in progress payment by the owner, deliberate underestimation of costs*, and *monopolization of special equipment* are the factors with the least influence on cost overrun;
- Factors affecting cost overrun during the construction phase were categorized into four main constructs—external, contractor's site management, pre-planning, and project management and contractual relationship were modeled in SmartPLS version 3.0 to determine and compare their impact on cost overrun. External factors—generally uncertain factors with less human controllability—had the greatest impact on cost overrun. This indicates that although cost estimations in Norway are based on stochastic estimations, there is still room for improvement. However, according to the respondents, planning phase factors did not strongly affect cost overrun during construction despite the suggestions in the previous literature.

The results of this study create knowledge on risk factors that can affect cost inaccuracy in both the planning and construction phases, and the relationships between them. Investigating such factors in the planning phase and their impact on the construction phase and overall cost overrun has not been considered in the literature yet. This research also highlights that studies of cost overrun address economic sustainability within project management.

Finally, it should be mentioned that this study also has limitations. First, the results of this study are not directly applicable to other countries, and similar studies should be carried out in individual countries. However, the methodology used in this study can be utilized for other similar studies. Second, the small sample size was the limitation of this study, which made the use of SEM challenging. However, the PLS-based method was used in this study, which is recommended in the literature for small sample sizes. In addition, with a bigger sample size, it could have been possible to cover more attitudes (e.g., contractors) in the research, and reduce the risk of biased answers. This could be suggested for further research, together with an assessment of the planning phase as a highly relevant parameter that can influence the cost performance of the project.

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References

1. Martínez-Perales, S.; Ortiz-Marcos, I.; Juan Ruiz, J.; Lázaro, F.J. Using certification as a tool to develop sustainability in project management. *Sustainability* **2018**, *10*, 1408. [CrossRef]
2. Uribe, D.F.; Ortiz-Marcos, I.; Uruburu, Á. What is going on with stakeholder theory in project management literature? A symbiotic relationship for sustainability. *Sustainability* **2018**, *10*, 1300. [CrossRef]
3. Eliasson, J.; Börjesson, M.; Odeck, J. and Welde, M. Does Benefit–Cost Efficiency Influence Transport Investment Decisions? *J. Transp. Econ. Policy* **2015**, *49*, 377–396.

4. Volden, G.H. Public funding, perverse incentives, and counterproductive outcomes. *Int. J. Manag. Proj. Bus.* **2019**, *12*, 466–486. [CrossRef]
5. Rodríguez-Rivero, R.; Ortiz-Marcos, I.; Ballesteros-Sánchez, L.; Martínez-Beneitez, X. Identifying Risks for Better Project Management between Two Different Cultures: The Chinese and the Spanish. *Sustainability* **2020**, *12*, 7588. [CrossRef]
6. Rodríguez-Rivero, R.; Ortiz-Marcos, I.; Romero, J.; Ballesteros-Sánchez, L. Finding the links between risk management and project success: Evidence from international development projects in Colombia. *Sustainability* **2020**, *12*, 9294. [CrossRef]
7. Norge, R. Grunnlagsdokument Nasjonal transportplan 2018–2029. *Oslo. Zugriff am* **2016**, *27*, 2016.
8. Cantarelli, C.C.; van Wee, B.; Molin, E.J.; Flyvbjerg, B. Different cost performance: Different determinants?: The case of cost overruns in Dutch transport infrastructure projects. *Transp. Policy* **2012**, *22*, 88–95. [CrossRef]
9. Odeck, J. Variation in cost overruns of transportation projects: An econometric meta-regression analysis of studies reported in the literature. *Transportation* **2019**, *46*, 1345–1368. [CrossRef]
10. Plebankiewicz, E. Model of predicting cost overrun in construction projects. *Sustainability* **2018**, *10*, 4387. [CrossRef]
11. Plebankiewicz, E.; Wieczorek, D. Prediction of cost overrun risk in construction projects. *Sustainability* **2020**, *12*, 9341. [CrossRef]
12. Pickrell, D.H. *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Costs [October 1989]*; (No. UMTA-MA-08-9021-89-1); Urban Mass Transportation Administration: Washington, DC, USA, 1990.
13. Skamris, M.K.; Flyvbjerg, B. Inaccuracy of traffic forecasts and cost estimates on large transport projects. *Transp. Policy* **1997**, *4*, 141–146. [CrossRef]
14. Flyvbjerg, B.; Holm, M.S.; Buhl, S. Underestimating costs in public works projects, error or lie? *J. Am. Plan. Assoc.* **2002**, *68*, 279–295. [CrossRef]
15. Odeck, J. Cost overruns in road construction—What are their sizes and determinants? *Transp. Policy* **2004**, *11*, 43–53. [CrossRef]
16. Nijkamp, P.; Ubbels, B. How reliable are estimates of infrastructure costs? A comparative analysis. *Int. J. Transp. Econ. Riv. Int. Econ. Trasp.* **1999**, *26*, 23–53.
17. Siemiatycki, M. Academics and auditors: Comparing perspectives on transportation project cost overruns. *J. Plan. Educ. Res.* **2009**, *29*, 142–156. [CrossRef]
18. Makovšek, D. Public–private partnerships, traditionally financed projects, and their price. *J. Transp. Econ. Policy JTEP* **2013**, *47*, 143–155.
19. Odeck, J. Do reforms reduce the magnitudes of cost overruns in road projects? Statistical evidence from Norway. *Transp. Res. A Policy Pract.* **2014**, *65*, 68–79. [CrossRef]
20. Cantarelli, C.C.; Molin, E.J.E.; van Wee, B.; Flyvbjerg, B. Characteristics of cost overruns for Dutch transport infrastructure projects and the importance. *Transp. Policy* **2012**, *22*, 49–56. [CrossRef]
21. Shehu, Z.; Endut, I.R.; Akintoye, A. Factors contributing to project time and hence cost overrun in the Malaysian construction industry. *J. Financ. Manag. Prop. Constr.* **2014**, *19*, 55–75. [CrossRef]
22. Love, P.E.; Sing, C.P.; Wang, X.; Irani, Z.; Thwala, D.W. Overruns in transportation infrastructure projects. *Struct. Infrastruct. Eng.* **2014**, *10*, 141–159. [CrossRef]
23. Welde, M.; Odeck, J. Cost escalations in the front-end of projects–empirical evidence from Norwegian road projects. *Transp. Rev.* **2017**, *37*, 612–630. [CrossRef]
24. Cantarelli, C.C.; Flybjerg, B.; Molin, E.J.; Van Wee, B. Cost overruns in large-scale transportation infrastructure projects: Explanations and their theoretical embeddedness. *arXiv* **2013**, arXiv:1307.2176.
25. Long, N.D.; Ogunlana, S.; Quang, T.; Lam, K.C. Large construction projects in developing countries: A case study from Vietnam. *Int. J. Proj. Manag.* **2004**, *22*, 553–561. [CrossRef]
26. Majid, I.A. Causes and Effects of delays in ACEH Construction Industry. Doctoral Thesis, Universiti Teknologi Malaysia, Skudai, Malaysia, 2006.
27. Ameh, O.J.; Soyingbe, A.A.; Odusami, K.T. *Significant Factors Causing Cost Overruns in Telecommunication Projects in Nigeria*; University of Lagos: Lagos, Nigeria, 2010.
28. Azhar, N.; Farooqui, R.U.; Ahmed, S.M. Cost overrun factors in construction industry of Pakistan. In Proceedings of the First International Conference on Construction in Developing Countries (ICCIDC–I), Advancing and Integrating Construction Education, Research & Practice, Karachi, Pakistan, 4–5 August 2008; pp. 499–508.
29. Al-Juwairah, Y.A. Factors Affecting Construction Costs in Saudi Arabia. Doctoral Thesis, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, 1997.
30. Doloi, H.; Sawhney, A.; Iyer, K.C.; Rentala, S. Analysing factors affecting delays in Indian construction projects. *Int. J. Proj. Manag.* **2012**, *30*, 479–489. [CrossRef]
31. Fugar, F.D.; Agyakwah-Baah, A.B. Delays in building construction projects in Ghana. *Australas. J. Constr. Econ. Build.* **2010**, *10*, 128–141. [CrossRef]
32. Al-Kharashi, A.; Skitmore, M. Causes of delays in Saudi Arabian public sector construction projects. *Constr. Manag. Econ.* **2009**, *27*, 3–23. [CrossRef]
33. Assaf, S.A.; Al-Hejji, S. Causes of delay in large construction projects. *Int. J. Proj. Manag.* **2006**, *24*, 349–357. [CrossRef]
34. Sambasivan, M.; Soon, Y.W. Causes and effects of delays in Malaysian construction industry. *Int. J. Proj. Manag.* **2007**, *25*, 517–526. [CrossRef]
35. Odeh, A.M.; Battaineh, H.T. Causes of construction delay: Traditional contracts. *Int. J. Proj. Manag.* **2002**, *20*, 67–73. [CrossRef]

36. Sweis, G.; Sweis, R.; Hammad, A.A.; Shboul, A. Delays in construction projects: The case of Jordan. *Int. J. Proj. Manag.* **2008**, *26*, 665–674. [CrossRef]
37. Yates, J.K. Construction decision support system for delay analysis. *J. Constr. Eng. Manag.* **1993**, *119*, 226–244. [CrossRef]
38. Yang, J.B.; Ou, S.F. Using structural equation modeling to analyze relationships among key causes of delay in construction. *Can. J. Civ. Eng.* **2008**, *35*, 321–332. [CrossRef]
39. Toor, S.U.R.; Ogunlana, S.O. Problems causing delays in major construction projects in Thailand. *Constr. Manag. Econ.* **2008**, *26*, 395–408. [CrossRef]
40. Rossi, P.H.; Wright, J.D.; Anderson, A.B. Sample surveys: History, current practice, and future prospects. In *Handbook of Survey Research*; University of Massachusetts, Academic press: Amherst, MA, USA, 1983; pp. 1–20.
41. Memon, A.H.; Rahman, I.A. Analysis of cost overrun factors for small scale construction projects in Malaysia using PLS-SEM method. *Mod. Appl. Sci.* **2013**, *7*, 78. [CrossRef]
42. Larsen, J.K.; Shen, G.Q.; Lindhard, S.M.; Brunoe, T.D. Factors affecting schedule delay, cost overrun, and quality level in public construction projects. *J. Manag. Eng.* **2016**, *32*, 04015032. [CrossRef]
43. Love, P.E. Influence of project type and procurement method on rework costs in building construction projects. *J. Constr. Eng. Manag.* **2002**, *128*, 18–29. [CrossRef]
44. Love, P.E.; Edwards, D.J.; Watson, H.; Davis, P. Rework in civil infrastructure projects: Determination of cost predictors. *J. Constr. Eng. Manag.* **2010**, *136*, 275–282. [CrossRef]
45. Nguyen-Phuoc, D.Q.; Phuong Tran, A.T.; Nguyen, T.V.; Le, P.T.; Su, D.N. Investigating the complexity of perceived service quality and perceived safety and security in building loyalty among bus passengers in Vietnam–a PLS-SEM approach. *Transp. Policy* **2021**, *101*, 162–173. [CrossRef]
46. Ali, F.; Kim, W.G.; Ryu, K. The effect of physical environment on passenger delight and satisfaction: Moderating effect of national identity. *Tour. Manag.* **2016**, *57*, 213–224. [CrossRef]
47. Diamantopoulos, A.; Winklhofer, H.M. Index construction with formative indicators: An alternative to scale development. *J. Mark. Res.* **2001**, *38*, 269–277. [CrossRef]
48. Hair, J.F., Jr.; Hult, G.T.M.; Ringle, C.; Sarstedt, M. *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*; Sage Publications: Thousand Oaks, CA, USA, 2016.
49. Tabachnick, B.G.; Fidell, L.S. *Using Multivariate Statistics*, 6th ed.; Pearson: Boston, MA, USA, 2013.
50. Fornell, C.; Larcker, D.F. Evaluating structural equation models with unobservable variables and measurement error. *J. Mark. Res.* **1981**, *18*, 39–50. [CrossRef]
51. Cohen, J. *Statistical Power Analysis for the Social Sciences*; Erlbaum: Hillsdale, NJ, USA, 1988.
52. Odeck, J. What determines decision-makers' preferences for road investments? Evidence from the Norwegian road sector. *Transp. Rev.* **2010**, *30*, 473–494. [CrossRef]
53. Volden, G.H. Up-Front Governance of Major Public Investment Projects. Doctoral Thesis, Norwegian University of Science and Technology, Trondheim, Norway, 2019.
54. Odeck, J.; Welde, M.; Volden, G.H. The impact of external quality assurance of costs estimates on cost overruns: Empirical evidence from the Norwegian road sector. *Eur. J. Transp. Infrastruct. Res.* **2015**, *15*, 286–303.
55. Flyvbjerg, B.; Skamris Holm, M.K.; Buhl, S.L. How common and how large are cost overruns in transport infrastructure projects? *Transp. Rev.* **2003**, *23*, 71–88. [CrossRef]
56. Ascher, W. The ambiguous nature of forecasts in project evaluation: Diagnosing the over-optimism of rate-of-return analysis. *Int. J. Forecast.* **1993**, *9*, 109–115. [CrossRef]
57. Lee, J.K. Cost overrun and cause in Korean social overhead capital projects: Roads, rails, airports, and ports. *J. Urban Plan. Dev.* **2008**, *134*, 59–62. [CrossRef]
58. Dahl, R.E.; Lorentzen, S.; Oglend, A.; Osmundsen, P. Pro-cyclical petroleum investments and cost overruns in Norway. *Energy Policy* **2017**, *100*, 68–78. [CrossRef]
59. Sabri, O.K.; Lædre, O.; Bruland, A. Why conflicts occur in roads and tunnels projects in Norway. *J. Civ. Eng. Manag.* **2019**, *25*, 252–264. [CrossRef]

Appendix B:

Paper 2

Accepted for publication in the journal of *‘Case Studies on Transport Policy’*

Ex-post evaluation of project efficiency and effectiveness within a Norwegian highway project

Abstract

The traditional view of transportation infrastructure projects' success evaluation has been focused on efficient time and cost performance (i.e., operational success), but there is an increased interest in considering a broader perspective that evaluates whether the project has performed as promised with respect to project goals (i.e., tactical success). This study presents a two-level success evaluation of a Norwegian highway that examines project efficiency and effectiveness, i.e., operational and tactical success. The evaluation suggests that while the project experienced a large cost increase during the construction period, it performed operationally efficiently with 0.015% cost underrun. The project was also tactically successful in effectively achieving the predetermined goals of reducing traffic accidents, traffic congestion, and travel time through the project area. Considering both aspects of success provide a more holistic understanding of the project's benefits, and this study contributes to further developing the overall understanding of project success evaluation through the case study.

Keywords: Cost overrun, ex-post evaluation, cost inaccuracy, project success, transport infrastructure, project management

1. Introduction

Transport infrastructures are expensive and put a burden on government finances. Planning, budget-making, and construction are components of a complex and costly process that demands considerable resources. Moreover, many projects often become more expensive than initially proposed or do not achieve the goals they were planned for (Welde and Odeck 2017). Infrastructure investments face different challenges and result in diverse effects. Therefore, the potential to improve project governance frameworks for such projects is significant, and these frameworks require evaluation to determine project success (Flyvbjerg, Bruzelius et al. 2003, Flyvbjerg, Skamris Holm et al. 2003, Odeck, Welde et al. 2015, Volden 2018).

Traditionally, the project management community has been focused narrowly on three parameters, known as the 'iron triangle,' to evaluate the success of a project: cost, time, and scope (where adjustments to the scope are focused on the impact to the time and cost of the project) (Volden 2019). Time and cost under/overrun and their dependence on several parameters, including the size of the project, project type (e.g., road, rail, etc.), geographical region, time length of completion, etc., have been widely studied and compared in large datasets of infrastructure projects around the world. However, there has been a shift to expand this limited view of project success to a broader and more strategic perspective on projects and their success. Baccarini (1999) defined two levels of project success, i.e., project management success (which concerns delivery) and product success (which concerns the outcome). As another example, Samset (2003) stated that a successful project should not only be successful operationally (i.e., considering the iron triangle legs) but also tactically and strategically. In his opinion, tactical success indicates to which extent the project has reached the predetermined formal goals that the project was intended for. Strategic success, however, evaluates the long-term effects and if the effects are sustainable over the long term.

Large infrastructure projects, which are mainly government-owned, are implemented for the betterment of society and not necessarily to improve the profitability of the government. From this, the benefits of these projects tend to be considered from a user perspective and a broader societal perspective to ensure the predetermined objectives of the project. Yet, the value of these benefits might not be properly considered when solely considering time and cost under/overrun within the traditional operational success perspective. Therefore, there is a need for a systematic evaluation of public projects from different perspectives and at different stages of project planning and implementation to include considerations of tactical and strategic success.

Currently, it is widely accepted that assuring quality at entry is essential in implementing a successful project. Yet, governments have an increased understanding of the importance of ex-post evaluation frameworks for large public infrastructure investments as another approach to evaluating project success. For instance, the Organization for Economic Cooperation and Development (OECD) recommends a five-factor framework for a project's ex-post evaluation (i.e., *relevance*: the project need, *efficiency*: use of time and cost, *effectiveness*: meeting the intended goals, *sustainability*: persistence of positive effects over the long term, and *other positive* *or negative impacts* due to implementation of the project) (OECD 1991, OECD 2002). However, ex-post evaluations of governmental infrastructure projects are still scarce (Volden 2018). Worsley (2014) uses the term 'the weak link' to describe the ex-post evaluation in the assessment process of the projects in OECD countries. Even in Norway, which has reached a high level of maturity in the evaluation of large, national governmental projects, systematic ex-post evaluation of public projects can be rarely found (Samset and Christensen 2017).

This paper aims to investigate the operational and tactical success of a project by examining efficiency and effectiveness within a case study of a Norwegian highway, E6: Frya-Sjoa. From an operational point of view, while the project was delivered within the expected timeframe, it resulted in significant cost inaccuracy, which impacts project efficiency. Yet the project effectiveness, i.e., the tactical success of the project, must also be considered to determine overall project success. Thus, within this study, the operation cost performance of the project is evaluated to consider the impact of cost inaccuracy on the determination of cost overrun, and the main causes and corresponding explanations of cost inaccuracy are thoroughly discussed. This is done using project documentation and interviews with key project personnel. Then, from a tactical perspective, the effectiveness of the project is examined using data from a national road database to evaluate whether the project has achieved its expected outcomes related to congestion relief and increased safety. These criteria can be studied through ex-post analysis to contribute to the understanding of project success as described in the OECD's framework.

The contributions of this research are multifold. The combined operational and tactical consideration results in a more holistic understanding of project success within the case study. This allows for accountability and practical learning from past experiences to improve future investment decisions and project management processes. This case study contributes to the overall body of knowledge on project success, particularly when ex-post analyses are used. Additionally, detailed case studies are essential to understanding country-specific contexts associated with project success which may be missed when studying the topic from a global perspective, and allow for practical interpretation and use of the results. The results from this study within the road infrastructure sector can also be considered and compared to similar studies within other sectors to increase overall knowledge of public infrastructure investments (Flyvbjerg, Skamris Holm et al. 2003).

The paper proceeds as follows. Section 2 provides a background on the definition of project success, cost overrun as an evident phenomenon of cost deviation, and the road planning process in Norway. Section 3 introduces the case study project, while section 4 elaborates on the data sources and methods used in this paper. Section 5 presents the results and discussion. Concluding remarks are presented in Section 6.

2. Background

This section provides a theoretical framing of project evaluation. First, widely accepted criteria for evaluating project success both globally and in Norway are described and presented together with the corresponding levels of success they represent. As the criteria of efficiency and effectiveness are the focus of this research, the section follows with a background on these criteria as two measures of success representing the operational and tactical levels, respectively. The concept of cost inaccuracy and its relationship with cost overrun, including a review of literature on cost overrun, and causes and explanations, is elaborated on in the subsection *'Operational success: Efficiency.'* The subsection '*Tactical success: Effectiveness*' presents a brief overview of the definition of effectiveness as a measure of project success. Lastly, a summary of the Norwegian road planning system, quality assurance regime, and the definition of cost overrun in the Norwegian road project governance is presented.

2.1. Project success evaluation

Evaluation can be generally defined as a systematic examination of the effectiveness of a project for use by project owners, decision-makers, and other stakeholders. Evaluation has two main requirements: evaluation expertise and strict scientific methods (Rossi, Lipsey et al. 2004). Depending on at which stage of the project's lifetime the evaluation is carried out, different approaches, and as a result, different questions may be raised. These questions mostly examine the need for a project, the theory/logic behind the project design, the implementation phase of the project, cost performance, and the outcome of the project (Rossi, Lipsey et al. 2004, Sarmento, Renneboog et al. 2017, Volden 2019).

A standard comprehensive evaluation framework model which is used by United Nations and several other relevant organizations and endorsed by OECD-Development Assistance Committee (OECD-DAC), includes five criteria:

1) Project need (relevance)
2) Reasonable use of time and cost (efficiency)
3) Whether intended goals are achieved (effectiveness)
4) Other positive or negative effects due to implementation of the project (other impacts)
5) Persistence of the positive effects after the conclusion of the project (sustainability).

This framework has been adapted and improved to meet the needs of different contexts and countries (European commission (2013), Beck (2006)). In Norway, a six-factor framework has been developed with an additional factor of 'cost-effectiveness.' This is done to expand the efficiency factor beyond the limited focus on time/cost-efficient delivery of the project to a more holistic view (Volden 2018). The six criteria used in Norway and the corresponding level of success they indicate are presented in Table 1, with efficiency and effectiveness being most relevant to this study.

Table 1. Six-criteria success evaluation framework

Level of success	**Evaluation criteria**
Operational	Efficiency
Tactical	Effectiveness
Strategic	Relevance Sustainability Other impacts Benefit-cost ratio

2.2. Operational success: Efficiency

Project efficiency is typically considered within the framework of time and cost performance, with cost performance being most notable within this study since the project was delivered within the time framework. Cost performance considers cost inaccuracy or the difference between the final actual costs of the project and the estimated costs. Cost inaccuracy gives a clear insight into the cost increase or decrease during the project implementation phase without explicit interpretation as cost under- or overrun (hereafter referred to as cost overrun).

In the literature on transportation economy and project management, *'cost overrun'* is a well-known term and can be found in a wide range of research. The concept of cost overrun has had numerous interpretations in the body of the literature, as well as different premises for calculation. Based on a review of the literature, the following definition for cost overrun is used within this study:

Cost overrun is measured based on the difference between the actual costs and estimated costs, where the result is positive. A negative value would imply a cost underrun (Flyvbjerg, Skamris Holm et al. 2003, Cantarelli 2011, Odeck 2019).

Studies conducted by Flyvbjerg et al. (2003) and Odeck (2004) are among the most prominent on cost performance of infrastructure projects. Flyvbjerg et al. (2003) assessed a sample of 258 infrastructure projects with different locations, project types, and implementation times. An average cost overrun of 28% was determined, and in 90% of projects with cost overruns, costs were underestimated. Additionally, they found that the implementation time did not affect the accuracy of cost estimations. Odeck (2004) evaluated 620 Norwegian road projects and found an average cost overrun of 8%. With respect to project size, Odeck demonstrated that cost overruns are more prevalent among smaller projects than large-scale projects (Odeck 2004). Berechman and Wu (2006) evaluated 163 road projects in Vancouver, Canada, and found an average overrun of 5.9%, which varied from -52 to 134%. Another study was conducted by Cantarelli et al. (2012) in which they evaluated 78 projects from three different types (e.g., road, rail, and fixed links), concluding that the length of the implementation and pre-construction phases are the most important determinants of cost overruns in the Netherlands. Yet, differences in overrun findings can be attributed to differences in price usage (i.e., nominal or real), time points for decision-making, budget-making, and project completion as the basis for calculations, as well as cost estimation methodologies (Cantarelli, van Wee et al. 2012). For instance, Meunier and Welde (2017) compared the ex-post evaluation systems in France and Norway. Despite of high similarity between the evaluation systems in both countries, the values of cost overrun varied considerably. They concluded one of the main reasons of difference is that Norway uses stochastic cost estimation which produces probability-based estimates, while estimations that are largely based on the assumption that the elements in the estimates are certain are being used in France (Meunier and Welde 2017).

Further, the causes of cost overrun have been discussed in numerous studies. Lee (2008) assessed 161 social overhead capital projects in Korea and found that changes in scope, delays during construction, and unreasonable estimation were among the main reasons for cost overrun. In another study, Herrera et al. (2020) performed a systematic review of the most important causes of cost overrun in road construction projects around the world. They identified 38 factors, where failures in design, price variation of materials, inadequate project planning, project scope changes, and design changes were determined to be the most influential.

Overrun causes can be connected to explanations to further understand the origins of the overrun. According to Flyvbjerg et al.(2004), causes imply the parameters and variables that result in cost overrun, while the explanation's definition is broader and may include several causes. For example, Morris (1990) found that price increase is the main cause of cost overrun, while poor project design, delay in implementation, and lack of coordination between different parties are the subsequent causes. Flyvbjerg et al. (2003) proposed a categorization for the causes leading to cost overrun comprised of four main explanations: technical, economical, psychological, and political. Table 2 presents the categorization of the causes and relevant explanations used in this study, as well as relevant studies which consider each explanation.

Table 2. Causes, explanations, and relevant references [adopted from (Cantarelli 2011)]

Explanation	Examples of causes	Relevant studies
Technical	• Poor project design • Price increase • Change in scope • Incomplete estimates • Uncertainties such as inefficient decision-making or planning process • Improper organizational structure	(Flyvbjerg, Bruzelius et al. 2003) (Faludi 1973, Pickrell 1992) (Bruzelius, Flyvbjerg et al. 2002, Lee 2008, Kaliba, Muya et al. 2009, Mahmud, Ogunlana et al. 2021)
Economical	Deliberate underestimation because of: • Lack of incentives or resources • Poor financing • Inefficient contract management • Strategic behavior • Ineffective use of resources	(Pickrell 1992, Odeck 2004) (Hall 1982, Skamris and Flyvbjerg 1997, Love and Ahiaga-Dagbui 2018)

Psychological	• Vigilant attitude toward risk • People's cognitive bias • Politicians' optimism bias	(Kahneman and Lovallo 1993, Skamris and Flyvbjerg 1997)
Political	• Intentional cost underestimation • Manipulation of estimations	(Hall 1982, Odeck 2004) (Wachs 1982, Flyvbjerg, Skamris Holm et al. 2003, Pinheiro Catalão, Cruz et al. 2019, Mahmud, Ogunlana et al. 2021)

In a similar approach, the causes leading to cost inaccuracies and overruns are classified as either endogenous or exogenous causes. Exogenous causes indicate political, governance, economic, and project determinants, while endogenous causes imply specific variables associated with each project (Catalão, Cruz et al. 2019, Pinheiro Catalão, Cruz et al. 2019, Catalão, Cruz et al. 2021). In a study conducted by Catalão et al. in (2019), the impact of each exogenous determinant on the cost performance of 1091 transport projects (between 1980 to 2012) was evaluated. They concluded that while some of these determinants have received little attention, they all influence the cost performance of the projects in terms of their statistical significance as well as the size of the impact.

2.3. Tactical success: Effectiveness

As mentioned before, public investments should not only perform well on efficient time and cost delivery but also on tactical and strategic perspectives in order to be truly successful (Volden 2019). Tactical performance is broader than operational performance and focuses on the extent that the project has reached its predetermined goals. Moreover, it evaluates whether the project is relevant in relation to current societal priorities and needs, requiring its evaluation to be carried out after the project completion (Samset 2003). This level of success evaluation considers the user's perspective and includes more uncertainty (Volden 2018, Volden 2019). Effectiveness is used as the measure which reflects the project's success at the tactical level (OECD 2002). There are few studies found in the literature that evaluate the tactical (i.e., effectiveness) and strategic success of road infrastructure projects, highlighting the need for more studies on this aspect of project success.

Welde (2018) evaluated the success of a road project in Norway with a focus on tactical success five years after the opening of the project for traffic. He assessed the impact of the project implementation on two parameters, namely severe traffic accidents and deaths, as well as the number of commuters using that link (which were primarily the main objective of the project). He demonstrated that there was a 75% reduction in the number of persons killed or seriously injured. In addition, congestion decreased, and consequently, travel time was reduced by 20% (Welde 2018). In another study, Volden (2018) utilized the Norwegian six-factor evaluation framework to assess the success of 20 infrastructure projects from different sectors in Norway (e.g., road, defense, railway, etc.). Her findings indicated that despite the 20 projects being highly successful in operational terms, more variations were observed in their tactical and strategic performance. For instance, some projects were highly relevant and sustainable while having a low benefit-cost efficiency, and vice versa. Moreover, she concluded that learning across different sectors can be useful and important for developing evaluation measures and methods.

2.3. Road planning process in Norway

During the road planning process, projects move through several stages, from idea development to implementation. The determination of cost overrun uses project costs at several specific time points; thus, it is important to understand the overall road planning process to understand the project efficiency.

Due to the large cost overruns, long delays, and low efficiency of public projects during the 1990s, the Norwegian government introduced a new scheme known as Quality Assurance 2 (QA2), or KS2[3] in Norwegian, for planning, financing, and implementing large public projects (currently defined as projects with presumed budgets exceeding 750 million Norwegian Krones (NOK)) in 2000. The main purpose of this scheme was to ensure that these projects would result in more benefits, lower overruns, and improved performance (Odeck 2004). The program was expanded

[3] *Kvalitetssikring*

in 2005 by adding an additional quality assurance earlier in the road planning process, referred to as QA1 (as it occurs before the original QA, QA2). QA1 occurs after the Conceptual Appraisal (CA), in which, based on societal needs, pre-studies consider various solutions and identify a conceptual solution. This solution is then presented to the Cabinet for a decision on whether to proceed to the pre-project phase. The process is illustrated in Fig. 1. The QA reviews are carried out by the respective external government agencies. Quality assurers review the documents, evaluate the feasibility and practicability of the assumptions, check the contingency, conduct their own independent analyses, and eventually make their recommendations. However, the recommendations made by the quality assurers are not mandatory, and the political authorities may decide whether to follow them or not.

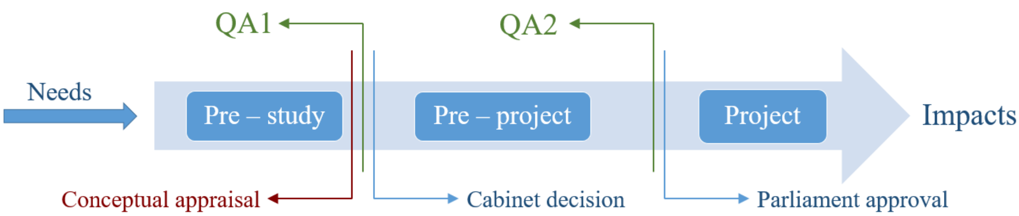


Fig. 1. Governance scheme for investment projects in Norway

During the road planning process, cost estimates are provided. The most important numbers with respect to the project's estimated costs are P50 and P85. In general, Px indicates that there is a probability of x% that the final actual cost is at or below this level. In the Norwegian context, P50 and P85 refer to the *management framework*[4] and *cost framework*[5], respectively. The cost framework is initially assigned by the Ministry, which has budgetary responsibility for the agency that will carry out the project. However, some ministries have also delegated the cost framework to the relevant agency, which itself has a relevant uncertainty provision (Andersen, Samset et al. 2016). The proposed budget is typically equal to P85 minus certain minor deductions (this is known as the *cut list)*, but the budget given to the agency is normally equal to P50 to reduce the

[4] *Styringsramme*
[5] *Kostnadsramme*

use of contingency reserves. Management and cost frameworks are also estimated by the quality assurers; however, the final numbers are decided by Parliament. During the implementation, if it is determined that the project cannot be delivered within the cost framework, either cost reduction measures must be implemented, or a request must be made to increase the limit. In the cases where costs exceed P85, a new QA2 is required with a new cost estimate for Parliament to approve in order to adopt a new cost framework (Samset and Volden 2013). Therefore, it may be concluded that based on this style of governance, cost overruns only happen if the actual costs exceed P85 (Welde 2017). Several studies conducted in Norway recently demonstrate that cost overrun in road projects has been curbed, and in some cases, the road (and railway) projects are seen to have cost underrun. This might be attributed to the introduction of the QA regime (Meunier and Welde 2017, Welde and Odeck 2017). However, more accurate cost estimations should also minimize cost underrun. Underruns are another indication of failure for the project, where the initial extra budget allocated to the project could have been otherwise spent, saved, or invested at the time of planning.

3. Case Study: E6 through Frya to Sjoa (2013-2017)

This study considers a case project, E6 (European route) Frya-Sjoa in east-central Norway (Fig. 2). The roadway construction project was largely motivated by the goals of a Vision Zero policy (reduction of fatal and severe injury accidents). The road network before the project completion contributed to a high number of accidents due to high traffic volumes and local and through traffic using the same infrastructure (where users of the local infrastructure included vulnerable road users and public transit). An additional main objective of the project was the reduction of travel time and traffic congestion, which again is impacted by local and through traffic sharing infrastructure. Other related project goals included better accessibility (as a basis for positive social development), improved perceived safety for both pedestrians and cyclists, fewer people exposed to indoor and outdoor noise, increased well-being, and a better local environment for individuals living beside the road, and a pleasant driving experience (Samferdselsdepartementet 2012).

As seen in Fig. 2, the four-lane highway, shown in red, is 33.7 km in length within the county of Oppland and passes through several municipalities. The road consists of two tunnels (Hundorp and Teigkampen, noted as red dashed lines in the figure) which in total comprise 8.1 km of the segment. Before the project implementation, both local traffic and through traffic had to use the old E6 (current municipality road Nr. 2522, shown in black in Fig. 2).

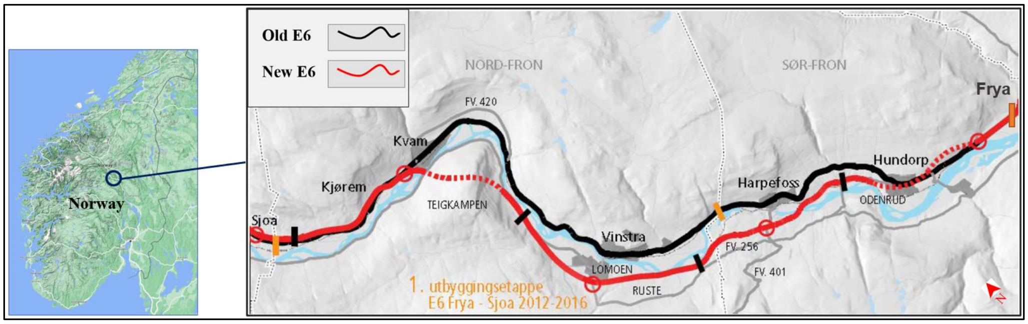
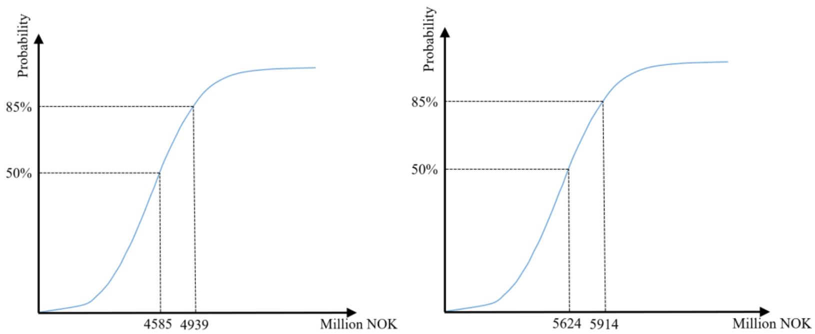


Fig. 2. Location of the E6 Frya-Sjoa in Norway (Google maps) (left), and illustration of old and new E6 (Frya-Sjoa) (Samferdselsdepartementet 2012) (right)

Fig. 3 presents the project's cost framework confidence graph with the corresponding values for P50 and P85 recommended by the quality assurers (advisory) and project contractors (Samferdselsdepartementet 2012, Vegvesen 2012). The difference between the proposed values presented by the two entities can be attributed to several parameters, including the calculation methodology, market situation, etc. The values of P50 and P85 proposed by the project contractor formed the basis for the cost performance of the project, which and subsequently approved by Parliament.



(a) (b)

Fig. 3. Confidence graph of the Frya-Sjoa project recommended by a) quality assurers, and b) project contractor

This project was among the three projects nominated and recommended by the Norwegian Public Roads Administration (NPRA) for ex-post evaluation due to the large cost increase during the implementation phase. The main reason for the selection of this project for further study was the negative reputation of the project due to large cost increases in the local and national media and, therefore, skepticism of the success of the project.

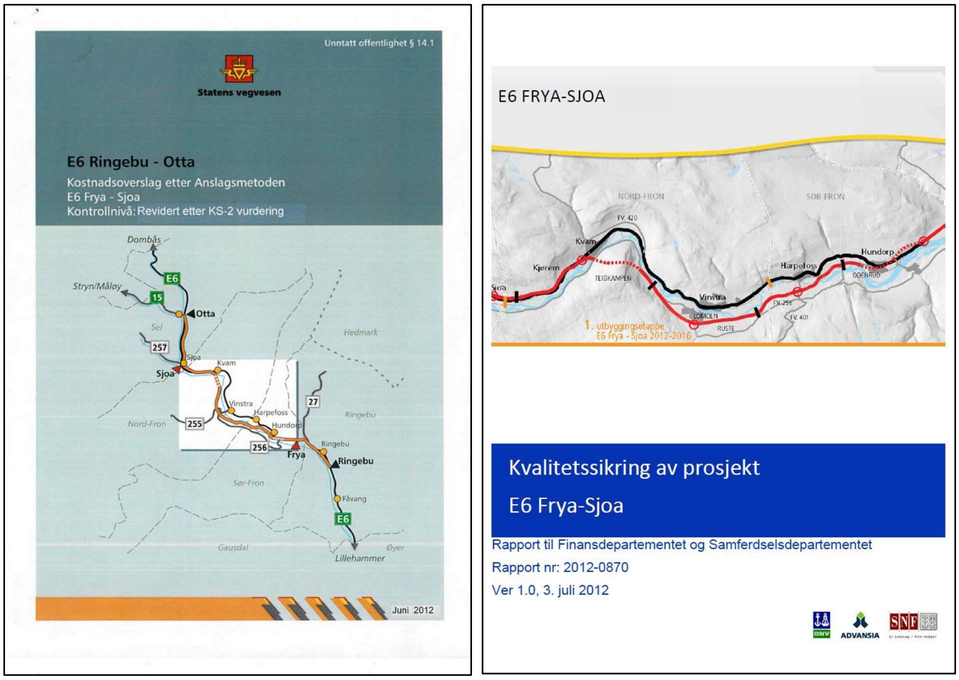
4. Data and methods

This section provides an overview of data sources and methods used in this study for evaluating the efficiency and effectiveness of the project E6 Frya-Sjoa. To consider efficiency, the magnitude of cost inaccuracy was first calculated using the official project documents, and thereafter interviews were held with individuals central to the project, including project managers and economists, to discuss the reasons for the cost increase. These reasons were then mapped to corresponding relevant explanations for cost inaccuracy identified in existing research to gain further insights into project efficiency. To then evaluate the effectiveness of the implementation of this project, traffic volume, and accident data were obtained and compared between pre- and post-project. This allowed for an assessment of whether the project was effective in reaching the goals it was planned and designed for.

4.1. Project documentation sources

Data variables used to examine efficiency in this study are estimated costs and actual costs. As stated before, estimated costs are an element of the forecasted budget formulated during the decision-making process that concludes with the Parliamentary decision on whether to go ahead with the project. Actual costs include all construction costs accumulated during the project's implementation, from right after the decision to build is made until the completed project is opened for public use. These two time points, the time of decision and project opening, are the widely accepted reference points for calculating overruns (Cantarelli 2011). Considering the definition of cost overrun in the Norwegian context and the two time points mentioned above, in this study, P50 refers to estimated costs at the time of decision-making, yet as previously stated, the overrun is determined using the value of P85.

Project cost data and estimations were derived from two main documents presented in Fig. 4. The official project document (Fig. 4.a) sent to the Parliament for budget allocation, which includes all the cost estimations for the project, was used as the basis for estimated costs for further comparisons in this study (Vegvesen 2012). This document is finalized after the QA2 assessments. The project's quality assurance (QA2) report (Fig. 4.b) was also used as a supplementary source, which includes additional documentation, including the assurer's cost estimations and evaluation (e.g., cost-benefit analysis) of the project (Samferdselsdepartementet 2012). Detailed final (actual) costs of the project were obtained from the NPRA databases, which are not publicly available. Additionally, project documentation includes the explanatory report sent to Parliament detailing the magnitude and reasons leading to the cost increase (as part of the budget reallocation process) (Prosjektavdelingen 2013). The magnitudes of cost increase in this report were used in the analysis of cost overrun in this study, and the corresponding reasons highlighted in the report were discussed in the in-depth interviews.



(a) (b)

Fig. 4. Project documents: (a) official project document sent to Parliament for budget allocation (Vegvesen 2012), and (b) quality assurance (QA2) report made by external evaluators (Samferdselsdepartementet 2012)

Within the study's evaluation of effectiveness, the official project documents (Samferdselsdepartementet 2012, Vegvesen 2012) also provide information about project goals. Additional data, including traffic data on the old E6 before the project construction, was obtained from the project document provided by the project's consultant (Multiconsult 2016).

4.2. Cost inaccuracy

In order to evaluate the magnitude of cost inaccuracy, the values of estimated and actual costs should be first converted to Net Present Value (NPV) in order to be compared using the same basis. NPV can be calculated as follows:

$$NPV = \frac{C}{(1+r)^i} \quad (1)$$

where C, r, and i represent cash flow during the time period, discount rate, and time period, respectively. In this study, a toolbox provided by Statistics Norway was used to convert all costs (e.g., monthly and yearly) to NPV in the reference year of 2018 (Statistics-Norway 2019).

Cost overrun can be expressed in an absolute way, which is defined as subtracting the estimated cost from the actual cost. Similarly, it can be measured as the ratio of the actual cost to the estimated cost. However, the most common method is to express the difference between actual and estimated cost as a percentage of estimated cost (Flyvbjerg, Skamris Holm et al. 2003, Cantarelli, Flyvbjerg et al. 2012). This method is used to calculate the magnitude of cost inaccuracy for the case examined in this study, as follows:

$$Cost\ inaccuracy = \frac{NPV_{Actual\ Cost} - NPV_{Estimated\ cost}}{NPV_{Estimated\ cost}}\ \% \qquad (2)$$

A positive value implies cost overrun, while a negative value indicates cost underrun.

4.3. In-depth interviews

In-depth interviews are used to further investigate the efficiency of the project by increasing the understanding of the causes and explanations of cost inaccuracy in the project. Key persons directly involved in the E6 Frya-Sjoa project were interviewed, including the project leader, three project managers, two project economists, and three control engineers. The interviewees were identified from the project documents and public Norwegian Public Road Administration (NPRA) databases. One two-hour group interview with all interviewees was held in a semi-formal environment and focused on detailed explanation of the reasons for cost increases during the construction phase that were identified in the official project documentation (Prosjektavdelingen 2013).

To further supplement the understanding of the reasons for cost increases, five individual interviews were held, two with the project leader and three with the project economists. This setting helped the respondents talk more openly about their ideas and opinions concerning cost overruns and their possible causes. Another advantage of this interview format is that it gives the interviewer the opportunity to more easily clarify the terms, expressions, and even issues brought up by the respondents. These interviews resulted in the interviewer's being able to both extract key values from the project documentation regarding costs incurred during different phases of project construction and identify the main causes of cost under/overruns.

4.4. National Road Data Bank

National Road Data Bank (NVDB[6] in Norwegian) is a public data bank provided by the NPRA, which includes a variety of available data and historical information (e.g., traffic accidents, road type, traffic volume, traffic station, road construction, etc.) about the Norwegian road network (NVDB 2022). There is the possibility to search and filter in this platform according to desired parameters.

As identified from project documentation, the main goals of the project E6 Frya-Sjoa concerned safety and traffic congestion. Thus, traffic accident and traffic volume data were retrieved from NVDB to evaluate the impact of the implementation of the project on these two parameters. Accident data is limited to the number of accidents, as accident type and the number of deaths per accident are not publicly available.

5. Results and Discussion

This section presents and discusses the results and findings of this study. In the first subsection, the project's operational success, or efficiency, is comprehensively evaluated and discussed. After that, effectiveness as the measure of tactical success is examined concerning the two main initial goals of the project, namely reducing traffic accidents and better access for local commuters, individual passengers, and public transit passengers.

5.1. Operational success (efficiency)

As mentioned previously, while this project was delivered accurately within the predetermined timeframe, there were large cost deviations, which impacted the operational success of the project. To further understand this aspect of operational performance, this subsection is divided into two

[6] Nasjonal veg databank

parts: (I) the magnitude of cost inaccuracy, and consequently, the percentage of cost under/overrun is calculated and presented, and (II) the causes and explanations for this inaccuracy are discussed thoroughly.

(I) Magnitude of cost inaccuracy

Fig. 5 presents the values of the main costs and cost frameworks examined in this study from the period of Parliamentary decision to project opening, including estimated costs (P50 and P85) and actual cost, with all values converted to their equivalent value in Norwegian *Krones* in the reference year of 2018. In 2014, P50 and P85 were increased by 19% and 25%, from 5,624 and 5,914 million NOK to 6,686 and 7,390 million NOK, respectively. Due to unforeseen incidents arising during construction (to be discussed further under *Causes and explanations*), it was predicted that the project could not be completed within the cost framework P85. Therefore, a proposal explaining the reasons leading to the cost increase was provided and sent to Parliament. The report was approved in mid-2014, and as a result, more money was allocated to the project, leading to an increase of P50 and, subsequently, P85.

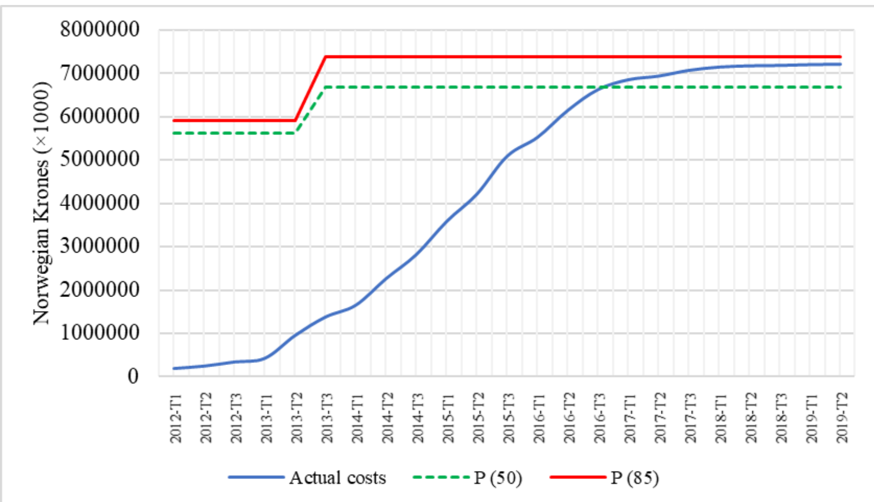


Fig. 5. Costs and frameworks for E6: Frya-Sjoa

When comparing the project's actual cost (7,207 million NOK) with its initial P50 framework (5,624 million NOK) reveals a cost increase of 1,583 million NOK (+28.15% more than estimated costs); however, considering the final value for P85 of 7,390 million NOK, this is not to be interpreted as cost overrun, but a 0.015% underrun for the project. Considering this slight underrun within the context of efficiency or operational cost performance of a project, the project can be categorized as a successful project with an acceptable cost accuracy. Yet, operational success has a narrow view of project success in measuring only short-term perspective targets such as the delivery of the project within budget and on time as defined in the project governance framework. Aspects such as the early planning phase before implementation, as well as the broader impact of the implementation of the project on society, are often ignored. Nevertheless, despite being cost-efficient according to the Norwegian framework, a 28.15% cost increase within the implementation phase indicates weak efficiency.

Moreover, given that the overrun calculation considers the revised, not initial, P85, any cost increases approved by Parliament are not included within the overrun determination, thus limiting the number of projects with overruns. This manner of determining cost overrun does not give a complete understanding of cost deviations within the project. To better understand the cost performance of the project, it is worthwhile to also consider the initial P50 cost estimate in the overrun calculation.

(II) Causes and explanations

To further investigate the cost performance, the magnitudes of cost increase were identified from the report on cost increase delivered to the Parliament for more budget allocation (Prosjektavdelingen 2013). The corresponding causes were then discussed in the group and individual interviews with the relevant project personnel. As previously described, the causes of cost increase are grouped into four main explanatory categories: technical, economical, political, and psychological (Flyvbjerg, Skamris Holm et al. 2003, Cantarelli 2011), and better described and understood through several theories where relevant. In the following section, the explanations for the project's cost increase are described within the context of the Norwegian governance framework, the author's interpretation, and relevant literature.

i) Market situation

The largest cause of cost increase for the Frya-Sjoa project was the fluctuation in the construction market itself. The project had been planned to be implemented through two contracts during two phases. As mentioned in the report on cost increase, after the completion of the first phase in 2014 (which was completed relatively on time and within the cost framework) and before the start of the second phase in the same year, prices in the construction market dramatically increased (Prosjektavdelingen 2013, Statistics-Norway 2020). The interviewees confirmed the changes in the market and used the term *'hot market'* to describe the situation at that time. This dramatic change in the market led to a cost increase of 611 million NOK (39% of the total cost increase).

The impact of the changing market situation is also noted in the literature. For example, Morris (1990) found that about 20-25% of cost overruns are due to market increases, and Nijkamp and Ubbels (1999) found that price change is one of the most critical parameters leading to cost overrun. While growth in the market situation could be a defensible justification for decision-makers to allocate more funding to an ongoing project, there is always the possibility that inflation and market increases could be better predicted in earlier phases. In this situation, decision-makers have the option of not funding the project or agreeing to allocate the required funding (Bruzelius, Flyvbjerg et al. 2002).

Price increase is among the causes classified as a **technical** explanation and relates mainly to problems with predicting the future. Cost increases as a result of market change can be supported by forecasting theory, as this theory investigates the reasons for the success or failure of a forecast (Armstrong 2001). Forecasting models in forecasting theory are used to give better insight into the problems and errors in forecasting, which lead to inaccurate cost estimates. One solution to this problem is to improve stochastic cost estimations by increasing the focus on uncertainty analysis. Currently, in the pre-study phase of Norwegian road planning, all the alternatives go through several uncertainty analyses within a quality assurance regime (CA, QA1, and QA2) to identify the extent of probable changes that may happen during project construction, which addresses this issue. Notably, the studied case has only been through QA2 due to its project timeline.

ii) New rules and regulations

During the construction phase, new rules and regulations were enacted regarding water resource security, flood and erosion protection, climate requirements, and frost protection layers for the pavement. These upcoming regulations, which are mentioned in the report on cost increase and were discussed during the interviews, had been unclear during the project budget development, leading to increased costs during the implementation phase. Specific to this case study project, the restriction zone for the drinking water resource and requirements for maintaining the water resource from pollution were expanded, resulting in 30 million NOK (2% of the total cost increase) in extra costs to the overall expenses. New rules regarding how to protect asphalt layers from frost were adopted; as a result of this requirement, new materials were employed in line with new regulations, which caused an extra cost of 70 million NOK (4%). Updated flood and erosion protection regulations led to a 65 million NOK (4%) increase in project expenses (Prosjektavdelingen 2013).

This uncertainty, which indicates an inappropriate organizational structure and resulting inefficient project structure (Kaliba, Muya et al. 2009, Cantarelli, Molin et al. 2012), is considered a **technical** explanation. According to the author's interpretation, forecasting theory explains this uncertainty because the estimations were made without considering or underestimating unforeseen uncertainties at the time of cost estimations. Therefore, increased provisions concerning uncertainty, third-party review, and utilizing experience from projects with similar conditions are remedies for minimizing these kinds of technical causes of cost increase.

iii) Design change

A change to the project's design was also identified as a cause of the cost increase in the report on cost increase and discussed in the interviews (Prosjektavdelingen 2013). In the early phases of project construction, the local authority in one of the involved municipalities asked the project managers to build a bridge that had not been previously planned. As a result of this new request, the project route was changed, and approximately 65 million NOK (4% of the total cost increase) was added to the project costs. Generally, scope changes, in addition to poor project design and implementation, are considered to be **technical** explanations. However, in this case, since the scope change was demanded by the local municipality and not created by the project managers, this cause is categorized as a **political** explanation. Therefore, according to the literature, either lack of discipline or organizational and political pressure were the reasons for this cost increase. This political demand is explained by the concept of Machiavellianism, which says people manipulate others for their own interests and personal gain (Cantarelli 2011). In addition, as Welde and Odeck (2017) state, this also happens due to competition between different political parties wanting to keep their policies at the forefront.

iv) Unforeseen events (Removing landfill)

A significant cost increase of 60 million NOK (4% of the total cost increase) was added to the project's costs due to removing a landfill along the construction alignment. Within the interviews, the project managers claimed that neither the municipalities nor local politicians informed them about the landfill's existence on the project alignment. As a result, the lack of coordination between the municipality and project teams and/or lack of discipline within the municipalities are the leading causes for this cost increase. It can be considered a **political** explanation. Ethical theory fits best in this context, as a lack of responsibility to inform resulted in an unforeseen event that needed to be addressed within the ongoing project. Authors believe that this phenomenon happened through no intent among the politicians; otherwise, it is interpreted as agency theory, in which people behave in their own self-interest, even if it does not include guile, deception, or betrayal.

v) Land acquisition

As stated in the report on cost increase, land acquisition costs were underestimated, and consequently, the costs were increased by about 60 million NOK. While this was only 4% of the total cost increase, it was 55% higher than the initial estimations. Based on what was discussed in the interviews, this results from a lack of experience and incomplete estimates, as quite often, during the early stages of designing and planning, there is not enough detail to accurately estimate how much land is needed. Therefore, the causes are considered to be **technical** explanations. Forecasting theory explains these technical errors, in which the estimations in an uncertain situation are evaluated. Using reference projects is an effective way to improve estimations, as a database of experience-based cost information on large projects is already available in different sectors in Norway.

It should be noted that financial and political explanations may play a role in this cause. For example, land acquisition is not only a cost but also strategic for all parties because it concerns landowners in the project's vicinity who will become involved in various stages of the project. Hence, deliberately underestimating the land acquisition costs gives a more favorable perception to politicians, and the chances that the public will accept the project will increase. Therefore, land acquisition cost underestimation results from strategically behaving to misrepresent the actual land acquisition and costs needed to get the proposal accepted. As there is a very narrow distinction between financial and political explanations, it should be clarified that political explanations originate from interest and power. In contrast, financial explanations are based on a lack of incentives or resources. Nonetheless, in this case study, project cost underestimation of land acquisition occurred due to reasons that could be classified as technical explanations.

vi) Additional costs

The previously described reasons and associated costs represent 61% of the total cost increase of the project. The remaining 39% (about 623 million NOK.) shown in Table 3 as "additional costs" was not described in detail in project documentation specific to the increase in budget. However, based on the interviews and other project documentation, this cost increase was seen in various aspects throughout the project (e.g., design, construction, etc.). Due to the lack of detailed information regarding these costs, they have been aggregated and considered as a whole when considering the explanation of the increase.

In determining the explanation, given that the cost increase occurred during the implementation phase, it is unlikely that political and psychological explanations, which typically happen in the early stages of project development, are relevant. Given the description of the additional costs from those interviewed, it is likely that some components of the costs can be explained as technical, related to poor design, incomplete estimates, or other uncertainties. Additionally, given that the framework of the Norwegian financing systems allows for cost increases (up to P85) over the budgeted cost (P50), it could be that in the budget adjustments, costs were underestimated to increase the chance of receiving money for the project completion. This can also be explained through rational choice theory, in which underestimating costs increases the possibility of receiving the expected benefits. Thus, an economic explanation due to poor financing, inefficient contract management, and ineffective use of resources are assumed to be the causes of this additional cost increase.

vii) Summary

To summarize, Table 3 provides an overview of the reasons for cost increase determined from the interviews and project documentation.

Table 3. Causes and explanations of cost increase

Cause	Explanation (supporting theory)	Amount of increase (mil. NOK) *	% of total cost increase
Market situation	Technical (forecasting)	611	39%
New rules and regulations	Technical (forecasting)	165	10%
Design change	Political (Machiavellianism)	65	4%
Removing landfill	Political (ethical)	60	4%
Land acquisition	Technical (forecasting)	60	4%
Additional costs	Technical / Economical (rational choice)	623	39%
Total (cost final cost increase)		1583	100%

*All prices are presented in 2018 Norwegian *Krones*

From the documented cost increases, technical explanations supported by forecasting theory account for more than half of the project cost increase. Improper uncertainty analysis, unstable market situation, unforeseen events, and new rules and regulations were the main causes for technical causes for cost increase. These results indicate that more emphasis should be placed on uncertainties, especially unforeseen events, which can lead to significant cost increases in the case of large projects. In addition to third-party reviews done within the quality assurance processes, using the experience of reference projects also helps avoid significant cost increases by providing more accurate initial estimates.

In addition, the results show a relatively low percentage of cost increase during the construction phase due to political reasons (8%). This was expected because politicians are more actively involved earlier in the planning process, i.e., before the Parliamentary decision. Odeck (2019) refers to the phase before formal decision-making as the “front-end” phase, which includes problem determination, recognition of the concept, rough estimations, initial planning, and, occasionally, decision-making. Formally, this includes the pre-study, Conceptual Appraisal, and QA1. Sometimes, planners and decision-makers are found to deliberately provide low-cost estimates to make it easier to gain acceptance for a particular project. By overestimating its benefits and underestimating its costs, the chance of getting a project accepted increases, whereas if the real costs are presented, the project will be rejected at its initial stages (Odeck 2010, Welde, Samset et al. 2014). However, it is difficult to provide conclusive evidence of political intervention. The most important criticism of this political misrepresentation of real costs is that the responsible people are aware that these costs are more expensive; however, to get their project accepted, they manipulate the cost figures (Flyvbjerg 2007). Thus, while not included in cost performance calculations, cost increases during a project’s planning phase can be significant and should be investigated in more detail (Sager 2016, Odeck 2019). No psychological cause could be attributed to the cost increase of the project.

The operational success and cost efficiency of the project Frya-Sjoa was evaluated in this subsection. As seen, despite a large cost increase (1,583 million NOK), this project was demonstrated to have a slight cost underrun within the Norwegian calculation basis and therefore interpreted as an operationally successful project. These findings clearly show why a narrow operational view is not a complete indication of project success. Further exploration into the cost increases indicates the technical reasons are the most dominant cause of cost increase within the project, although the introduction of an expanded quality assurance system in Norway (QA2) has been found to improve initial costs estimates, thus reducing overall increases (Odeck, Welde et al. 2015). But, as previously stated, the results demonstrate that there is a risk of considering the success of a project from an administrative, technical, or internal perspective without being representative of user groups and the broader society.

6.2. Tactical success (effectiveness)

While the operational success of a project can be measured at the completion of the project, to determine the tactical success or effectiveness of a project, a longer period (typically 3-5 years later) for evaluation after the project completion is needed to recognize to what extent the project has reached the goals it was designed and implemented for. The two main goals of the project were described in detail in Section 3 and evaluated here to determine the effectiveness of the project.

I. Reduction of traffic accidents to improve traffic safety

One primary goal of the project was to achieve safety-related goals and reduce traffic accidents along the project stretch. The project's impact on safety was evaluated by comparing accident data from identical length periods of time (70 months). The evaluations consider registered traffic accidents in the NPRA database, which aggregates light damage, severe damage, and fatality accidents. Accident details are not publicly available.

The data shows that traffic accidents have been significantly reduced since the opening of the project, as illustrated in Table 4, which shows the accidents before (March 2007 – December 2012) and after (January 2017 – November 2022) the opening of the project. A simple comparison between equivalent six-year time periods before and after project completion indicates a reduction from 61 registered accidents on the old E6 to four accidents on E6 Frya-Sjoa plus five accidents on the old E6, for a total of nine accidents during the after period. This reduction also occurred as traffic volumes have steadily increased in Norway (with the exception of 2021 due to the COVID pandemic). From this, it can be inferred that this project has been successful in reaching the goal of improved road safety by considerably reducing the number of accidents along the project stretch.

Table 4. Traffic accidents comparison before and after project implementation

Time period	Number of traffic accidents	
	Old E6	New E6
2007	13	-
2008	10	-
2009	11	-
2010	7	-
2011	8	-
2012	12	-
Sum (before)	**61**	

2017	1	1
2018	1	1
2019	0	2
2020	2	0
2021	1	0
2022 (through Nov.2022)	0	0
Sum (after)	**5**	**4**

II. Better accessibility and reduced travel time

Another important aim of this project was to improve accessibility and consequently reduce travel time for both local traffic users (e.g., drivers, cyclists, pedestrians, etc.) as well as through traffic on the E6. Before the project implementation, both local and through traffic used the old E6 (current municipality road nr. 2522) shown in black in Fig. 6. After completion of the project, local traffic users continued using the old E6, while those who are travelling through the project area use the main road E6 Frya-Sjoa. Fig. 6 presents the traffic volumes on both the old E6 and E6 Frya-Sjoa, before and after the project implementation (Multiconsult 2016). The AADT on the old E6 ranged between 5000 and 6500 on different segments of the stretch, while the project aimed to reduce this amount to 1000-2000 for daily traffic users (Multiconsult 2016). As shown in the figure, as per November 2022, the AADT on the old E6 varies from 1600 to 1900, which is within the desired range. Additionally, the AADT for E6 Frya-Sjoa is found to vary between 5040 (northern segment in the vicinity of Sjoa) and 7290 (southern segment of the near Frya). This difference over the length of the project is expected since the traffic volume on E6 reduces northwards. Hence, it can be realized that the separation of the local traffic users from the travelers on E6 has been successfully achieved.

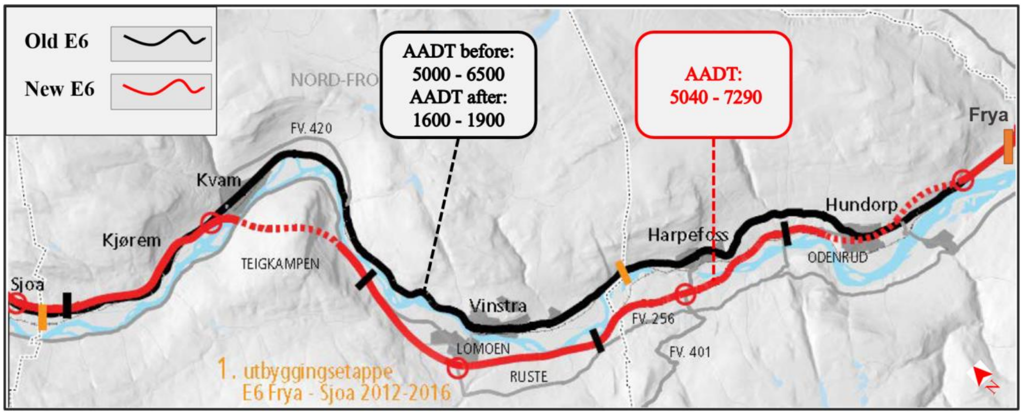


Fig. 6. Comparison of traffic volume on E6 Frya-Sjoa and the two parallel local municipality roads

In addition to changes in traffic volume distribution, travel time through the project area is reduced by 8 minutes, from 38 to 25 minutes, as stated in the QA2 report of the project. This is a result of reduced congestion, reduction of mixed traffic on local municipality roads, reduced driving distance compared to the previous alternative (3 km shorter), as well as higher speed limits (increase from 45 - 60 km/hr at different stretches to 90 km/hr, except for tunnels with 80 km/hr) on E6 Frya-Sjoa.

The tactical success, or effectiveness, of the project was evaluated by examining the impact of the project on goals related to congestion relief and increased safety. Based on before and after accident counts and traffic values, the project was found to be tactically successful by achieving project goals. In this case, the specific goals of the project allowed for a quantifiable evaluation of effectiveness, although this is not true for all project goals, for example, accessibility as a basis for positive social development or increased well-being and a better local environment for those who live along the old E6. To further the use of tactical evaluation, it is important to consider how project goals can be measured after project completion and to benchmark needed metrics in the pre-construction phase to allow for a more complete and accessible evaluation after project completion.

Considering the results of the evaluation of tactical success along with the criteria for operational success widens the perspective for project success. At the operational level, evaluation of project effectiveness is important in order to improve the performance of future investments and to strengthen scope, accuracy, transparency, and accountability within transportation infrastructure projects. Yet, the results of this study show that the framework for cost performance calculations can impact the results of such evaluations and declare projects operational successful despite large cost increases during the implementation phase. Including additional aspects of project success, particularly those from a tactical perspective, allows for a more holistic evaluation which includes considerations of long-term goals that have a positive impact on society. This results in a more complete view of project success to be used for the improvement of project selection and implementation processes.

6. Concluding remarks

Traditionally, the measure of success for large-scale transport infrastructure projects has been limited to operational evaluations of the project to assess whether the project is delivered within the predetermined time and budget frame or not. Operational success evaluation is important and gives a quick assessment of how a project performed within these metrics. But, such a narrow perspective, which is measured immediately after the project completion, ignores the short- and long-term impacts of the project on the users, the society, and the environment. Thus, there is a push towards a systematic evaluation of such projects with a broader view with respect to the projects' outcomes. Such frameworks consider not only time and cost efficiency (operational level) but also effectiveness (tactical level), relevance, sustainability, other impacts, and benefit-cost ratio (strategic level). Such broad evaluations are scarce within the literature, motivating this study of a two-level success evaluation of a case study of a highway in Norway (new E6 Frya - Sjoa) which considers the operational and tactical performance of the project to provide a more complete assessment of project success.

The operational assessment using project documentation indicated a cost increase of 1,583 million NOK during project implementation, which can be an indication of poor cost performance, yet this project is interpreted to have a slight cost underrun (0.015%) given the Norwegian framework for cost overrun determination. A conclusion to be made here is that the current framework for determining cost overrun in Norway may skew the impression of a project's cost performance. Beyond the calculation of cost performance, there is value in further exploring the causes of cost increase. Through document review and interviews for the case study, technical explanations were found to account for more than half of the project cost increase, while political reasons accounted for 8% of the cost increase (a combination of various technical and economic reasons accounted for the remaining increase). Improper uncertainty analysis, unstable market situations, and unforeseen events were determined to be the main causes of technical explanations. Hence, it can be concluded that improved uncertainty analysis, as well as better coordination of involved decision-making parties/organizations, could be practical solutions to improving cost accuracy and, thus, project efficiency. Thus, while the evaluation shows the project to have achieved operational success, there is room for interpretation of the strength and relevance of this success.

To further study the project performance, project goals were considered within the tactical evaluation of the project, where the project was determined to be effective. Traffic safety goals were evaluated six years after the project's opening, indicating an 85% reduction in accidents in the project area. Additionally, the project was found to improve accessibility and reduce travel times by facilitating the separation of through traffic and local traffic and increasing speed limits for through traffic. This was confirmed through traffic volume comparisons, which were reduced for local roads, calculating a travel time reduction of 8 minutes through the project stretch. The results of the effectiveness evaluation clearly show that despite the high cost increase, this project has achieved positive impacts on society and the well-being of the infrastructure users, which may be ignored by purely operational evaluation. Thus, considering both aspects of success provide a more holistic understanding of the benefits of the project, and this study contributes to further developing the overall understanding of project success evaluation through the case study. The results and discussions within this study will improve the performance of future investments and provide insights to strengthen scope, accuracy, transparency, and accountability within transportation infrastructure projects globally.

The results of this study serve as a starting point for recognizing and specifying the causes behind cost overrun in a well-organized framework for single case studies. Every project is explicitly or implicitly dependent on a set of casual relationships between project inputs, activities, outputs, and outcomes. Ex-post evaluations are essential for providing a detailed comprehension of country-specific contexts related to project success which may be ignored when studying the topic from an aggregated and/or global perspective. Yet, evaluating case studies can illustrate important aspects and challenges related to project definitions, goals, outputs, and outcomes that can be useful for understanding beyond the case study itself.

While the findings cannot be directly generalized to other countries, the findings of this study are helpful for the purpose of improvement, learning, and accountability within project management. For example, the results identify uncertainties and risk factors that should be further examined by the responsible authority. Moreover, the results can be used as beneficial input for further improvement of the appraisal and planning process for future large-scale public projects since past project success is not a guarantee for future success. Finally, the framework for quality assurance provided in Norway, which is largely seen as successful, can serve as a model for other countries. This framework is particularly of value in large and complex projects where there are more considerable consequences if projects are not successful. Comparison of the efficiency of the Norwegian framework with that of other countries can be a topic for further research.

Declarations of Competing Interest

There are no conflicts of interest.

7. References

Abedi, M., et al. (2022). "GAN-Based Approaches for Generating Structured Data in the Medical Domain." Applied Sciences **12**(14): 7075.

Afzal, F., et al. (2021). "A review of artificial intelligence based risk assessment methods for capturing complexity-risk interdependencies: Cost overrun in construction projects." International Journal of Managing Projects in Business **14**(2): 300-328.

Akinosho, T. D., et al. (2020). "Deep learning in the construction industry: A review of present status and future innovations." Journal of Building Engineering **32**: 101827.

Al-Hazim, N. and Z. A. Salem (2015). "Delay and cost overrun in road construction projects in Jordan." International Journal of Engineering & Technology **4**(2): 288.

Ambrule, V. R. and A. N. Bhirud (2017). "Use of artificial neural network for pre design cost estimation of building projects." Interational Journal on Recent and Innovation Trends in Computing and Communication **5**(2): 173-176.

Andersen, B., et al. (2016). "Low estimates–high stakes: underestimation of costs at the front-end of projects." International Journal of Managing Projects in Business.

Anguera, R. (2006). "The Channel Tunnel—an ex post economic evaluation." Transportation Research Part A: Policy and Practice **40**(4): 291-315.

Aretoulis, G. N. (2019). "Neural network models for actual cost prediction in Greek public highway projects." International Journal of Project Organisation and Management **11**(1): 41-64.

Armstrong, J. S. (2001). Principles of forecasting: a handbook for researchers and practitioners, Springer.

Ashtari, M. A., et al. (2022). "Cost Overrun Risk Assessment and Prediction in Construction Projects: A Bayesian Network Classifier Approach." Buildings **12**(10): 1660.

Baccarini, D. (1999). "The logical framework method for defining project success." Project Management Journal **30**(4): 25-32.

Barros, L. B., et al. (2018). "Construction cost estimation of Brazilian highways using artificial neural networks." International Journal of Structural and Civil Engineering Research **7**(3): 283-289.

Beck, T. (2006). Evaluating humanitarian action using the OECD-DAC criteria: An ALNAP guide for humanitarian agencies, ALNAP/Overseas Development Institute.

Beniwal, S. and J. Arora (2012). "Classification and feature selection techniques in data mining." International journal of engineering research & technology (ijert) **1**(6): 1-6.

Berechman, J. and Q. Wu (2006). Cost overruns risk analysis in transportation infrastructure investments, Phelps Centre for the Study of Government and Business, Sauder School of ….

Blanc-Brude, F., et al. (2006). "Ex ante construction costs in the European road sector: a comparison of public-private partnerships and traditional public procurement."

Blanc-Brude, F., et al. (2009). "A comparison of construction contract prices for traditionally procured roads and public–private partnerships." Review of Industrial Organization **35**(1): 19-40.

Bolón-Canedo, V., et al. (2013). "A review of feature selection methods on synthetic data." Knowledge and information systems **34**: 483-519.

Bordat, C., et al. (2004). "An analysis of cost overruns and time delays of INDOT projects."

Bray, S., et al. (2014). "Features selection based on fuzzy entropy for Data Envelopment Analysis applied to transport systems." Transportation research procedia **3**: 602-610.

Brundage, M., et al. (2018). "The malicious use of artificial intelligence: Forecasting, prevention, and mitigation." arXiv preprint arXiv:1802.07228.

Bruzelius, N., et al. (2002). "Big decisions, big risks. Improving accountability in mega projects." Transport policy **9**(2): 143-154.

Cantarelli, C. C. (2011). "Cost overruns in large-scale transport infrastructure projects: A theoretical and empirical exploration for the Netherlands and worldwide."

Cantarelli, C. C., et al. (2012). "Geographical variation in project cost performance: the Netherlands versus worldwide." Journal of Transport Geography **24**: 324-331.

Cantarelli, C. C., et al. (2008). Cost overruns in large-scale transportation infrastructure projects: Which explanations can be given? 2008 First International Conference on Infrastructure Systems and Services: Building Networks for a Brighter Future (INFRA), IEEE.

Cantarelli, C. C., et al. (2012). "Characteristics of cost overruns for Dutch transport infrastructure projects and the importance of the decision to build and project phases." Transport policy **22**: 49-56.

Cantarelli, C. C., et al. (2012). "Different cost performance: different determinants?: The case of cost overruns in Dutch transport infrastructure projects." Transport policy **22**: 88-95.

Catalão, F. P., et al. (2019). "The determinants of cost deviations and overruns in transport projects, an endogenous models approach." Transport policy **74**: 224-238.

Catalão, F. P., et al. (2021). Determinants of cost deviations and overruns in UK transport projects. Proceedings of the Institution of Civil Engineers-Transport, Thomas Telford Ltd.

Cavalieri, M., et al. (2019). "On the magnitude of cost overruns throughout the project life-cycle: An assessment for the Italian transport infrastructure projects." Transport policy **79**: 21-36.

Chapulut, J., et al. (2005). "The new ex-post evaluation methods for large projects in France." PROCEEDINGS OF ETC 2005, STRASBOURG, FRANCE 18-20 SEPTEMBER 2005-RESEARCH TO INFORM DECISION-MAKING IN TRANSPORT INNOVATIVE METHODS IN TRANSPORT ANALYSIS-PLANNING AND APPRAISAL-APPRAISAL I.

Chen, S. H. and C. A. Pollino (2012). "Good practice in Bayesian network modelling." Environmental Modelling & Software **37**: 134-145.

Chen, T. and C. Guestrin (2016). Xgboost: A scalable tree boosting system. Proceedings of the 22nd acm sigkdd international conference on knowledge discovery and data mining.

Cheng, L., et al. (2020). "Applying an ensemble-based model to travel choice behavior in travel demand forecasting under uncertainties." Transportation Letters **12**(6): 375-385.

CHEVROULET, T. and C. REYNAUD (2010). "Assessment of high speed rail projects: selection of European cases and recommendations from EVA-TREN research." Notes **4015**(4338): 8.

Chollet, F. (2017). Deep learning with Python, Simon and Schuster.

Commission, E. (2013). "The resource for the evaluation of socio-Economic development – Evaluation guide.".

Cooper, D. R., et al. (2006). Business research methods, Mcgraw-hill New York.

Creedy, G. D., et al. (2010). "Evaluation of risk factors leading to cost overrun in delivery of highway construction projects." Journal of Construction Engineering and Management **136**(5): 528-537.

Davis, J. and M. Goadrich (2006). The relationship between Precision-Recall and ROC curves. Proceedings of the 23rd international conference on Machine learning.

De Myttenaere, A., et al. (2016). "Mean absolute percentage error for regression models." Neurocomputing **192**: 38-48.

El-Kholy, A. (2021). "Exploring the best ANN model based on four paradigms to predict delay and cost overrun percentages of highway projects." International Journal of Construction Management **21**(7): 694-712.

Ellis Jr, R. D., et al. (2007). "Evaluation of alternative contracting techniques on FDOT construction projects."

Faludi, A. (1973). "The "systems view" and planning theory." Socio-Economic Planning Sciences **7**(1): 67-77.

Flyvbjerg, B. (2006). "Five misunderstandings about case-study research." Qualitative inquiry **12**(2): 219-245.

Flyvbjerg, B. (2007). "Policy and planning for large-infrastructure projects: problems, causes, cures." Environment and Planning B: planning and design **34**(4): 578-597.

Flyvbjerg, B., et al. (2018). "Five things you should know about cost overrun." Transportation Research Part A: Policy and Practice **118**: 174-190.

Flyvbjerg, B., et al. (2003). Megaprojects and risk: An anatomy of ambition, Cambridge university press.

Flyvbjerg, B., et al. (2003). "How common and how large are cost overruns in transport infrastructure projects?" Transport Reviews **23**(1): 71-88.

Flyvbjerg, B., et al. (2004). "What causes cost overrun in transport infrastructure projects?" Transport Reviews **24**(1): 3-18.

Foroutan Mirhosseini, A., et al. (2023). Application of Artificial Neural Networks to Investigate Cost Overrun of Road Projects. Journal of Research in Transportation Economics, (Revised, Unpublished work).

Fouracre, P., et al. (1990). The performance and impact of rail mass transit in developing countries.

Garson, G. D. (1991). "Interpreting neural-network connection weights." AI expert **6**(4): 46-51.

Goodfellow, I., et al. (2014). "Generative adversarial nets." Advances in neural information processing systems **27**.

Gulrajani, I., et al. (2017). "Improved training of wasserstein gans." Advances in neural information processing systems **30**.

Gustafsson, J. (2017). Single case studies vs. multiple case studies: A comparative study.

Hall, M. A. and L. A. Smith (1999). Feature selection for machine learning: comparing a correlation-based filter approach to the wrapper. FLAIRS conference.

Hall, P. (1982). Great planning disasters, University of California press.

Herrera, R. F., et al. (2020). "Cost overrun causative factors in road infrastructure projects: A frequency and importance analysis." Applied Sciences **10**(16): 5506.

Huo, T., et al. (2018). "Measurement and dependence analysis of cost overruns in megatransport infrastructure projects: Case study in Hong Kong." Journal of Construction Engineering and Management **144**(3): 05018001.

Kahneman, D. and D. Lovallo (1993). "Timid choices and bold forecasts: A cognitive perspective on risk taking." Management science **39**(1): 17-31.

Kahraman, C. (2006). Fuzzy applications in industrial engineering, Springer.

Kaliba, C., et al. (2009). "Cost escalation and schedule delays in road construction projects in Zambia." International journal of project management **27**(5): 522-531.

Khan, M. and A. Mangaraj (2022). "Time and Cost Estimation of Pre-Fabrication Construction by Using ANN."

Klakegg, O. J. and G. H. Volden (2016). "Governance in public projects: the Norwegian case." Governance and governmentality for projects: Enablers, practices and consequences.

Larsen, J. K., et al. (2016). "Factors affecting schedule delay, cost overrun, and quality level in public construction projects." Journal of management in engineering **32**(1): 04015032.

Lee, J.-K. (2008). "Cost overrun and cause in Korean social overhead capital projects: Roads, rails, airports, and ports." Journal of Urban Planning and Development **134**(2): 59-62.

Lee, J. and O. Lee (2021). "Ctgan vs tgan? which one is more suitable for generating synthetic eeg data." Journal of Theoretical and Applied Information Technology **99**(10).

Lin, D. and X. Tang (2006). Conditional infomax learning: An integrated framework for feature extraction and fusion. European conference on computer vision, Springer.

Lipton, Z. C., et al. (2014). "Thresholding classifiers to maximize F1 score." arXiv preprint arXiv:1402.1892.

Liu, H. and H. Motoda (2012). Feature selection for knowledge discovery and data mining, Springer Science & Business Media.

Love, P. E. and D. D. Ahiaga-Dagbui (2018). "Debunking fake news in a post-truth era: The plausible untruths of cost underestimation in transport infrastructure projects." Transportation Research Part A: Policy and Practice **113**: 357-368.

Love, P. E., et al. (2016). "Cost overruns in transportation infrastructure projects: Sowing the seeds for a probabilistic theory of causation." Transportation Research Part A: Policy and Practice **92**: 184-194.

Love, P. E., et al. (2011). "Moving beyond optimism bias and strategic misrepresentation: An explanation for social infrastructure project cost overruns." IEEE transactions on engineering management **59**(4): 560-571.

Love, P. E. and L. A. Ika (2021). "The 'context'of transport project cost performance: Insights from contract award to final construction costs." Research in Transportation Economics **90**: 101062.

Lundberg, M., et al. (2011). Cost overruns in Swedish transport projects, Centre for Transport Studies Stockholm, Swedish National Road & Transport ….

Mahmoodzadeh, A., et al. (2022). "Optimized machine learning modelling for predicting the construction cost and duration of tunnelling projects." Automation in construction **139**: 104305.

Mahmud, A. T., et al. (2021). "Key driving factors of cost overrun in highway infrastructure projects in Nigeria: a context-based perspective." Journal of Engineering, Design and Technology.

Makovšek, D., et al. (2012). "A cost performance analysis of transport infrastructure construction in Slovenia." Transportation **39**(1): 197-214.

Meharie, M. G., et al. (2022). "Application of stacking ensemble machine learning algorithm in predicting the cost of highway construction projects." Engineering, Construction and Architectural Management **29**(7): 2836-2853.

Memon, A. H., et al. (2011). "Preliminary study on causative factors leading to construction cost overrun." International Journal of Sustainable Construction Engineering and Technology **2**(1).

Merewitz, L. (1973). Cost overruns in public works, Institute of Urban & Regional Development, University of California.

Meunier, D. and M. Welde (2017). "Ex-post evaluations in Norway and France." Transportation research procedia **26**: 144-155.

Miller, M. and E. Szimba (2015). "How to avoid unrealistic appraisal results? A concept to reflect the occurrence of risk in the appraisal of transport infrastructure projects." Research in Transportation Economics **49**: 65-75.

Morris, P. (2013). "Reconstructing project management reprised: A knowledge perspective." Project Management Journal **44**(5): 6-23.

Morris, P. W. and J. Geraldi (2011). "Managing the institutional context for projects." Project Management Journal **42**(6): 20-32.

Morris, S. (1990). "Cost and time overruns in public sector projects." Economic and Political Weekly: M154-M168.

Müller, R., et al. (2016). Organizational enablers for project governance, Project Management Institute.

Multiconsult (2016). FORPROSJEKT E6 Frya - Sjoa.

Naik, M. G. and V. Radhika (2015). "Time and cost analysis for highway road construction project using artificial neural networks." Journal of Construction Engineering and Project Management **5**(1): 26-31.

Nelwamondo, F. V., et al. (2013). "A dynamic programming approach to missing data estimation using neural networks." Information Sciences **237**: 49-58.

Nicolaisen, M. S. (2012). "Forecasts: fact or fiction?: Uncertainty and inaccuracy in transport project evaluation."

Nijkamp, P. and B. Ubbels (1999). "How reliable are estimates of infrastructure costs? A comparative analysis." International Journal of Transport Economics/Rivista internazionale di economia dei trasporti: 23-53.

NVDB (2022). "Nasjonal vegdatabank (NVDB)." from https://vegkart.atlas.vegvesen.no/#kartlag:geodata/@600000,7225000,3.

Odeck, J. (2004). "Cost overruns in road construction—what are their sizes and determinants?" Transport policy **11**(1): 43-53.

Odeck, J. (2010). "What determines decision-makers' preferences for road investments? Evidence from the Norwegian road sector." Transport Reviews **30**(4): 473-494.

Odeck, J. (2014). "Do reforms reduce the magnitudes of cost overruns in road projects? Statistical evidence from Norway." Transportation Research Part A: Policy and Practice **65**: 68-79.

Odeck, J. (2019). "Variation in cost overruns of transportation projects: An econometric meta-regression analysis of studies reported in the literature." Transportation **46**(4): 1345-1368.

Odeck, J., et al. (2010). "Economic appraisal of universal design in transport: Experiences from Norway." Research in Transportation Economics **29**(1): 304-311.

Odeck, J. and H. Høyem (2021). "The impact of competitive tendering on operational costs and market concentration in public transport: The Norwegian car ferry services." Research in Transportation Economics **90**: 100883.

Odeck, J. and A. Kjerkreit (2019). "The accuracy of benefit-cost analyses (BCAs) in transportation: An ex-post evaluation of road projects." Transportation Research Part A: Policy and Practice **120**: 277-294.

Odeck, J. and T. Skjeseth (1995). "Assessing Norwegian toll roads." Transportation Quarterly **49**(2).

Odeck, J., et al. (2015). "The impact of external quality assurance of costs estimates on cost overruns: empirical evidence from the Norwegian road sector."

OECD, D. (1991). DAC Assistance Committee: Principles for Evaluation of Development Assistance, Paris, OECD DAC. http://www. oecd. org/dac/evaluation/50584880. pdf.

OECD, D. (2002). Evaluation and Aid Effectiveness, Glossary of Key Terms in Evaluation and Results Based Management, OECD, Development Assistance Committee.

Office, U. N. A. (2007). Estimating and monitoring the costs of building roads in England. Department for Transport. Audit report.

Park, Y. I. and T. C. Papadopoulou (2012). "Causes of cost overruns in transport infrastructure projects in Asia: their significance and relationship with project size." Built Environment Project and Asset Management.

Pérez, L. D., et al. (2015). "Fuzzy Linear Regression Models: A Medical Application." Departamento de Computación, Centro de Estudios de Informática. Facultad Matemática, Física y Computación, Universidad, All content following this page was uploaded by Lisset Denoda on **9**.

Peško, I., et al. (2013). "A preliminary estimate of time and cost in urban road construction using neural networks." Tehnički vjesnik **20**(3): 563-570.

Pickrell, D. H. (1992). "A desire named streetcar fantasy and fact in rail transit planning." Journal of the American Planning Association **58**(2): 158-176.

Pinheiro Catalão, F., et al. (2019). "Exogenous determinants of cost deviations and overruns in local infrastructure projects." Construction management and economics **37**(12): 697-711.

Pinsonneault, A. and K. Kraemer (1993). "Survey research methodology in management information systems: an assessment." Journal of management information systems **10**(2): 75-105.

Pinto, J. K. and D. P. Slevin (1988). Project success: definitions and measurement techniques, Project Management Institute Newton Square, PA.

PMI (2017). A guide to the project management body of knowledge (PMBOK® Guide). 6th ed.

Prosjektavdelingen (2013). Notat ved kostnadsutvikling E6 frya sjoa. Lillehammer.

Qiao, J.-F. and H.-G. Han (2010). "Optimal structure design for RBFNN structure." Acta Automatica Sinica **36**(6): 865-872.

Qu, S. Q. and J. Dumay (2011). "The qualitative research interview." Qualitative research in accounting & management.

Raj, P. and P. Evangeline (2020). The digital twin paradigm for smarter systems and environments: The industry use cases, Academic Press.

Rajakumar, A. (2016). "Analysis of cost overrun in road construction activities–a critical." International Research Journal of Engineering and Technology (IRJET) **3**.

Rajan, T. A., et al. (2014). "PPPs and project overruns: evidence from road projects in India." Journal of Construction Engineering and Management **140**(5): 04013070.

Riksrevisionsverket (1994). Infrastrukturinvesteringar- en kostnadsjamforelse mellan plan och utfall i storre projekt inom Vagverket och Banverket. **23**.

Ringle, C. M., et al. (2010). Response-based segmentation using finite mixture partial least squares. Data Mining, Springer.

Rossi, P., et al. (2004). "Measuring and monitoring program outcomes." Evaluation: a systematic approach. 7th ed. Thousand Oaks, CA: Sage: 203-232.

Rossi, P. H., et al. (1983). "Sample surveys: History, current practice, and future prospects." Handbook of survey research: 1-20.

Rouhi, A. and H. Nezamabadi-Pour (2020). "Feature selection in high-dimensional data." Optimization, Learning, and Control for Interdependent Complex Networks **1123**: 85.

Roxas, N. R. and S. Chalermpong (2008). Forecasting inaccuracies in transportation projects in selected South East Asian countries. Proceedings of the 16th Annual Conference of the Transportation Science Society of the Philippines, Pasay City, Philippines.

Rwakarehe, E. E. and D. A. Mfinanga (2014). "Effect of inadequate design on cost and time overrun of road construction projects in Tanzania." Journal of Construction Engineering and Project Management **4**(1): 15-28.

Sabri, O. K., et al. (2019). "Why conflicts occur in roads and tunnels projects in Norway." Journal of Civil Engineering and Management **25**(3): 252-264.

Sager, T. Ø. (2016). "Why don't cost-benefit results count for more? The case of Norwegian road investment priorities." Urban, Planning and Transport Research **4**(1): 101-121.

Samarghandi, H., et al. (2016). "Studying the Reasons for Delay and Cost Overrun in Construction Projects: The Case of Iran."

Samferdselsdepartementet (2012). Kvalitetssikring av prosjekt E6 Frya-Sjoa.

Samset, K. (2003). "Project evaluation." Making investments succeed, Trondheim, Tapir Akademisk Forlag.

Samset, K. and T. Christensen (2017). "Ex ante project evaluation and the complexity of early decision-making." Public Organization Review **17**(1): 1-17.

Samset, K. and G. H. Volden (2017). "Quality Assurance in Megaproject Management: The Norwegian Way."

Samset, K. F. and G. H. Volden (2013). Investing for Impact. Lessons with the Norwegian State Project Model and the first ivvestment projects that have been subjected to external quality assurance, Ex Ante Akademisk forlag.

Samset, K. F. and G. H. Volden (2014). "Front end Governance of Major Public Projects-Lessons with a Norwegian Quality Assurance Scheme."

Sarmento, J., et al. (2017). "Measuring highway efficiency by a DEA approach and the Malmquist index." European Journal of Transport and Infrastructure Research **17**(4).

Sharma, S., et al. (2021). "A survey on applications of artificial intelligence for Pre-Parametric Project Cost and Soil Shear-Strength estimation in construction and geotechnical engineering." sensors **21**(2): 463.

Siemiatycki, M. (2009). "Academics and auditors: Comparing perspectives on transportation project cost overruns." Journal of Planning Education and Research **29**(2): 142-156.

Siemiatycki, M. (2016). Cost overruns on infrastructure projects: Patterns, causes, and cures, Institute on Municipal Finance and Governance.

Singh, R. (2010). "Delays and cost overruns in infrastructure projects: extent, causes and remedies." Economic and Political Weekly: 43-54.

Situ, H. (2022). The Costs of Megaprojects: An Analysis of the Hong Kong-Zhuhai-Macau Bridge. Viterbi Conversations in Ethics, USC Viterbi School of Engineering. **6**.

Skamris, M. K. and B. Flyvbjerg (1997). "Inaccuracy of traffic forecasts and cost estimates on large transport projects." Transport policy **4**(3): 141-146.

Śmieja, M., et al. (2018). "Processing of missing data by neural networks." Advances in neural information processing systems **31**.

Song, Y., et al. (2018). "Segment-based spatial analysis for assessing road infrastructure performance using monitoring observations and remote sensing data." Remote Sensing **10**(11): 1696.

Statistics-Norway (2019). "Consumer price index." from https://www.ssb.no/en/priser-og-prisindekser/konsumpriser/statistikk/konsumprisindeksen.

Statistics-Norway (2020). "Production index for construction."

Sug, H. (2010). "Investigating better multi-layer perceptrons for the task of classification." WSEAS Trans. Comput **9**(5): 475-480.

Tijanić, K., et al. (2020). "Cost estimation in road construction using artificial neural network." Neural Computing and Applications **32**(13): 9343-9355.

Towne, L. and R. J. Shavelson (2002). Scientific research in education, National Academy Press Publications Sales Office.

Turochy, R. E., et al. (2001). Highway project cost estimating methods used in the planning stage of project development, Virginia Transportation Research Council.

ÜRESİN, U. (2021). "Correlation Based Regression Imputation (CBRI) Method for Missing Data Imputation." Turkish Journal of Science and Technology **16**(1): 39-46.

Van Wee, B. (2007). "Large infrastructure projects: a review of the quality of demand forecasts and cost estimations." Environment and Planning B: planning and design **34**(4): 611-625.

Vartabedian, R. (2021). Years of Delays, Billions in Overruns: The Dismal History of Big Infrastructure. The new York Times.

Vegvesen, S. (2012). E6 Ringebu - Otta kostnadsoverslag etter anslagsmetoden.

Vinzi, V. E., et al. (2010). PLS path modeling: from foundations to recent developments and open issues for model assessment and improvement. Handbook of partial least squares, Springer**:** 47-82.

Volden, G. H. (2018). "Public project success as seen in a broad perspective.: Lessons from a meta-evaluation of 20 infrastructure projects in Norway." Evaluation and program planning **69**: 109-117.

Volden, G. H. (2019). "Up-Front Governance of Major Public Investment Projects."

Wachs, M. (1982). "Ethical Dilemmas in Forecasting for Public Policy." Public Administration Review(42): 557-562.

Wang, Z., et al. (2006). "Optimized multilayer perceptrons for molecular classification and diagnosis using genomic data." Bioinformatics **22**(6): 755-761.

Welde, M. (2017). Kostnadskontroll i store statlige investeringer underlagt ordningen med ekstern kvalitetssikring, Ex ante akademisk forlag.

Welde, M. (2018). "In search of success: Ex-post evaluation of a Norwegian motorway project." Case Studies on Transport Policy **6**(4): 475-482.

Welde, M., et al. (2020). "Road investments and the trade-off between private and public funding." Research in Transportation Economics **82**: 100875.

Welde, M. and J. Odeck (2017). "Cost escalations in the front-end of projects–empirical evidence from Norwegian road projects." Transport Reviews **37**(5): 612-630.

Welde, M., et al. (2014). "Lav prising–store valg en studie av underestimering av kostnader i prosjekters tidligfase." Concept rapport.

Windeatt, T. (2008). Ensemble MLP classifier design. Computational Intelligence Paradigms, Springer**:** 133-147.

Worsley, T. (2014). Ex-post assessment of transport investments and policy interventions, OECD/ITF.

Wu, Q. (2006). Transportation infrastructure project cost overrun risk analysis: risk factor analysis models, University of British Columbia.

Xu, H., et al. (2022). "Application of Artificial Neural Networks in Construction Management: A Scientometric Review." Buildings **12**(7): 952.

Xu, L., et al. (2019). "Modeling tabular data using conditional gan." arXiv preprint arXiv:1907.00503.

Yang, Y., et al. (2011). L2, 1-norm regularized discriminative feature selection for unsupervised. Twenty-second international joint conference on artificial intelligence.

Yang, Y., et al. (2022). "A novel radial basis function neural network with high generalization performance for nonlinear process modelling." Processes **10**(1): 140.

Yin, R. K. and D. Davis (2007). "Adding new dimensions to case study evaluations: The case of evaluating comprehensive reforms." New directions for evaluation **2007**(113): 75-93.

Appendix C:

Paper 3

Revised in the journal of *'Research in Transportation Economics',* in the process of revision based on the feedback from the first review round.

This paper is awaiting publication and is not included in NTNU Open

Appendix D:

Paper 4

In progress

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Hall, P. (1982). Great planning disasters, University of California press.

Herrera, R. F., et al. (2020). "Cost overrun causative factors in road infrastructure projects: A frequency and importance analysis." Applied Sciences **10**(16): 5506.

Huo, T., et al. (2018). "Measurement and dependence analysis of cost overruns in megatransport infrastructure projects: Case study in Hong Kong." Journal of Construction Engineering and Management **144**(3): 05018001.

Kahneman, D. and D. Lovallo (1993). "Timid choices and bold forecasts: A cognitive perspective on risk taking." Management science **39**(1): 17-31.

Kahraman, C. (2006). Fuzzy applications in industrial engineering, Springer.

Kaliba, C., et al. (2009). "Cost escalation and schedule delays in road construction projects in Zambia." International journal of project management **27**(5): 522-531.

Khan, M. and A. Mangaraj (2022). "Time and Cost Estimation of Pre-Fabrication Construction by Using ANN."

Klakegg, O. J. and G. H. Volden (2016). "Governance in public projects: the Norwegian case." Governance and governmentality for projects: Enablers, practices and consequences.

Lane, B. W. and C. P. Sherman (2013). "Using the Kaldor–Hicks Tableau to assess sustainability in cost–benefit analysis in transport: An example framework for rail transit." Research in Transportation Business & Management **7**: 91-105.

Larsen, J. K., et al. (2016). "Factors affecting schedule delay, cost overrun, and quality level in public construction projects." Journal of management in engineering **32**(1): 04015032.

Lee, J.-K. (2008). "Cost overrun and cause in Korean social overhead capital projects: Roads, rails, airports, and ports." Journal of Urban Planning and Development **134**(2): 59-62.

Lee, J. and O. Lee (2021). "Ctgan vs tgan? which one is more suitable for generating synthetic eeg data." Journal of Theoretical and Applied Information Technology **99**(10).

Lin, D. and X. Tang (2006). Conditional infomax learning: An integrated framework for feature extraction and fusion. European conference on computer vision, Springer.

Lipton, Z. C., et al. (2014). "Thresholding classifiers to maximize F1 score." arXiv preprint arXiv:1402.1892.

Liu, H. and H. Motoda (2012). Feature selection for knowledge discovery and data mining, Springer Science & Business Media.

Love, P. E. and D. D. Ahiaga-Dagbui (2018). "Debunking fake news in a post-truth era: The plausible untruths of cost underestimation in transport infrastructure projects." Transportation Research Part A: Policy and Practice **113**: 357-368.

Love, P. E., et al. (2016). "Cost overruns in transportation infrastructure projects: Sowing the seeds for a probabilistic theory of causation." Transportation Research Part A: Policy and Practice **92**: 184-194.

Love, P. E., et al. (2011). "Moving beyond optimism bias and strategic misrepresentation: An explanation for social infrastructure project cost overruns." IEEE transactions on engineering management **59**(4): 560-571.

Love, P. E. and L. A. Ika (2021). "The 'context'of transport project cost performance: Insights from contract award to final construction costs." Research in Transportation Economics **90**: 101062.

Lundberg, M., et al. (2011). Cost overruns in Swedish transport projects, Centre for Transport Studies Stockholm, Swedish National Road & Transport ….

Mahmoodzadeh, A., et al. (2022). "Optimized machine learning modelling for predicting the construction cost and duration of tunnelling projects." Automation in construction **139**: 104305.

Mahmud, A. T., et al. (2021). "Key driving factors of cost overrun in highway infrastructure projects in Nigeria: a context-based perspective." Journal of Engineering, Design and Technology.

Makovšek, D., et al. (2012). "A cost performance analysis of transport infrastructure construction in Slovenia." Transportation **39**(1): 197-214.

Meharie, M. G., et al. (2022). "Application of stacking ensemble machine learning algorithm in predicting the cost of highway construction projects." Engineering, Construction and Architectural Management **29**(7): 2836-2853.

Memon, A. H., et al. (2011). "Preliminary study on causative factors leading to construction cost overrun." International Journal of Sustainable Construction Engineering and Technology **2**(1).

Merewitz, L. (1973). Cost overruns in public works, Institute of Urban & Regional Development, University of California.

Meunier, D. and M. Welde (2017). "Ex-post evaluations in Norway and France." Transportation research procedia **26**: 144-155.

Miller, M. and E. Szimba (2015). "How to avoid unrealistic appraisal results? A concept to reflect the occurrence of risk in the appraisal of transport infrastructure projects." Research in Transportation Economics **49**: 65-75.

Morris, P. (2013). "Reconstructing project management reprised: A knowledge perspective." Project Management Journal **44**(5): 6-23.

Morris, P. W. and J. Geraldi (2011). "Managing the institutional context for projects." Project Management Journal **42**(6): 20-32.

Morris, S. (1990). "Cost and time overruns in public sector projects." Economic and Political Weekly: M154-M168.

Müller, R., et al. (2016). Organizational enablers for project governance, Project Management Institute.

Müller, R. and J. R. Turner (2005). "The impact of principal–agent relationship and contract type on communication between project owner and manager." International journal of project management **23**(5): 398-403.

Multiconsult (2016). FORPROSJEKT E6 Frya - Sjoa.

Naik, M. G. and V. Radhika (2015). "Time and cost analysis for highway road construction project using artificial neural networks." Journal of Construction Engineering and Project Management **5**(1): 26-31.

Nelwamondo, F. V., et al. (2013). "A dynamic programming approach to missing data estimation using neural networks." Information Sciences **237**: 49-58.

Nicolaisen, M. S. (2012). "Forecasts: fact or fiction?: Uncertainty and inaccuracy in transport project evaluation."

Nijkamp, P. and B. Ubbels (1999). "How reliable are estimates of infrastructure costs? A comparative analysis." International Journal of Transport Economics/Rivista internazionale di economia dei trasporti: 23-53.

NVDB (2022). "Nasjonal vegdatabank (NVDB)." from https://vegkart.atlas.vegvesen.no/#kartlag:geodata/@600000,7225000,3.

Odeck, J. (2004). "Cost overruns in road construction—what are their sizes and determinants?" Transport policy **11**(1): 43-53.

Odeck, J. (2010). "What determines decision-makers' preferences for road investments? Evidence from the Norwegian road sector." Transport Reviews **30**(4): 473-494.

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Odeck, J. (2019). "Variation in cost overruns of transportation projects: An econometric meta-regression analysis of studies reported in the literature." Transportation **46**(4): 1345-1368.

Odeck, J., et al. (2010). "Economic appraisal of universal design in transport: Experiences from Norway." Research in Transportation Economics **29**(1): 304-311.

Odeck, J. and H. Høyem (2021). "The impact of competitive tendering on operational costs and market concentration in public transport: The Norwegian car ferry services." Research in Transportation Economics **90**: 100883.

Odeck, J. and A. Kjerkreit (2019). "The accuracy of benefit-cost analyses (BCAs) in transportation: An ex-post evaluation of road projects." Transportation Research Part A: Policy and Practice **120**: 277-294.

Odeck, J. and T. Skjeseth (1995). "Assessing Norwegian toll roads." Transportation Quarterly **49**(2).

Odeck, J., et al. (2015). "The impact of external quality assurance of costs estimates on cost overruns: empirical evidence from the Norwegian road sector."

OECD, D. (1991). DAC Assistance Committee: Principles for Evaluation of Development Assistance, Paris, OECD DAC. http://www. oecd. org/dac/evaluation/50584880. pdf.

OECD, D. (2002). Evaluation and Aid Effectiveness, Glossary of Key Terms in Evaluation and Results Based Management, OECD, Development Assistance Committee.

Office, U. N. A. (2007). Estimating and monitoring the costs of building roads in England. Department for Transport. Audit report.

Park, Y. I. and T. C. Papadopoulou (2012). "Causes of cost overruns in transport infrastructure projects in Asia: their significance and relationship with project size." Built Environment Project and Asset Management.

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Pickrell, D. H. (1992). "A desire named streetcar fantasy and fact in rail transit planning." Journal of the American Planning Association **58**(2): 158-176.

Pinheiro Catalão, F., et al. (2019). "Exogenous determinants of cost deviations and overruns in local infrastructure projects." Construction management and economics **37**(12): 697-711.

Pinsonneault, A. and K. Kraemer (1993). "Survey research methodology in management information systems: an assessment." Journal of management information systems **10**(2): 75-105.

Pinto, J. K. and D. P. Slevin (1988). Project success: definitions and measurement techniques, Project Management Institute Newton Square, PA.

PMI (2017). A guide to the project management body of knowledge (PMBOK® Guide). 6th ed.

Prosjektavdelingen (2013). Notat ved kostnadsutvikling E6 frya sjoa. Lillehammer.

Qiao, J.-F. and H.-G. Han (2010). "Optimal structure design for RBFNN structure." Acta Automatica Sinica **36**(6): 865-872.

Qu, S. Q. and J. Dumay (2011). "The qualitative research interview." Qualitative research in accounting & management.

Raj, P. and P. Evangeline (2020). The digital twin paradigm for smarter systems and environments: The industry use cases, Academic Press.

Rajakumar, A. (2016). "Analysis of cost overrun in road construction activities–a critical." International Research Journal of Engineering and Technology (IRJET) **3**.

Rajan, T. A., et al. (2014). "PPPs and project overruns: evidence from road projects in India." Journal of Construction Engineering and Management **140**(5): 04013070.

Riksrevisionsverket (1994). Infrastrukturinvesteringar- en kostnadsjamforelse mellan plan och utfall i storre projekt inom Vagverket och Banverket. **23**.

Ringle, C. M., et al. (2010). Response-based segmentation using finite mixture partial least squares. Data Mining, Springer.

Rossi, P., et al. (2004). "Measuring and monitoring program outcomes." Evaluation: a systematic approach. 7th ed. Thousand Oaks, CA: Sage: 203-232.

Rossi, P. H., et al. (1983). "Sample surveys: History, current practice, and future prospects." Handbook of survey research: 1-20.

Rouhi, A. and H. Nezamabadi-Pour (2020). "Feature selection in high-dimensional data." Optimization, Learning, and Control for Interdependent Complex Networks **1123**: 85.

Roxas, N. R. and S. Chalermpong (2008). Forecasting inaccuracies in transportation projects in selected South East Asian countries. Proceedings of the 16th Annual Conference of the Transportation Science Society of the Philippines, Pasay City, Philippines.

Rwakarehe, E. E. and D. A. Mfinanga (2014). "Effect of inadequate design on cost and time overrun of road construction projects in Tanzania." Journal of Construction Engineering and Project Management **4**(1): 15-28.

Sabri, O. K., et al. (2019). "Why conflicts occur in roads and tunnels projects in Norway." Journal of Civil Engineering and Management **25**(3): 252-264.

Sager, T. Ø. (2016). "Why don't cost-benefit results count for more? The case of Norwegian road investment priorities." Urban, Planning and Transport Research **4**(1): 101-121.

Samarghandi, H., et al. (2016). "Studying the Reasons for Delay and Cost Overrun in Construction Projects: The Case of Iran."

Samferdselsdepartementet (2012). Kvalitetssikring av prosjekt E6 Frya-Sjoa.

Samset, K. (2003). "Project evaluation." Making investments succeed, Trondheim, Tapir Akademisk Forlag.

Samset, K. and T. Christensen (2017). "Ex ante project evaluation and the complexity of early decision-making." Public Organization Review **17**(1): 1-17.

Samset, K. and G. H. Volden (2017). "Quality Assurance in Megaproject Management: The Norwegian Way."

Samset, K. F. and G. H. Volden (2013). Investing for Impact. Lessons with the Norwegian State Project Model and the first ivvestment projects that have been subjected to external quality assurance, Ex Ante Akademisk forlag.

Samset, K. F. and G. H. Volden (2014). "Front end Governance of Major Public Projects-Lessons with a Norwegian Quality Assurance Scheme."

Sarmento, J., et al. (2017). "Measuring highway efficiency by a DEA approach and the Malmquist index." European Journal of Transport and Infrastructure Research **17**(4).

Sharma, S., et al. (2021). "A survey on applications of artificial intelligence for Pre-Parametric Project Cost and Soil Shear-Strength estimation in construction and geotechnical engineering." sensors **21**(2): 463.

Siemiatycki, M. (2009). "Academics and auditors: Comparing perspectives on transportation project cost overruns." Journal of Planning Education and Research **29**(2): 142-156.

Siemiatycki, M. (2016). Cost overruns on infrastructure projects: Patterns, causes, and cures, Institute on Municipal Finance and Governance.

Singh, R. (2010). "Delays and cost overruns in infrastructure projects: extent, causes and remedies." Economic and Political Weekly: 43-54.

Situ, H. (2022). The Costs of Megaprojects: An Analysis of the Hong Kong-Zhuhai-Macau Bridge. Viterbi Conversations in Ethics, USC Viterbi School of Engineering. **6**.

Skamris, M. K. and B. Flyvbjerg (1997). "Inaccuracy of traffic forecasts and cost estimates on large transport projects." Transport policy **4**(3): 141-146.

Śmieja, M., et al. (2018). "Processing of missing data by neural networks." Advances in neural information processing systems **31**.

Song, Y., et al. (2018). "Segment-based spatial analysis for assessing road infrastructure performance using monitoring observations and remote sensing data." Remote Sensing **10**(11): 1696.

Statistics-Norway (2019). "Consumer price index." from https://www.ssb.no/en/priser-og-prisindekser/konsumpriser/statistikk/konsumprisindeksen.

Statistics-Norway (2020). "Production index for construction."

Sug, H. (2010). "Investigating better multi-layer perceptrons for the task of classification." WSEAS Trans. Comput **9**(5): 475-480.

Tijanić, K., et al. (2020). "Cost estimation in road construction using artificial neural network." Neural Computing and Applications **32**(13): 9343-9355.

Towne, L. and R. J. Shavelson (2002). Scientific research in education, National Academy Press Publications Sales Office.

Turochy, R. E., et al. (2001). Highway project cost estimating methods used in the planning stage of project development, Virginia Transportation Research Council.

ÜRESİN, U. (2021). "Correlation Based Regression Imputation (CBRI) Method for Missing Data Imputation." Turkish Journal of Science and Technology **16**(1): 39-46.

Van Wee, B. (2007). "Large infrastructure projects: a review of the quality of demand forecasts and cost estimations." Environment and Planning B: planning and design **34**(4): 611-625.

Vartabedian, R. (2021). Years of Delays, Billions in Overruns: The Dismal History of Big Infrastructure. The new York Times.

Vegvesen, S. (2012). E6 Ringebu - Otta kostnadsoverslag etter anslagsmetoden.

Vinzi, V. E., et al. (2010). PLS path modeling: from foundations to recent developments and open issues for model assessment and improvement. Handbook of partial least squares, Springer**:** 47-82.

Volden, G. H. (2018). "Public project success as seen in a broad perspective.: Lessons from a meta-evaluation of 20 infrastructure projects in Norway." Evaluation and program planning **69**: 109-117.

Volden, G. H. (2019). "Public funding, perverse incentives, and counterproductive outcomes." International Journal of Managing Projects in Business **12**(2): 466-486.

Volden, G. H. (2019). "Public funding, perverse incentives, and counterproductive outcomes." International Journal of Managing Projects in Business.

Volden, G. H. (2019). "Up-Front Governance of Major Public Investment Projects."

Wachs, M. (1982). "Ethical Dilemmas in Forecasting for Public Policy." Public Administration Review(42): 557-562.

Wang, Z., et al. (2006). "Optimized multilayer perceptrons for molecular classification and diagnosis using genomic data." Bioinformatics **22**(6): 755-761.

Welde, M. (2017). Kostnadskontroll i store statlige investeringer underlagt ordningen med ekstern kvalitetssikring, Ex ante akademisk forlag.

Welde, M. (2018). "In search of success: Ex-post evaluation of a Norwegian motorway project." Case Studies on Transport Policy **6**(4): 475-482.

Welde, M., et al. (2020). "Road investments and the trade-off between private and public funding." Research in Transportation Economics **82**: 100875.

Welde, M. and R. E. Dahl (2021). "Cost escalation in road construction contracts." Transportation Research Record **2675**(9): 1006-1015.

Welde, M. and J. Odeck (2017). "Cost escalations in the front-end of projects–empirical evidence from Norwegian road projects." Transport Reviews **37**(5): 612-630.

Welde, M., et al. (2014). "Lav prising–store valg en studie av underestimering av kostnader i prosjekters tidligfase." Concept rapport.

Welde, M. and G. H. Volden (2018). "Measuring efficiency and effectiveness through ex-post evaluation: Case studies of Norwegian transport projects."

Windeatt, T. (2008). Ensemble MLP classifier design. Computational Intelligence Paradigms, Springer**:** 133-147.

Wondimu, P. A. (2019). "Early contractor involvement (ECI) approaches for public project owners."

Worsley, T. (2014). Ex-post assessment of transport investments and policy interventions, OECD/ITF.

Wu, Q. (2006). Transportation infrastructure project cost overrun risk analysis: risk factor analysis models, University of British Columbia.

Xu, H., et al. (2022). "Application of Artificial Neural Networks in Construction Management: A Scientometric Review." Buildings **12**(7): 952.

Xu, L., et al. (2019). "Modeling tabular data using conditional gan." arXiv preprint arXiv:1907.00503.

Yang, Y., et al. (2011). L2, 1-norm regularized discriminative feature selection for unsupervised. Twenty-second international joint conference on artificial intelligence.

Yang, Y., et al. (2022). "A novel radial basis function neural network with high generalization performance for nonlinear process modelling." Processes **10**(1): 140.

Yin, R. K. and D. Davis (2007). "Adding new dimensions to case study evaluations: The case of evaluating comprehensive reforms." New directions for evaluation **2007**(113): 75-93.