Identifying Leading Indicators in the Engineering Phase of Infrastructure Projects

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Preface

As my time at TU Delft draws to a close through this thesis, I reflect on an incredible journey of growth and discovery. Today, I stand transformed, having embraced every challenge and opportunity for growth along the way. I am eternally grateful to my parents for believing in me and supporting me to pursue this degree.

The journey of my thesis was indeed a roller coaster ride. There were moments when I felt confident and sure about my approach, but there were also times when I questioned whether I was on the right track. However, my uncertainties were short-lived, often lasting no more than a week. This was due to the weekly meetings I had with my company supervisor, Pieter. I am profoundly grateful to you for generously dedicating your time to guide me.

I would also like to express my gratitude to Martijn. Our discussions have played a significant role in clarifying many concepts and ideas. Your insights have been invaluable.

I extend my heartfelt appreciation to Prof. Hans Bakker for providing me with detailed feedback. Your guidance has driven me to enhance my report, pushing me to think beyond boundaries.

Mr. Hans Ramler, your constant motivation has been truly uplifting. During our progress meetings, your positive comments always managed to boost my confidence. Even if it was a simple compliment on my presentation or topic choice, it made a meaningful difference.

Furthermore, I would like to express my gratitude to the individuals at Sweco. They consistently showed openness to discuss various aspects of this research and willingly participated in numerous interviews. I am also grateful to my friends at CME, in the Netherlands, and in India for their motivation throughout my thesis and master's journey.

This journey wouldn't have been possible without my invaluable support system - my greatest cheerleaders: my sister, Saurabh, and Payal. Even though my sister and I have been miles apart, it never felt like we were separated. Your presence has always been with me, and I'm truly grateful for that. Saurabh, your unwavering support is something I can't thank you enough for. I genuinely appreciate having you in my life. I acknowledge that surviving at TU Delft would have been considerably more challenging without all three of you. A special mention goes to Payal for her continuous encouragement and support. Your presence has made a meaningful difference on this journey.

And with that, it's a wrap! Sneha Singh bidding farewell to an incredible journey at TU Delft. These past seven months have been a dedicated hustle on my thesis – that's where all my energy went lately. I've poured my heart and soul into crafting this report. Now, it's your turn to dive in and enjoy the read!

Executive Summary

Infrastructure projects commonly face delays or cost issues (Koirala, 2017). A recent PMI survey found that 70% of construction projects experience scope creep, 73% exceed budgets, and 72% encounter delays (Uwaegbulam, 2022). The frequent cost overruns being a norm, especially in large projects (Gale, 2011) (Ika, 2009) (Flyvbjerg et al., 2002), demands for focus on cost and schedule performance. Cost influence is most prominent in the initial project phase, with costs rising in subsequent phases due to limited initial information (Gale, 2011). Therefore, this research concentrates on cost and schedule performance during the initial phase of infrastructure projects.

The Key Performance Indicators (KPIs) are broadly divided into two categories: leading indicators and lagging indicators. Leading indicators measure activities that have a significant effect on future performance of a project. The leading indicator thus help in taking proactive measures, while lagging indicators measure the output of past activities, thus enables in taking reactive measures. The emphasis of this research is on leading indicators.

The existing performance assessment system mainly relies on lagging indicators. Since, lagging performance indicators represent outcomes of the events that have already, they are of little value in improving the current performance. On the other hand, leading indicators predict the potential issue in the project before it affects the project baseline. They are used to predict the likelihood of the future lagging indicators, and so they help in providing actionable information that can be used to predict the likelihood of a future lagging indicator (Peng et al., 2011).

There is a lack of research and focus on identifying leading indicators. Therefore, the objective of this research is to identify the most relevant leading indicators in the engineering phase from the perspective of engineering consultants and determine how these indicators can be monitored. The primary research question this study aims to address is:

How can leading indicators be used to monitor the performance of an infrastructure project during the engineering phase?

The main research question is answered by using a qualitative research approach. The research is divided into four phases.
The first phase of the research is dedicated to literature study. During this phase, the literature on leading indicators was reviewed and a theoretical framework was created. There are very few articles on leading indicators in construction industry. A total of three articles were identified. However, the articles were based on extensive literature review and empirical research data collection, which lends credibility to their findings. Moreover, the articles considered design and construction phase, as the focus of this research is only on engineering phase, the indicators that belong to construction phase were excluded. The leading indicators in the framework are based on team alignment, change management, contracting, quality, team building, decision making by client and resource management. It was also discovered in the literature that the engineering phase receives very little attention (Habibi et al., 2018), although having the greatest potential to influence the cost of a project (Gale, 2011).

The leading indicators identified in the literature involve perspectives of different stakeholders. Moreover, the articles consider design phase, but it does not explicitly mention whether the design phase consists of conceptual design, detailed design or the entire engineering design. This gives rise to the subsequent phase.

The second phase of the research comprises of expert interviews. Along with identifying the leading indicators in practice, the aim of this phase was to understand the familiarity of project managers with leading indicators and understand the current performance management. A total of eight

expert interviews were conducted in a semi structured manner. It was observed that after the first six interviews, a saturation point in the was reached. The interview analysis revealed that the project managers were not familiar with the term leading indicators, however they acknowledged the rationale behind the leading indicators. It was also found that the current performance system is highly based on lagging indicators. After comparing the leading indicators identified in the interviews with the theoretical framework, the indicators relevant to the engineering phase were identified.

The completion of phase 2 resulted in an exhaustive list of leading indicators. Thus, out of the two research objectives, the first objective of identifying the most relevant leading indicators in the engineering phase was achieved. The most relevant indicators identified are change requests, decision-making by the client, communication, project size, bidding at low prices, resource allocation, project team turnover, team efficiency, and external factors.

The subsequent phase involved testing these leading indicators to observe their manifestations in a project. As a result, four case studies were conducted, and the project managers for each case were interviewed. The interviews confirmed the leading indicators identified during expert interviews. This confirmation demonstrated that all project challenges and opportunities were encompassed by these leading indicators, validating their comprehensiveness.

The secondary objective of the case study interviews was to determine how these indicators affected the project's cost and schedule performance. It was observed that external factors and communication had a neutral impact on the project's cost and schedule performance. Bidding at low price was also identified in only one phase of the project.

Thus, the indicators that exert a significant impact on the project's cost and schedule performance are Change Requests, Decision Making, Resource Allocation, Team Efficiency, and Project Team Turnover. Based on the below mentioned factors, the indicators had a positive and/or negative impact on the cost and schedule performance of the project

The factors influencing change requests include the change management process. Factors influencing client decision-making included the clarity of decisions made, the time taken to decide, and the provision of essential input. Factors affecting team efficiency were the availability of required expertise, enthusiastic designers, and effective communication within the team. Resource allocation factors were also determined by the availability of required expertise. Additionally, project team turnover led to team instability.

While Communication was not identified to have a direct impact on the project's cost and schedule, it functions as a hygiene factor, and its absence can indeed influence the outcomes. Therefore, Communication is also considered. Consequently, these indicators are incorporated in the final phase for framework development.

Leading indicators: Change Requests, Team Efficiency, Project Team Turnover, and Decision Making—evolve during the project. In contrast, resource allocation is determined at the start of the project. Consequently, monitoring these indicators should initiate from project inception. Given their evolving nature, leading indicators necessitate ongoing monitoring throughout the project, as depicted in Figure 1.

During the project:
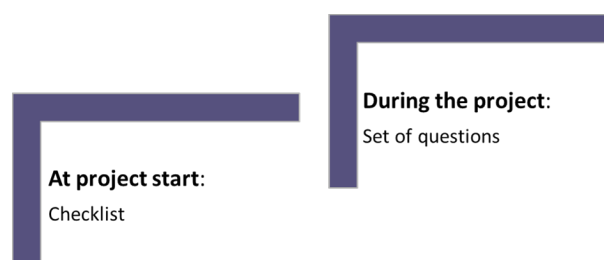Set of questions

At project start:
Checklist

Figure 1: Phases of monitoring leading indicators

At the project start a checklist is made that should be used by the project managers. The checklist is to gain insight into the formation and composition of the project team including the required expertise and skill sets. As the project commences, the project manager should monitor the indicators using the second part of the framework that is based on a set of questions. The framework as described in figure 2 is built on the basis of the results of the case study interviews and expert interviews

With the development of the framework, the research's second objective of monitoring the most relevant leading indicators is also accomplished. The framework should be utilised by the project managers and the project controls. The proposed framework enhances project managers' ability to predict and manage potential issues. By introducing regular monitoring, it strives for greater predictability in project cost and schedule performance. This proactive approach empowers timely issue identification and informed actions. A crucial aspect is the generic framing of questions, facilitating application across diverse projects. This adaptability is reinforced by the framework's concise question set, promoting efficiency and effortless integration into project managers' workflows.

Checklist: At Project Start

1. The required expertise are present in the project.

2. Expertise are hired from a different location.

3. Expertise are hired from an external party/secondment.

4. The procedure and timeline for responding to design change is defined.

5. Communication plan with team is made.

6. Communication plan with the client is made.

List of Questions: During the Project

1. How is the change request process?

1.1 Has the client approved of the extra time and cost incurrerd due to the change?
1.2 Agreement for extra work is present?
1.3 What is your intuitive sense about the process?

2. How is the decision making by client in the project?

2.1 Is it required by the project team to frequently go to the client to clarify decisons?
2.2 Is the client making decisions in time?
2.3 Is the client providing the essential information requested in time?
2.4 What is your intuitive sense about the process?

3. How efficient is the project team?

3.1 Are the team members able to deliver the requirements as per the internal deadlines?
3.2 Is the required expertise avaliable in the team?
3.3 What is your intuitive sense about the team performance?

4. How is project team turnover in the project?

4.1 Are the project members leaving the project?
4.2 Are new members joining the project?
4.3 What is your intuitive sense about the turnover?

5. Is the communication taking place as planned?

Figure 2: Framework

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Chapter 1

Introduction

In this chapter, the groundwork for this research is established. The background on leading indicators is explained in section 1.1. In the next section 1.2 company introduction is provided. Subsequently in section 1.3 and 1.4 the problem statement and the research gap is outlined. Section 1.5 illustrates the research objective. Finally section 1.6 highlights the research questions adopted for this research.

1.1   Background

Most of the infrastructure projects are overdue in terms of either time or cost (Koirala, 2017). A recent survey by Project Management Institute (PMI), has revealed that 70% of construction projects experience scope creep, and 73% of such projects ended over budget. Moreover, it is also found that 72 % of construction projects often experience project delays (Uwaegbulam, 2022).

Despite the severity and frequency of cost overrun, it is considered a rule rather than an exception in the construction projects (Gale, 2011), (Ika, 2009), and especially large and complex projects are subjected to cost overruns (Flyvbjerg et al., 2002). Therefore, there is a need to focus more on the cost and schedule performance of the project.

The influence on cost is most significant during the initial phase of a project. Additionally, the cost of each subsequent phase increases as the project progresses towards its final stages (Hendrickson, 2008), as illustrated in Figure 1.1. One contributing factor to this trend is the limited availability of information at the project's outset, with clarity improving as the project advances.
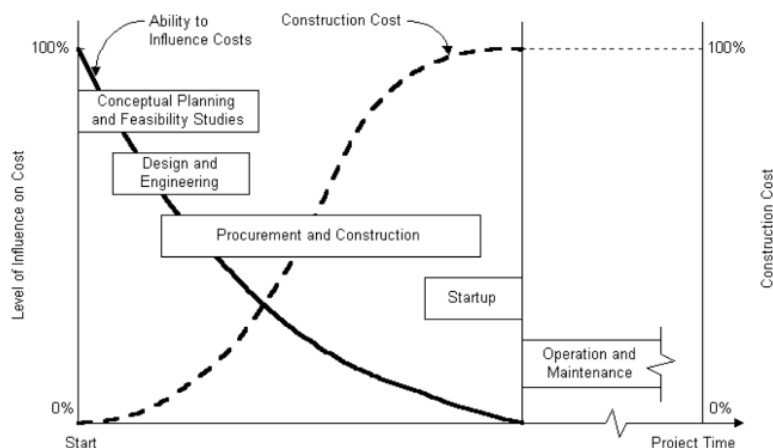
Figure 1.1: Cost/Influence Curve, (Hendrickson, 2008)

Thus, the core of this research is based on cost and schedule performance in the initial phase of infrastructure projects.

Performance Measures

According to Parmenter, (2015) there are four types of performance measures - Key Result Indicators (KRI), Result Indicators (RIs), Performance Indicators (PIs), and Key Performance Indicators (KPIs). KRIs provide insights into achievements from a perspective or critical success factor. RIs indicate what actions needs to be taken, PIs indicate what actions must be taken, and KPIs indicate the specific steps that needs to be taken to greatly improve performance (Badawy et al., 2016). The emphasis of this research is on the Key Performance Indicators. He explains performance measures with the help of an onion ring as described in figure 1.2.

"The outside skin describes the overall condition of the onion, the amount of sun, water, and nutrients it has received; and how it has been handled from harvest to the supermarket shelf. The outside skin is a key result indicator. However, as we peel the layers off the onion, we find more information. The layers represent the various performance and result indicators, and the core represents the key performance indicator."
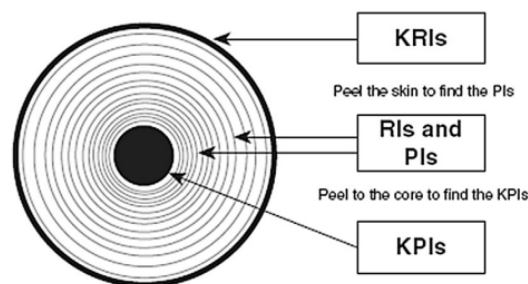
Figure 1.2: Types of Performance measures, (Parmenter, 2015)

The Key Performance indicators are broadly divided into the following two types:

1. **Leading Indicator:** A KPI that measures activities with a substantial impact on future performance, which serve as the causal factors for the outcome they influence (referred to as lagging indicators), and are actionable for future performance against one or more lagging indicators. (Peng et al., 2011).
2. **Lagging Indicator:** A KPI that measures the output of past activities is the lagging indicator (Peng et al., 2011).

The KPIs in practice are majorly dependent on the lagging indicators. However, lagging indicators are historical in nature, reporting outcomes and the consequences of past actions thus, they are of little use in improving current performance (Pekuri et al., 2011) (Atkinson, 1999);(Kululanga et al., 2001); (Bassioni et al., 2004). The current dominance of outcome-based project performance measurement with lagging indicators must give way to a more balanced measurement system that includes prediction-based measurement. (Zheng et al., 2019)(Yun et al., 2016).

To develop a balanced monitoring system, it is necessary to first identify the leading indicators. Monitoring the progress of the project should be done carefully by considering "what" should be measured, or more precisely, selecting a system of performance indicators (Zheng et al., 2019). Thus, this research aims to identify the most relevant leading indicators in the engineering phase of infrastructure projects and establish a framework that can be used to monitor these indicators regularly.

1.2 Company Introduction: Sweco Netherlands B.V.

The research is facilitated and supported by Sweco, Netherlands B.V., a Scandinavian company founded in 1958. With its roots in Sweden, Sweco is Europe's leading architectural and engineering consultancy, boasting a workforce of 20,000 employees and a turnover of approximately 2.2 billion euros. The company is listed on the Nasdaq Stockholm.

Sweco is a service-providing company that offers engineering and consultancy services in the three major departments of Buildings and Urban Areas, Mobility and Infrastructure, and Water, Energy, and Industry.

This research primarily focuses on the mobility and infrastructure services provided by the company, specifically within the Transport and Mobility department. This department is composed of five subdivisions, as depicted in figure 1.3 and focuses on providing engineering solutions for the infrastructure in the Netherlands.
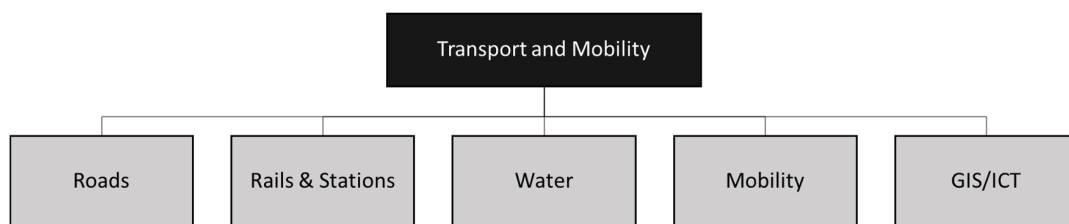
Figure 1.3: Transport and Mobility department

    The department has projects in the engineering phase in either one or all of phases in the engineering as described in figure 1.4. The engineering phase begins with defining the project requirements and conducting research. Based on the research findings, a feasibility study is conducted to determine whether the project is viable. This study serves as a go/no-go scenario. After completing the feasibility study, a conceptual design is developed. This phase involves exploring various design options and selecting the final concept at the end.
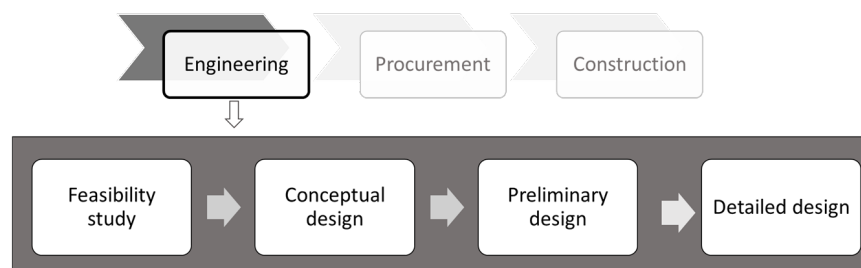
Figure 1.4: Engineering phase

    In this research, the engineering consultants of the case company, Sweco Netherlands B.V., will be referred to as "engineering consultants," and the term "project" will specifically denote engineering design projects unless otherwise stated.

1.3 Problem Statement

The intensity of project overruns has remained unchanged for decades especially in the infrastructure industry. Therefore, it is imperative to address these issues as project overruns do not occur abruptly; rather, they stem from a series of consecutive events that ultimately lead to such overruns (Bhattad, 2019). Similarly, delays are not sudden discoveries but rather the result of a gradual accumulation of

problems (Wijtenburg, 2018). Thus, monitoring these problems can give better and early feedback of the project performance.

Despite the importance of leading indicators, they are often neglected. As mentioned earlier, the current performance monitoring system relies majorly on lagging indicators. Thus, the problem statement for this research is formulated as:

"*The current performance monitoring system relies on lagging indicators, resulting in a more reactive approach rather than a proactive one.*"

1.4 Research Gap

Project performance measurement has been extensively studied by both academics and practitioners, leading to significant methodological advancements. Examples of these include earned value project management (Anbari, 2003; Hall, 2012; Lipke et al., 2009), performance measurement of engineering projects (Guo & Yiu, 2016; Shi et al., 2015), and benchmarking project performance management (Barber, 2004; Kim & Huynh, 2008). One common characteristic of these techniques is that they are all lag-based, meaning they assess project performance based on past data.

Extensive research has been conducted to identify the leading indicators in the health and safety of construction (Bhagwat et al., 2022; Neamat, 2019; Versteeg et al., 2019).

In the construction industry, the Engineering phase has received less attention compared to the Construction phase in terms of identifying performance indicators (Yang & Wei, 2010); (Liao et al., 2011); (Habibi et al., 2018); (Habibi & Kermanshachi, 2018). The engineering phase, known for its high uncertainties and limited information, has a significant impact on project costs (Liao et al., 2011). However, despite its importance, this phase has not received adequate attention. The scarcity of information during this phase necessitates a proactive approach to effectively manage project changes.

Despite the recognition of the importance of leading indicators in predicting future project performance, there is a limited amount of research on this topic. While project performance measurement has made significant progress, the utilization of leading indicators beyond health and safety remains restricted. Further research and practical application are necessary to explore the potential of leading indicators in measuring performance across various project dimensions. As a result, the identified research gap is:

"*There is a lack of research and focus on identifying the leading indicators in the engineering phase of an infrastructure project.*"

1.5 Research Objective

To approach the research problem and address the research gap, a research objective needs to be formulated. Therefore, the goal of the research is twofold

1. To identify the most relevant leading indicators in the engineering phase of an infrastructure project.
2. To determine how the identified leading indicators can be monitored.

1.6 Research Question

To tackle the current research gap, the following research question is formulated.

How can leading indicators be used to monitor the performance of an infrastructure project during the engineering phase?

In order to, answer this overarching research question, the following sub-questions (SQ) are defined:

1. ***What are the most relevant leading indicators in literature?***
   The aim of this sub-question is to identify the most relevant leading indicators that have been mentioned in the existing literature. By exploring the literature, the research seeks to gain insights into which indicators are commonly considered significant for monitoring project performance in the engineering phase of infrastructure projects.

2. ***What are the most relevant leading indicators in practice?***
   The aim of this sub-question is to identify the most relevant leading indicators that are identified in practice by conducting expert interviews. By gathering information from real-world project management practices, the research aims to understand which indicators are commonly identified and considered important for monitoring project performance in the engineering phase.

3. ***How do the identified indicators affect the cost and schedule performance of a project?***
   The aim of this sub-question is to identify how the identified indicators influence project performance by conducting case study interviews.

4. ***How can the identified leading indicators be monitored?***
   The final sub-question ultimately addresses the main research question by aiming to propose a monitoring approach for the identified leading indicators in a project.

Chapter 2

Research Methodology

This chapter is dedicated to providing insights into the methodology used to answer the research questions. In section 2.1 the scope of this research is defined. In the following section 2.2 research characteristics is explained. Finally, in section 2.3 the research framework is depicted.

2.1 Research Scope

To ensure that the research is focused, rigorous, and relevant, it is important to establish the boundary conditions of the research that will assist in distinguishing what is included and excluded in the research. Thus the coverage of the research is limited to the following parameters.

1. **Construction Project Management**
   Project management is widely practiced in various industries, including information technology (IT) and manufacturing. While project management tools and techniques such as Earned Value Management, Benchmarking, and Cost Benefit Analysis are applied in a similar way across industries, leading indicators cannot be uniformly applied since they are sector-specific. Therefore, this research focuses solely on construction project management to investigate sector specific issues. The researcher's enthusiasm for the construction industry is one primary reason for selecting this industry for study. Additionally, compared to other industries, the construction industry still struggles to complete projects on time and within budget.

2. **Dutch Infrastructure Projects**
   The case study conducted for this research are all infrastructure projects based out of Netherlands. If a similar study is done in another country, the results might be different. This is because leading indicators are based on people's opinions and ideas, and the way people think can be different in other countries. So, the outcomes could vary in different places.

3. **Engineering Phase of an infrastructure project**
   Engineering phase involves making numerous important decisions during pre-project planning and holds the highest level of influence on the project (Habibi & Kermanshachi, 2018). Hence, the scope of this research is specifically limited to the engineering phase.

4. **Cost and Schedule Performance**
   The project performance of the infrastructure industry depends on several factors, such as client and stakeholder satisfaction, quality, scope, cost, and schedule performance. However, this research focuses specifically on investigating the leading indicators of cost and schedule performance in the engineering phase of an infrastructure project.

5. **Engineering Consultants**
   Infrastructure projects in the engineering phase typically involve the participation of numerous actors. This research focuses on gaining insight from the viewpoint of engineering consultants. Sweco, an engineering firm, actively participates in the research, providing valuable practical resources.

6. **Post Bid phase**
   The scope of this research is limited to identifying the leading indicators after the engineering contract is awarded to the engineering consultants. Therefore, the bidding phase is not included in the scope of this study.

7. **Identifying and monitoring leading indicators**
   The research aims to identify the leading indicators and propose a monitoring method. It is essential to note that the research does not cover how to respond to these leading indicators. Instead, the emphasis is solely on their identification and the provision of a monitoring approach.

2.2 Research Characteristics

The research is conducted using a qualitative research technique. The rationale behind choosing this research technique is as follows:

1. Qualitative method is used to understand people's beliefs, experiences, attitudes, behavior, and interactions (Pathak et al., 2013). Since the research involves leading indicators, it is important to focus on these subjective dimensions.

2. Use of open-ended questions gives participants the opportunity to respond in their own words, rather than forcing them to choose from fixed responses. They allow the researcher the flexibility to probe initial participant responses – that is, to ask why or how (Mack et al., 2005).

3. Qualitative research is appropriate if a concept needs to be explored and introduced, as the topic of this thesis (Creswell, 2009).

2.3 Research Framework

The research is divided into four phases, as shown in figure 2.1. The first phase is dedicated to the literature study, while the second and third phases involve empirical data collection through interviews. The fourth phase consists of framework development and expert validation as described in figure 2.1
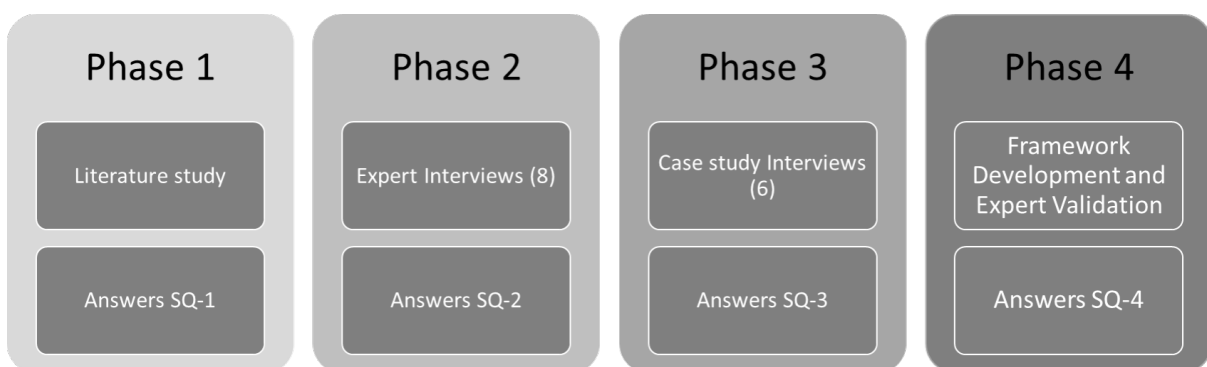
Figure 2.1: Research Framework

    The first phase of the study involves a literature review addressing the first sub-research question. Various sources, such as web articles, research articles, conference proceedings, books, and thesis reports, were examined. To ensure comprehensive coverage, multiple electronic databases, including Web of Science, ResearchGate, Google Scholar, Academia, and the TU Delft repository, were utilized. The search keywords used were leading indicators, lagging indicators, performance measurement, monitoring and control, early warning signals, engineering phase, EPC, cost overrun, and schedule overrun. Reputable journals like the International Journal of Project Management, Construction

Management, and Economics were also referenced.

The second phase of the research involves expert interviews, which are described in detail in section 4.1. The third phase consists of conducting case study analysis to understand the effects of the identified leading indicators, the process is described in detail in section 5.1. In phase 4, based on the findings from the first three phases, a framework for monitoring leading indicators will be developed and expert validation will be conducted to understand the practicality and validity of the research from an external perspective. The research process is explained with the help of input-output model in table 2.1.

Table 2.1: Input-Output Model

Phase	Input	Process	Output
Phase 1	Relevant papers on leading indicators	Literature study	Theoretical framework
Phase 2	Expert PM infrastructure project, Theoretical framework	Expert Interviews	Exhaustive list of leading indicators
Phase 3	Exhaustive list of indicators, 4 cases	Case Study Analysis	Validation and impact of leading indicators in projects.
Phase 4	Results of expert interviews, results of case study analysis and theoretical framework	Analysis and Expert validation	Framework for monitoring leading indicators

Chapter 3

Literature Review

This chapter provides a review of the literature on the topic of leading indicators. This refers to the first of four research phases. The purpose of this chapter is to identify the leading indicators in literature. The sub question that is answered in this chapter is:

SQ1: What are the most relevant leading indicators in literature?

In order to answer this sub research question, it is first important to define leading indicators. Therefore in section 3.1, the definition of leading indicators is established. In next section 3.2, the effectiveness of using leading indicators is described. Section 3.3 describes the leading indicators identified in literature. Furthermore, section 3.4 represents the analysis of the identified leading indicators, based on this theoretical framework is developed. In the final section 3.5, conclusion of the chapter is presented.

3.1 Definition of Leading Indicators

In the Construction Industry Institute (CII), based in University of Texas at Austin, Leading indicators are defined as *fundamental project characteristics and/or events that reflect or predict project health. Revealed in a timely manner, these indicators allow for proactive management to influence project outcomes* (Choi, 2007). The same definition was also used by Zheng et al., (2019) in his study to study the importance of leading indicators in project performance.

The definition provided by the Construction Industry Institute has been widely accepted and adopted. It clearly shows the link between leading indicators and project outcomes while depicting the proactive characteristics of the leading indicators. Therefore, the definition provided by Choi, (2007) will be considered for this research. However, since the focus of this research is on cost and schedule performance, project health is replaced by cost and schedule performance. To provide a more clear explanation, the definition is expanded to explicitly state that leading indicators reflect project performance before they affect the project baseline. Thus, for this research, the following definition will be adopted.

"Leading indicators are the fundamental project characteristics and/or events that reflect or predict the possible cause of cost and schedule performance before they affect the project baseline. Revealed in a timely manner, these indicators allow for proactive management to influence the project baseline and ultimately the project output."

3.2 Effectiveness of using leading indicators

While paying attention to time and cost is crucial in project management, additional measures are needed to comprehensively assess project performance (Saladis & Kerzner, 2011). Leading indicators helps in taking proactive measures to manage project performance (Almahmoud et al., 2012). Leading indicators predict changes or trends in the project and it can reduce performance risk on a project by identifying potential performance variances before they cross the tolerance

threshold (Project Management Institute, 2021).

They serve as a means of tracking or monitoring the performance of a process as it is taking place and provide a way of determining whether a particular process or processes are being implemented as planned (Hinze et al., 2013). These indicators are used to predict the likelihood of future lagging indicators, thereby providing actionable information that can be used to prevent future negative events (Grabowski et al., 2007); (Sinelnikov et al., 2015), (Yun et al., 2016).

3.3   Leading Indicators Identified in Literature

Three articles have identified the leading indicators in construction projects. The articles categorize leading indicators into three distinct groups: rework-based indicators, project phase-based indicators, and project outcome-based indicators. The first two rely solely on literature reviews, while the third incorporates empirical data collection as a fundamental aspect of its research methodology as described in figure 3.1. The extensive research conducted in these three sources lends credibility and reliability to the findings. The articles are further discussed in detail below.

Based on Rework, (Safapour, Kermanshachi, and Taneja 2019)
- Literature Review paper
- Reviewed 100+ peer-reviewed articles, papers, dissertations, and reports on rework variables (organization, project, human)

Based on Project Phases, (Habibi, Kermanshachi, and Safapour 2018)
- Literature Review paper
- Reviewed 200+ peer-reviewed articles, papers, dissertations, and reports on cost overrun and delay.

Based on Project Outcomes (2007)
- Master's thesis involving project managers from the Construction Industry Institute (CII) in the research team.
- Empirical data.
- Conducted two rounds of survey with industrial experts, receiving 100+ responses. Third round involved all members of the Construction Industry Institute (90+ organizations, including companies and government agencies).

Figure 3.1: Literature overview for identifying leading indicators

1. Based on Rework

Safapour et al., (2019) emphasize that rework is inevitable in all types of construction projects and early prediction of these indicators in the design and construction phase will benefit the project managers.

To identify early indicators of rework, they categorize them into three groups: organization, project, and people, based on existing literature. Through a critical examination of numerous rework leading indicators from over 100 peer-reviewed journal articles, conference papers, dissertations, and research reports, they present the identified indicators as included in table 3.1. Only the leading indicators with the highest occurrence frequency in the literature are explained in the article, and accordingly, only those indicators are considered in this research.

Table 3.1: Leading Indicators of Re-work (Safapour et al., 2019)

Project-based	Organization-based	Human-based
Inappropriate/Poor design	Ineffective coordination	Lack of experience
Unclear Scope definition	Lack of resource management	Lack of skill
Site location issues	Ineffective communication	Lack of knowledge
Material issues		

2. Based on Project Phase

A research was conducted by Habibi et al., (2018) to identify the leading performance indicators (LPIs) that can affect project schedule and cost performance. It was emphasized that identifying the LPIs helps construction practitioners to proactively prepare preventive strategies and best practices to mitigate schedule and cost overruns. The leading indicators were identified considering the entire project life cycle and categorized into three phases: Engineering, Procurement, and Construction. As the scope of this research is limited to engineering phase, only the indicators in the engineering phase are described below.

The authors identified leading schedule and cost performance indicators by prioritizing them based on their frequency of occurrence in articles. More than two hundred peer-reviewed journal articles focusing on cost overrun and delay from 1971 to 2017 were identified and collected from various regions around the world (Habibi et al., 2018).

The authors highlight that the research on engineering phase is limited because the number of articles in the literature that focuses on engineering phase was very less as compared to the construction and procurement phase. They emphasize the critical role of the engineering phase in identifying and designing owner requirements, yet it receives comparatively less attention in the literature, indicating a lack of focus on this phase. Table 3.2 describes the comprehensive list of the identified indicators in the Engineering phase. The authors indicate that "design change" has the most significant impact on schedule/cost performance during the engineering phase.

Table 3.2: Leading Indicators Categorized by Project Phases (Habibi et al., 2018)

Leading Performance Indicators	
Category	Indicator
Engineering Phase	
Schedule Performance Indicators	
Change	Design change.
Client related	Slowness in making decisions.
	Delay in approval stage.
Management	Poor communication between stakeholders.
Cost Performance Indicators	
Change	Design change.
Project related	Project size.
Management	Poor communication between stakeholders.

3. Based on Project Outcomes

Choi, 2007, (2007) conducted a survey of industry professionals, and identified 43 leading indicators. The survey included questionnaires distributed to over 90 member companies of the Construction Industry Institute, comprising both organizations and government agencies. The indicators identified were categorized into eight groups: alignment, change management, constructability, contracting, quality management, safety practices, project control, and team building.

This research excludes the constructability and safety practices group, as well as the indicator related to vendors and contractors performing functions outside their expertise, because these indicators

are explicitly mentioned to be in the construction phase. Additionally, the project controls group is excluded due to its emphasis on financial aspects, that reflects after the project baseline is affected. The indicator "Construction is awarded before adequate completion of the project design, including discipline design packages, resulting in an incomplete scope definition at the time of award/start of construction" primarily pertains to the perspective of the contractor. However, since this research focuses on the perspective of engineering consultants, this indicator will not be considered in the research. The complete list of indicators can be found in Appendix A, and Table 3.3 provides the list of indicators considered in this research.

Table 3.3: Leading Indicators identified by (Choi, 2007)

Group	Leading Indicators
Alignment	The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project.
	Business goals, project objectives and priorities, and critical success factors are not being consistently used by project team members and key stakeholders to guide decisions.
	The level of maintenance and reliability personnel involvement in detailed design is low and the personnel lack alignment with other project team personnel with respect to maintenance issues for the facility.
	The project manager (or team leader) is lacking in the required level of experience and skills.
	Commitments are increasingly made with the intention of not being met and are almost always not met.
	The project is experiencing difficulties due to the lack of understanding cultural differences.
	The client and/or upper management is frequently making unreasonable requests (includes setting unrealistic goals.)
Change Management	The project team's response to Requests for Information, questions, and changing events that can significantly impact the project results is slow, inadequate, or incomplete.
	Owner and/or contractor is requesting an excessive number of contract changes and/or scope changes during project execution (detailed design, procurement, construction, and start-up).
	The project team is failing to identify and/or address missing requirements during detail design reviews.
	Project changes are not being processed in a timely manner for decision making (includes defining cost and mark-up rates, evaluating schedule impact, obtaining appropriate approval authority, and initiating dispute resolution procedures.)
Contracting	Construction is awarded before adequate completion of project design, including discipline design packages, resulting in an incomplete scope definition at time of award/start of construction.
	Significant project scope items are inadvertently omitted from bid packages.
	Some project participant companies become financially unstable.
Quality	The project is experiencing a high level of engineering/design/specification errors and scope changes.
	A project-specific quality plan is not consistent with the contract documents (plans and specifications.)
Team Building	The project team is experiencing a high turnover rate and instability in team membership.
	Owner and contractor project personnel are not properly aligned.
	Key project stakeholder(s) is (are) exhibiting poor relationships and pursuing private agendas.
	The project team is not being realistic and truthful when project circumstances are unfavorable.

3.4   Analysis and Theoretical Framework

The leading indicators identified in the literature encompass the entire construction project lifecycle. While Habibi et al., (2018) provides a clear distinction between project phases, the other two sources focus on indicators for the design and construction phase without specifying which indicators occur in which phase. Certain indicators grouped by Choi, (2007) explicitly reflect construction phase and hence those were excluded.

The remaining indicators, although not exclusively mentioned to be present in the engineering phase, can also occur during the engineering phase. Since there is no specific distinction provided in the literature, it is assumed that these indicators may arise during the engineering phase. However, during the expert interviews, their relevance to the engineering phase will be further validated.

In their study, Habibi et al., (2018) classified leading indicators based on cost and schedule performance. However, other articles do not make this distinction between cost or schedule indicators, and it is observed that cost and schedule performance indicators overlap. As a result, for this research, the indicators will be considered to impact both cost and schedule without making a separate distinction between the two.

Additionally, all the identified leading indicators primarily focus on the negative impacts. However, for this research, a balanced approach will be taken to consider both positive and negative impacts. As a result, the leading indicators are framed neutrally to accommodate both perspectives.

3.4.1   Overlapping Indicators

The literature identifies several leading indicators, which are found to overlap. As a result, these indicators have been merged into a single category. Moreover, the sentence framing is neutral as these indicators are used to monitor both positive and negative performance.

Choi, (2007) identified two indicators related to experience: (1) "The project team has the necessary expertise, experience, breadth, and depth to successfully execute the project" and (2) "The project manager (or team leader) is lacking in the required level of experience and skills." Additionally, Safapour and Kermanshachi, (2019) mentioned three indicators: lack of skill, lack of knowledge, and lack of experience. Since all five indicators pertain to experience and expertise, they are combined under the name "The project team has the necessary expertise, experience, breadth, and depth to successfully execute the project" as it encompasses all aspects of these indicators. All of these indicators fall under this umbrella category.

Furthermore, the indicators "Commitments are increasingly made with the intention of not being met and are almost always not met" and "The project team's response to Requests for Information, questions, and changing events that can significantly impact the project results is slow, inadequate, or incomplete" essentially address the same aspect. Both indicators focus on the responsiveness of the project team to the need for additional information or decisions. Therefore, these indicators are combined into one under the name "The responsiveness of the project team to Requests for Information, questions, and changing events that can significantly impact the project."

Similarly, the indicators mentioned by Choi et al. (Choi, 2007) under quality management and change management share the same rationale. As a result, these indicators are combined into one. Habibi et al., (2018) also mentioned "Design change." Since these indicators, pertains to changes in scope and contract, it is included under the umbrella category of "Change in client/contractor requirements."

In addition, the indicators "The client and/or upper management is frequently making unreasonable requests (includes setting unrealistic goals)" and "Business goals, project objectives and priorities, and critical success factors are not being consistently used by project team members and key stakeholders to guide decisions" are related. When the client makes unreasonable requests, it implies that the project objectives are not being followed or are not clearly defined (Choi, 2007). Hence, this indicator is encompassed within the broader indicator of "Business goals, project objectives and priorities, and critical success factors are not being consistently used by project team members and key stakeholders to guide decisions." Consequently, these two indicators are combined together.

Additionally, the indicator "The project team is not being realistic and truthful when project circumstances are unfavorable. This added in the other specification" helps identify projects where communication of bad news is not happening effectively or in a timely manner (Choi, 2007). Additionally, poor communication between stakeholders is mentioned by Habibi (Habibi et al., 2018), and similarly, ineffective communication is mentioned by Safapour (Safapour & Kermanshachi, 2019). All these indicators pertain to communication within the project team and key stakeholders. Therefore, they are merged under the name "Communication within the project team and key stakeholders."

Furthermore, the indicator "Owner and contractor project personnel are not properly aligned" conveys the issue regarding the coordination between stakeholders and the project team. Therefore, it is combined with the indicator "Ineffective Coordination" mentioned by Safapour (Safapour & Kermanshachi, 2019) and named as "Effective Coordination between Project Team and Key Stakeholders." The table 3.4 represents the overlapping indicators, along with the corresponding article references, and the combined name of each indicator.

3.4.2 Theoretical Framework

The leading indicators from the three articles, along with the combined indicators from overlapping indicators, are compiled for further research. Negative sentence framing is transformed into neutral, resulting in a concise list of indicators that address both positive and negative aspects. The list of leading indicators can be found in table 3.5.

Table 3.4: Overlapping Indicators

Indicator	Reference	Combined
The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project.	(Choi, 2007)	The project team has the necessary expertise, experience, breadth, and depth to successfully execute the project.
The project manager (or team leader) is lacking in the required level of experience and skills.		
Lack of skill.	(Safapour et al., 2019)	
Lack of knowledge.		
Lack of experience.		
Commitments are increasingly made with the intention of not being met and are almost always not met.	(Choi, 2007)	The responsiveness of the project team to Requests for Information, questions, and changing events that can significantly impact the project.
The project team's response to Requests for Information, questions, and changing events that can significantly impact the project results is slow, inadequate, or incomplete.		
The project is experiencing a high level of engineering/design/specification errors and scope changes. (under quality)	(Choi, 2007)	Change in client/contractor requirement.
Owner and/or contractor is requesting an excessive number of contract changes and/or scope changes during project execution (detailed design, procurement, construction, and start-up).		
Design change	(Habibi et al., 2018)	
The client and/or upper management is frequently making unreasonable requests (includes setting unrealistic goals).	(Choi, 2007)	Business goals, project objectives and priorities, and critical success factors are being consistently used by project team members and key stakeholders to guide decisions.
Business goals, project objectives and priorities, and critical success factors are not being consistently used by project team members and key stakeholders to guide decisions.		
The project team is not being realistic and truthful when project circumstances are unfavorable.	(Choi, 2007)	Communication within the project team and key stakeholders.
Poor communication between stakeholders	(Habibi et al., 2018)	
Ineffective Communication	(Safapour et al., 2019)	
Owner and contractor project personnel are not properly aligned.	(Choi, 2007)	Effective Coordination between project team and key stakeholders
Ineffective Coordination	(Safapour et al., 2019)	

Table 3.5: Theoretical Framework

No.	Leading Indicators	References
	Alignment	
1	The project team has the necessary expertise, experience, breadth, and depth to successfully execute the project.	(Choi, 2007), (Safapour et al., 2019) .
2	Business goals, project objectives and priorities, and critical success factors are consistently used by project team members and key stakeholders to guide decisions.	(Choi, 2007).
3	The level of maintenance and reliability personnel involvement in detailed design is low and the personnel lack alignment with other project team personnel with respect to maintenance issues for the facility.	(Choi, 2007).
4	The project team members are from different cultures.	(Choi, 2007).
5	Communication within the project team and key stakeholders.	(Choi, 2007), (Habibi et al., 2018), (Safapour et al., 2019).
	Change Management	
6	The responsiveness of the project team to Requests for Information, questions, and changing events that can significantly impact the project.	(Choi, 2007).
7	Change in client/contractor requirements.	(Choi, 2007), (Habibi et al., 2018).
8	The ability of the project team to identify and/or address missing requirements during detail design reviews.	(Choi, 2007).
9	Time taken to process design change.	(Choi, 2007).
	Contracting	
10	Significant project scope items are inadvertently omitted from bid packages.	(Choi, 2007).
11	Financial stability of the project participant companies.	(Choi, 2007).
	Quality	
12	A project specific quality plan is defined and used in the project.	(Choi, 2007).
	Team Building	
13	Project Team Turnover rate	(Choi, 2007).
14	Relationship between key project stakeholders	(Choi, 2007).
15	Effective coordination between project team and key stakeholders.	(Choi, 2007), (Safapour et al., 2019).
	Client Related	
16	Time taken for Decision making.	(Habibi et al., 2018) .
17	Time taken for approval stage	(Habibi et al., 2018).
	Organization Based	
18	Resource management	(Safapour et al., 2019).
19	Project Size	(Habibi et al., 2018)

3.5   Conclusion & Next Steps

This chapter conducts an extensive literature review on leading indicators. At first the definition for leading indicators is established. The importance of using leading indicators was studied. After that, the leading indicators identified in the literature were illustrated.

A total of three articles were identified in the literature, the indicators from these three articles were compiled to develop the theoretical framework. The framework consists of nineteen leading indicators classified into seven categories of alignment, change management, contracting, quality, team building, client related and organization based.

Based on the research scope, the leading indicators identified in the literature are are based on different perspective, while the focus of this research is on engineering consultants. Moreover, the leading indicators identified in the literature consider the entire project life cycle and the focus of this research is on engineering phase. Therefore, it is crucial to explore further in the engineering phase. To achieve this, expert interviews will be conducted with individuals who have experience working in the engineering phase of infrastructure projects. These interviews will help gain insights into the real scenarios in the industry and understand the relevant leading indicators that occur in the engineering phase.

Chapter 4

Expert Interviews

The aim of this chapter is to identify the leading indicators in practice. To achieve this, eight experts were interviewed with three primary goals: firstly, to assess Project Managers' familiarity with the leading indicators; secondly, to understand the existing performance monitoring system in the industry; and thirdly to explore the leading indicators in the engineering phase of an infrastructure projects. This chapter aims to answer the second sub-research question:

SQ 2: What are the most relevant leading indicators in practice?

This sub research question is answered by conducting eight expert interviews and it corresponds to phase two of the research.

This chapter is constructed as follows. In section 4.1, the expert interview approach is explained, this section explains the expert selection criteria and the interview design. Section 4.2 consists of interview analysis which represents the analysis of the interview based on the leading indicators identified, the familiarity of project manager with leading indicators and the current performance monitoring system. Section 4.3, compares the theoretical framework with the interviews. Finally, section 4.4, represents the conclusion of the chapter.

4.1 Expert Interview Approach

4.1.1 Expert selection criteria

A total of 8 interviews were conducted, and the list of interviewees can be found in Appendix B. For convenience, the interviewees are referred to as i1 to i8, as described in Table 4.1. The interview is held with the employees of Sweco, specifically from the Transport and Mobility department. As described in section 1.2, the department is divided in four sub departments. Atleast, one expert from each department is interviewed. The selection of experts was based on the following three criteria:

1. More than 10+ years of experience in infrastructure projects.
2. Variation in project department.
3. Variation in roles.

4.1.2 Interview Design

The interviews were conducted in a semi-structured manner, and the interview questions used can be found in Appendix C. The interview began with an introduction, where the experts were provided with the context of the research. This introductory phase allowed the experts to understand the research objectives and scope, enabling them to provide relevant responses to the questions. Following the introduction, the experts were asked about their experiences and roles to gain a better understanding of their backgrounds.

The subsequent section of the interview focused on cost performance, while the following part delved into schedule performance. Interviewees were asked to provide examples of projects in their

Table 4.1: List of experts

Ref.	Current function	Department	Experience
i1	Project Director	Transport & Mobility	30+
i2	Project Director	Transport & Mobility	25+
i3	Team Manager	Mobility	25
i4	Project Manager	Roads	25
i5	Team Manager	Roads	10+
i6	Team Manager	Water	15+
i7	Project Manager	Water	20+
i8	Project Manager	Rail & Stations	15

experience with both overruns and projects that were on track. They were given the freedom to discuss projects that were fresh in their memory, aiding in the identification of leading indicators. Leading indicators are often qualitative and can be challenging to remember for an extended period of time. As a result, interviewees did tend to talk about recently completed or ongoing projects.

The interview questions started with an event of cost or schedule overrun in positive and negative scenarios. The cause of these overruns was then traced back to identify the leading indicators. Leading and lagging indicators have a causal relationship; therefore, cost overrun, which is lagging indicator, the cause of this cost overrun are the leading indicators. The interviewees were asked "why" and "how" questions to get to the root cause of the problem.

Additionally, the second objective of the interview is to gain insights into the current performance management system. This involved asking the interviewees about their response strategies, monitoring systems, and key performance indicators (KPIs) they used to monitor project performance in both scenarios.

In the final section, interviewees were asked about general factors that affect project cost and schedule performance. This question was added to ensure that no relevant leading indicators were overlooked, as certain indicators may not occur in a specific project due to project-specific conditions or other reasons. Therefore, this question was asked to provide a comprehensive understanding of the factors influencing project performance. The familiarity of project managers with leading indicators was also assessed in this section.

4.2 Interview Analysis

4.2.1 Familiarity of Project Managers with Leading indicators

The interviewees were not familiar with the term "leading indicator" prior to the interview. However, they recognized the rationale behind leading indicators. Currently leading indicators are not utilized as key performance indicators. The current emphasis is primarily on time and cost, but the experts mention that considering the leading indicators would be advantageous.

4.2.2 Leading indicators identified

As mentioned earlier, leading and lagging indicators have a causal relationship. The events of cost overrun and schedule overrun were used to trace them back and identify the factors that led to these overruns. Thus, the causes of these overruns are the leading indicators of cost and schedule performance. The leading indicators identified in the interviews are depicted in figure 4.1.

Change Request

Change request was mentioned by all the experts in the interviews. The interviewees mention that the change requests in a project led to cost overruns. Change request was identified as an indicator that impacts the project very largely during the engineering phase, this was acknowledged by all

Leading Indicators

1. Design change
2. Decision making
3. Communication
4. Project size
5. Bidding at low price
6. Resource allocation
7. Project team turnover
8. Team efficiency
9. Stakeholder management

1 2 3 4 5 6 7 8

No. of experts

Figure 4.1: Leading indicators identified in interviews

the experts. They mentioned specific examples of projects, where the client requested numerous changes. One of the changes mentioned by (i2)(i6) was a switch in construction method from pre-cast to in-situ, which led to change in design principles. This change in design principles caused rework and additional work hours, ultimately increasing the project cost and affecting the schedule.

A change request can lead to additional work or a change in the original project scope, which requires extra working hours. This directly impacts both the project timeline and cost. Although scope extensions may involve additional payments, it is often not feasible to complete the project within the original budget and time-frame due to the added scope.

Decision making

The decision-making process by the client was addressed by five experts. The effect of client decision-making on the cost and schedule of the project was that the project team had to wait or remain idle until decisions were made by the client.

The delay in decision making by clients impacts the schedule but this delay also impacts cost. In a lump sum contract type, the consultants are paid for the assignment and they have to finish the project in the assigned time. The team has to either wait for the decisions or make an assumption and mover further.

According to (i2; i6), the decision-making process took a significant amount of time. Similarly, (i5) mentioned that there were extensive discussions between the client and other stakeholders. In a project that could only be initiated during summers, this delay in decision-doubled the project duration. It was also highlighted that decision-making tends to be slow in government projects (i5).

Furthermore, i2 emphasized that sometimes a wrong decision is preferable to no decision at all. This is because even with a wrong decision, the team can still make progress, and taking some action is better than taking no action. While it may not be a perfect or ideal decision, it allows for forward movement.

The delay in decision making by client, definitely impacts the schedule but it also impacts the cost of the project because in the mean time the project team has to wait for the decision making by the client, this delays the time and it impacts with prolonged resource allocation.

Communication

Communication was identified by all the experts. The experts believe that constant communication with the project team and the client, helps in keeping the team aligned and also helps in building good relationship with the client and the external stakeholder.

Communication is very important and therefore these instances for communication should be planned. Especially in large projects and complex projects, where a number of people are involved, it is difficult to communicate. Absence of communication planning was one of the problems that resulted in cost overrun (i5).

Frequent and effective communication with clients has a positive impact on the project, as it allows for early warnings to be communicated and helps build trust between the project manager and the

client (i4, i7). Trust between the project manager and the client is essential and is developed over time through proper communication (i7).

Project Size

The size of the project has a significant impact. Large projects generally involve a larger number of people, making managing such a large group challenging (i2)(i6)(i7).

Bidding at low price

The cause of cost overrun begins right from the tendering stage. The major reason of cost and schedule overrun was because of underestimation of budget for three projects. To begin with, the consultants are keen to get the projects either because they don't have enough work (i4)(i5) or the project involves new knowledge and innovation (i5)(i3), interviewee mentions the latter as strategic move. So, they bid for the projects at lower price. The other reason to bid at low price is also because there is over optimism to finish the project in budget. i4 mentioned these optimism as "wishful thinking" and "fooling ourselves". Furthermore, When the market is competitive it becomes important to bid at low price to win. Additionally, the bidding manager focuses on the list of requirements provided by the client and overlooks the cost of the general aspects of project like cost of travelling to site. This causes underestimation of budget which ultimately results in cost overrun.

Resource allocation

In addition, it was discovered that resource allocation in the project is determined by individual availability rather than project requirements, leaving the project manager to work with the assigned resources (i2). It was also discovered that having the right people in team have positive effects on the project performance (i8).

Project team turnover

Project Managers are changed quite often in big complex projects (i1),(i4),(i7). There have been projects wherein the project manager was changed over three times in six years. The reason for this is that sometimes the Project Manager is inefficient. Other times, there is change because the PM has expertise in design phase and once the phase is completed during construction a new PM is appointed who has more expertise during construction. In both cases, it impacts the team. The interviewee mentioned the key people in the project team as "Backbone of the project" and if one of these members leave the project it creates discontinuity in the team and also affects communication. It takes time for the new PM to understand the project requirements and build social dynamics with the project team and the client. 3 out of 7 interviewees were not a part of the project since the start, the joined the project mid way, "to clear the mess" says i1. This indicates the presence of the indicators turnover rate. Moreover, one of the project manager was replaced.

Team efficiency

Inefficiency in the project team was identified by all the interviewees. Inefficiency in the project team occurs due to a myriad of reasons. Starting with underestimation of efforts required to complete the project. The reason behind this is one of the three. Firstly, the project manager is over optimistic about finishing the project in budget (i3). Secondly, the proposal is prepared with a prospective that a qualified engineer will be involved in the project. However, the project team is formed on the basis of availability of people and not the requirements of the project (i2). Lastly, the designers and modellers are over ambitious about the design and they spent a lot of time in creating the best design without sticking to the requirement. This affects the timeline and cost. This was mentioned by all the interviewees.

As mentioned earlier, the resource allocation is based on the availability of team members and not the requirements. This leads to working with juniors in a project wherein there is a requirement of a medior or a Senior manager. i2 states "For smaller projects it is possible to work however, in

complex projects it is important to have the right people in the team. The responsibility given to the juniors is higher, which is a difficult for a fresh university graduate to comply with. This also gives rise to rework and change management." He further mentions "It is not only about expertise and experience, it also has to do with competencies. How do they address things to the clients? How do they manage their own team that's competencies. On the other hand, it was observed that in smaller projects the PM aspect of the project is often over looked (i5). The interviews consistently highlighted the enthusiasm of both designers and engineers in creating the best solution. However, this ambition often leads to a lack of attention to completing the design within the given time and budget constraints. As a result, when a change request is raised by the client, the team's excessive ambition about the design can cause delays in responding to the change.

External Stakeholder related

Changes in legislation can sometimes be anticipated, but "that's more of a gut feeling" (i8). These insights highlight the potential influence of media, regulatory bodies, and political factors on project dynamics.

Especially with infrastructure projects, "If you have a new highway of 10km, there will be neighbours of 20kms," says i2. The interviews mention that the external stakeholders, especially the neighbors, have a significant effect on the project.

In project (P1) as stated earlier, interviewee i8 states that "Client asked to go the traditional way because they were sceptical about the new approach because it was new insight, new knowledge, different stakeholders were involved and they had different opinion, and different asset managers were involved and they all had opinion." (i7) mentions that we had to make a lot of design changes because the stakeholders were not convinced that it was a safe solution, so in order to prove that the solution was safe, they had to redesign which ultimately led to cost overrun and ultimately it was proved that the design was safe , but in an expensive way. Everybody in the Netherlands understand the importance of water safety projects (i7). He says "The need for the project is not a debate but its about how the dike is built. People want a dike but not in their backyard, or in the backyard but far away. Its different than a road because when a road is built we need to explain why the road is necessary but with water safety that's not the case, People understand the importance of the project"

Politicians sometimes have to try to please everyone, even if it means asking for things that are extremely difficult to achieve. As the scope of their tasks increases, they deal with stakeholders who have specific desires that might be hard to meet. Resistance from politicians and the neighbours were acknowledged(i4)(i5)(i7)(i8). Politicians try to please everyone so sometimes, they ask something impossible to make. Scope is being added, stakeholders who have explicit wishes, that may be granted (i4). "If you don't know the key stakeholders They can block the whole project and act as killer" (i1). Scope extension is the result of high involvement of stakeholder. Demands from stakeholder has to be fulfilled, this was mentioned by all directly or indirectly. Delay in identifying the stakeholders can also be a problem. Extra requirement because it is their interest and they give extra requirement. So that is something the client has to take care of, but it ultimately delays the process (i5).

4.2.3 Current Performance Monitoring System

The primary focus of monitoring is on cost and time, with a specific emphasis on tracking hours spent. This was achieved by dividing the budget by the timeline, and the burn rate of hours was used as an indicator for monitoring costs. Monitoring also involves dividing the budget by hours and comparing expenses to invoices and payments received. Additionally, estimating the time to completion is also looked after along with creating a detailed project plan and monitoring the baseline.

(i2) discussed the utilization of an issues list and Earned Value Management (EVM), but acknowledged the challenge of monitoring earned value for a large-scale project. Additionally, regular update meetings are conducted within the team, as well as with the client on a biweekly basis, and monthly progress meetings are held within Sweco. It is worth noting that the frequency of these meetings may vary depending on the project, but meetings are organized internally, with the client, and within the organization.

To facilitate effective monitoring, larger projects are often divided into smaller projects for better oversight. Additionally, the identification and monitoring of risks were emphasized, with the maintenance of risk registers. Furthermore, the monitoring of actual extra work was highlighted as a crucial aspect of project management.

4.3 Theoretical Framework v/s Interview Findings

The theoretical framework as described in section3.4.2 consists of eighteen leading indicators. Out of the eighteen leading indicators ten leading indicators were identified in the interviews. The indicators that are not identified in the interviews will be excluded from this research. Two additional leading indicators of bidding at low price and external stakeholders were also identified in the interviews as described in table 4.2.

Table 4.2: Leading Indicators identified in interviews

No.	Leading Indicators in literature	Interviews
	Alignment	
1	The project team has the necessary expertise, experience, breadth, and depth to successfully execute the project.	This was acknowledged by all the interviewees. It was mentioned under team efficiency.
2	The project team members are from different cultures.	Not explicitly mentioned in project but mentioned in general context.
3	Communication within the project team and key stakeholders.	Identified .
	Change Management	
4	The responsiveness of the project team to Requests for Information, questions, and changing events that can significantly impact the project.	Team efficiency
5	Change in client/contractor requirements.	Identified
6	Time taken to process design change.	Identified
	Team Building	
7	Project Team Turnover rate	identified .
8	Relationship between key project stakeholders	identified but was mentioned that communication leads to good relationship between key stakeholders.
	Client Related	
9	Time taken for Decision making	Identified .
	Organization Based	
10	Resource management	Identified as resource allocation.
11	Project Size	Identified
	Additional Indicators in interviews	
12	Bidding at low price	
13	External (Stakeholder, Media, changes in rules and regulations)	

Thus, the table 4.2 consists of an exhaustive list of leading indicators. The leading indicators 5 and 6 are combine into one, under change request. It is defined as the number of change request and time taken to process the change request. Experience of the project team and responsiveness of the project team are combined into one under team efficiency, Communication and relationship between key stakeholders are combined into one, as in the interviews it was identified that good communication leads to good relationship between stakeholders and vice versa. Thus after combining these leading indicators, a total of nine leading indicators are present as described in table 4.3. As the leading indicators identified are not large in numbers, it will be easier to follow if they are not classified.Therefore, the classifications are removed.

Table 4.3: List of Leading indicators

Leading Indicators		
No.	Indicators	Description
1	Change request	Change in client requirements and the time taken to process design change.
2	Decision making	The precision and duration of decision making by the client.
3	Communication	The frequency of communication and the clarity in the delivered message.
4	Project size	Project size in terms of budget, cost, and number of stakeholders involved.
5	Bidding at low price	Submitting the bid at a price lower than expected.
6	Resource allocation	The basis on which resources are allocated to the project team.
7	Project team turnover	The number of people leaving or joining the team during the project.
8	Team efficiency	The ability of the project team to complete tasks within the given time.
9	External	The degree to which stakeholders are identified and managed. Changes in rules and regulations, Politics, Media.

4.4 Conclusion & Next steps

The aim of this chapter was to identify the leading indicators in practice. In order to achieve this eight expert interviews were conducted. After the first six interviews, it was observed that a saturation point with regard to the interview content was achieved. Hence after conducting two more interviews, the interview process was concluded.

The interviews revealed that the project managers were not familiar with term leading indicators, but they understand the rationale behind the leading indicators and acknowledge the use of these indicators will be advantageous for monitoring project performance. It was also discovered that the current monitoring system is highly based on lagging indicators.

A total of nine leading indicators were identified as a result after comparing the theoretical framework with the leading indicators identified in the interviews. The indicators identified are change request, decision making by client, communication, Project size, Bidding at low price, Resource allocation, Project team turnover, team efficiency and external stakeholder related.

The next step is to test these indicators in projects by conducting case study analysis. This process will validate the list of indicators, and will help to identify how these indicators impact the cost and schedule performance of a project.

Chapter 5

Case study analysis

This chapter contains the result of the case study conducted on four infrastructure projects in the Netherlands. The goal is to test the list of leading indicators identified through the literature study and the expert interviews and to investigate the impact of these leading indicators on cost and schedule performance of a project. This corresponds with the phase three of this research. The sub-question that is answered in this chapter is

SQ 3: How do the identified indicators affect the cost and schedule performance of a project?

This chapter is constructed as follows. Section 5.1 elaborates on the case study design. Section 5.2 discusses the case study approach. Subsequently section 5.3 focuses on the general results of the interviews. The results per case are presented in sections 5.4, 5.5, 5.6, 5.7. Cross case analysis is elaborated in section 5.8. Finally, in section 5.9, conclusions are drawn.

5.1 Case study Design

The objective of the case study is twofold. Firstly, to verify the identified leading indicators, and secondly, to understand the influence of the identified leading indicators on the cost and schedule performance of a project. Since every indicator can have varying influences on different projects. Therefore, it is important to understand the narratives behind the influence.

5.1.1 Selection criteria

The selection criteria for case studies are as follows:
1. The project must be characterized as complex.
2. The project should be either recently completed or ongoing.
3. The project should be in the engineering phase.

1. **The project must be characterized as complex.**
   Sweco has implemented a project classification system that takes into account project risks and the disciplinary involvement. As we move from Classification E to A, the project complexity increases due to factors such as the involvement of a greater number of disciplines, increased uncertainties and risks, and the consideration of third-party involvement as described in table 5.1. The research will focus on projects classified as A and B, which represent the highest levels of complexity.

2. **The project should be either recently completed or ongoing.**
   The leading indicators play a significant role right from the start of the project. Moreover, an ongoing project allows the project manager to reflect more effectively as it is still in progress. Similarly, a recently completed project will be fresh in their memory, enabling them to recall details and insights more easily. Additionally, a completed project provides the project manager with the opportunity to reflect on the entire project and draw valuable lessons from their experience. Therefore, a combination of these two types of projects are considered.

Table 5.1: Project Classification in Sweco

Class	Description	Scope (€)
E	Monodisciplinary, no risks (low)	$< 50,000$
D	Monodisciplinary or dominant multidisciplinary, no special risks, no third-party involvement	$< 150,000$
C	Monodisciplinary with deviations or multidisciplinary, special risks, third-party deployment	$< 250,000$
B	Multidisciplinary, special risks, different contract forms	$< 1,000,000$
A	Interdisciplinary, cross-divisional, international, third-party involvement, deviation liabilities, innovations	$> 1,000,000$

3. **The project should be an infrastructure project in the engineering phase.**
   The project should be involved in either one or more than one phase of the engineering phase as described in section 2.1.

5.2   Case Study Approach

Based on the selection criteria, the research includes four identified projects: A9, N-59, Guisweg and Tiel-Waardenburg (dike renovation). These projects encompass a range of infrastructure types, including national highways, national roadways, local roadways, and dike renovation respectively. Table 5.2 presents an overview of the projects included in the study, providing details on the number of interviews conducted for each project and the experience of the involved interviewees.

Table 5.2: Case overview

	Project Name	Category	Project Classification	Interviewees	Experience
Case 1	A9	Highway	A	C1.1	20+
				C1.2	20+
Case 2	Guisweg	Local Road Network	B	C2.1	20+
				C2.2	20+
Case 3	N59	National Road	A	C3.1	20+
Case 4	Tiel-Waardenburg	Dike	A	C4.1	20+

The primary focus of the interview was the Project Manager of each respective project. However, for the A9 project, an additional perspective was considered by including insights from the project controls department. This was particularly relevant due to the scale and complexity of the A9 project, which involved a dedicated department for project controls.

For the Guisweg project, two different Project Managers were involved during different phases of the project. Therefore, the perspectives of both Project Managers were taken into account to gain a comprehensive understanding.

In the case of the N-59 project, although a different Project Manager was initially involved, their tenure on the project was relatively short. Consequently, the interview focused solely on the perspective of the current Project Manager, who had a more substantial and recent involvement in the project.

In the case of the dike renovation project, Tiel-Waardenburg (TiWa), multiple project managers were initially involved in the project. However, as the project started five years ago with feasibility studies, some of the project managers have since left the company. Therefore, the project manager who has stayed the longest on the project, particularly during the conceptual design and preliminary design phases, was selected for the interview.

The selected projects are involved in various phases of engineering. Table 5.3 describes the specific phases in which each project is involved or the scope of the project.

Table 5.3: Phases of Project

	Current status	Feasibility study	Conceptual Design	Preliminary Design	Detailed Design
Case 1	ongoing		✓	✓	✓
Case 2	recently completed		✓	✓	
Case 3	ongoing		✓	✓	
Case 4	recently completed	✓	✓	✓	✓

The project managers were interviewed to gather insights on the influence of each leading indicator on the cost and schedule performance of the identified projects. They were specifically asked to evaluate whether the indicators had a positive or negative influence on the cost or schedule performance. Additionally, the project managers were requested to elaborate on their assessments, providing explanations and suggestions for potential improvements. Appendix D, describes the list of interview questions.

5.3 General results of the case study

The identified leading indicators, obtained from expert interviews, were tested in the identified projects. After asking the influence of these leading indicators, the interviewees were asked if there are any other additional challenges that are influencing the project cost/schedule performance. The answer was always a no, thus demonstrating the relevance and comprehensive nature of the identified leading indicators.

A detailed description of each leading indicator in relation to each project are discussed in the following sections.

5.4   Case 1: A-9 Highway

The A9 Amsterdam project is a public-private partnership (PPP) initiative in the Netherlands. Its objective is to widen the 11km lanes of the A9 Highway between the Badhoevedorp and Holendrecht junctions near Amsterdam. This lane extension, from 2x3 to 2x4, aims to alleviate congestion on the existing motorway and within the corridor (European Investment Bank, 2018). According to European Investment Bank, (2018), the A9 Amsterdam project will not only enhance connectivity but also contribute to the overall liveability of the wider Amsterdam region. It is an integral part of the Schipol-Amsterdam-Almere (SAA) road expansion plan.

The project was initiated by Rijkswaterstaat (RWS), the executive agency of the ministry of road and water in the Netherlands. RWS has awarded the project (DBFM) to the VEENIX consortium, which comprises Macquarie Capital, Siemens, Count& Cooper, and FCC. The consortium will assume responsibility for the design, construction, and pre-financing of the project, as well as maintenance for a duration of 14 years (Rijkswaterstaat, 2019). Sweco is appointed by FCC to do the conceptual, preliminary and detailed design of the project as described in figure 5.1.
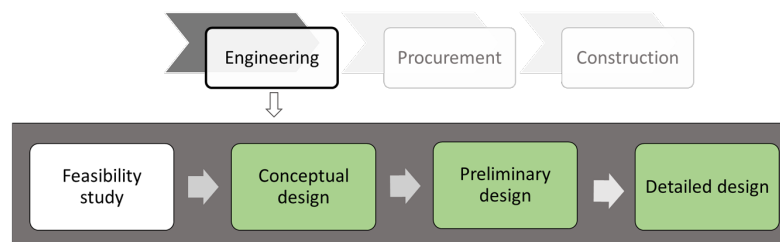
Figure 5.1: Project Phases A-9

5.4.1   Current Cost and Schedule Performance of the project

At present the project is running over budget and over cost. At present, the cost and schedule overrun are more than 200% in the project.

5.4.2   Effect of Leading Indicators on Cost and Schedule Performance

The effect of each leading indicator on the cost and schedule performance of the project is described below.

1. Change Request
In alignment, both the project manager and project controller agree that the change requests initiated by the client has had a negative effect on the project's cost and schedule.

With over 120 change requests, amounting to more than 50% of the contract value, the original scope undergoes significant modifications. Often, when the project team is nearing completion, new change requests arise, resulting in rework and increased costs. However, the burden of these rework costs does not always fall on the client. This is primarily due to a lump sum contract, where they argue that we should have factored in these risks within our budget. Claims for rework costs lead to extensive discussions and negotiations, consuming valuable time.

The interviewees also mention that it is easy to manage extra work, it is easy to claim for the extra work. Because new milestones for cost and schedule are set it does not affect the original cost or schedule of the project.

However, the process of getting extra work takes an extended period of time. In certain cases, the work is delivered even before receiving the agreement or assignment for the extra work. This situation creates a false perception of project performance. It indicates cost overrun scenario within that specific time frame and when, the agreement is received it results in a positive scenario because the work has already been performed prior to receiving the agreement. Although payment for extra

work is generally handled efficiently, there have been instances where assignments have been delayed for up to one and a half years.

2. Decision Making

The interviewees shared the same viewpoint regarding the negative impact of the client's decision-making on the project's cost and schedule.

The client's decision-making process is significantly delayed, leading to various challenges and negative impacts on the project. The decisions not only experience delays but also lack essential information, causing further complications. The client's lack of timely input and changing information further exacerbate the situation. As a consequence, the project team has to operate without crucial information, relying on assumptions and subsequently facing rework.

Adding to the challenges, the client expects the engineering consultants to bear the risks associated with the contract, despite the late provision of necessary information. This results in subsequent delays and cost overruns, as the team's additional efforts in rework remain uncompensated.

The progress of the project is significantly impeded by delays in the client's decision-making process. The extended duration of decision-making regarding extra works leads to uncertainty and forces the team to continue working without a guarantee. This situation not only adds months to the project timeline but also increases costs, creating financial implications for the project.

3. Communication

Both interviewees acknowledge regular communication within the team and with the client, with a good personal relationship and client appreciation for the project team's efforts. However, challenges arise in decision-making and providing clear starting points, making communication cumbersome at times. Overall, communication is considered good.

The project controls manager highlights that the project team has a clear understanding of the client's requirements. However, a challenge arises with the starting point due to missing essential information from third parties. Although both interviews acknowledge that the impact of communication is neutral, as there is sufficient frequency of communication, difficulties arise when providing starting points for the project team. These difficulties stem from inadequate information received from third parties appointed by the client, which hampers the team's progress.

4. Bidding at low price

The project was bid at a fair price. The project managers says "if all would have gone first time right, I think we could have done it within the anticipated budget and time."

5. Resource Allocation

The expertise required in team were not available. So the people who were available in the project were assigned to the project. Since the team didn't have the required expertise, they took more time to finish the design causing increased working hours and delays in the projects. The amount of hours spent on design was not proportional to the amount of money spent. More than 50% of the budget was spent and not even 10% of progress was made in the design. This was not solely because of unavailability of resources, but it has also significantly contributed to the overrun.
There is required expertise in the team, but we could use more, said the project controls manager.

6. Turnover Rate

The project manager acknowledges the negative impact of team turnover, highlighting potential disruptions and knowledge gaps. Conversely, the project controls manager notes that team members typically leave after completing their tasks, suggesting minimal impact on ongoing project activities.

The team experiences frequent turnover, resulting in costs and delays due to discontinuity (Project Manager).

The project controls mentioned that the stability within the team is generally good, as members leave once their responsibilities are fulfilled. However, concerns arise when individuals leave with a sense of relief and reluctance to return. Although the impact on cost and schedule overruns is limited, re-engaging them for additional work becomes challenging due to their dissatisfaction with

the project environment. This dissatisfaction stems from inadequate client inputs, extensive changes, and delayed decision-making.

7. Team Efficiency

The two interviewees had a difference of opinion here. The project manager said that he found too difficult to find the right person for the project, it took him a lot of time and effort. While the manager from the project controls department, stated that we can use more expertise in the project, but the main reason for inefficiencies is the lack of input from the third parties involved in the project.

The Project Manager highlighted the issue of having good team members but not the right ones. The necessary expertise was unavailable, and there was a lack of proper coaching for junior members by the seniors. In one instance, a junior team member was assigned a task without it being reviewed by a senior, resulting in numerous client comments and significant rework hours. The juniors require appropriate guidance and coaching from the seniors to prevent such inefficiencies.
Despite making revisions, the team still received numerous client comments, leading to the need for working on the same design three times due to internal inefficiencies. However, the client cannot be held responsible for these rework hours as they are a result of internal issues. The inefficiencies lead to additional working hours that are often not compensated, resulting in cost and schedule overruns. Furthermore, as a result of the unavailability of the necessary expertise within the organization, an external team was contracted to complete the project. However, the project manager highlights that the external parties exhibited a lack of commitment towards achieving the project objectives. Their focus seemed to be solely on completing the designated number of hours rather than actively working towards the project's success.

8. External

For one of the bridge there was delay because the architect of the municipality had a different design idea and he was over ambitious about the architecture and the shape of the structure and we as engineers were focused more on the feasibility of the structure and that led to a lot of rework. However, extra budget and time was awarded for the design and it did not affect the cost or the schedule performance largely. The project controls manager also mentioned that the external stakeholders did not impact the project cost or budget.

5.4.3   Summary of Case 1

The impact of leading indicators on the cost and schedule performance of this project is described in table 5.4. It was observed that the change requests and delay in decision making by client are the main reasons for negative project performance. Both the interviewees agreed to this. Moreover, communication had a neutral effect on the cost and the performance. The communication was good in the project, The project was not bid at low price this was also attested by both interviewees. Additionally, it was observed that the external stakeholders also do not play a major role in impacting the project performance.

For the project manager, high turnover and inefficiency in the team have a negative impact on the

Table 5.4: Impact of leading indicators: Case 1

No.	Leading Indicators	Case 1 - I1	Case 1 - I2
1	Change Requests	Negative	Negative
2	Decision making	Negative	Negative
3	Communication	Neutral	Neutral
4	Bidding at low price	N/A	N/A
5	Resource allocation	Negative	Neutral
6	Project team turnover	Negative	Neutral
7	Team efficiency	Negative	Neutral
8	External	Neutral	Neutral

project's cost and schedule. This is because the team members lack the right skills or spend too

much time on design without considering the project's limits. When people leave or join the team, it causes disruptions, making the project take longer and cost more. On the other hand, the project controls team doesn't think turnover and team efficiency have a big effect on cost and schedule. They believe the team is good, but sometimes the client doesn't provide the necessary information. They agree that having more expertise in the team would be helpful.

The change in perspective makes sense because the project manager has a deep understanding of the whole project. They are closely aligned with the team, enabling them to have access to the intricate details and challenges faced by the project firsthand. Additionally, being in direct contact with both the client and design leads gives the project manager insights into the project's broader goals, scope, and constraints. These interactions provide a more holistic view, making the project manager's perspective valuable in assessing how resource allocation team turnover, and efficiency impact the project's overall success.

5.5 Case 2: Guisweg

The Guisweg level crossing in Zaanstad has long been a bottleneck for car traffic, cyclists, and pedestrians. Additionally, infrastructural issues in the surrounding area and the untapped potential of the nearby Zaandijk Zaanse Schans station and housing further exacerbate the problem. To address these issues, the Amsterdam Transport Region, in collaboration with five partners, including the municipality of Zaanstad and the Ministry of Infrastructure & Water Management, has initiated an exploration to find an integrated solution. This exploration, led by the Amsterdam Transport Region, is part of the Amsterdam Hoorn Corridor Study (CAH), and the Guisweg project is included under its umbrella.

Sweco has been appointed by the Amsterdam Transport Region to conduct the conceptual and preliminary design of the project as described in figure 5.2.
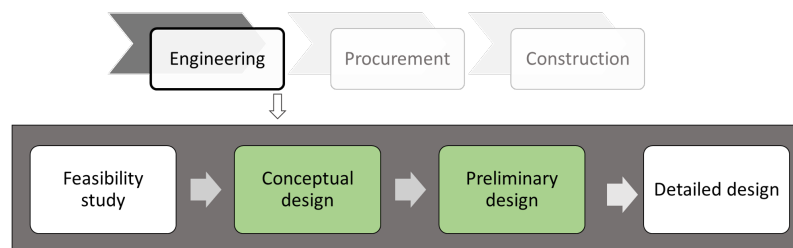
Figure 5.2: Project Phases Guisweg

5.5.1 Current Cost and Schedule Performance

The two phases of the project are considered as separate projects within the organization because the preliminary design phase was awarded after the conceptual design phase. Each phase underwent its own bidding process. In the first phase of the project had an overrun of less than 8%. The cost and schedule overrun in the second phase of the project was more than 50%.

5.5.2 Effects of Leading indicators identified in the project

The effect of each leading indicator on the cost and schedule performance of the project is described below.

1. Change request
The project manager of the first phase mentioned that project experienced minimal change requests. However, the project exhibited flexibility due to the client's need to obtain permits and manage stakeholders effectively. This allowed the consultant ample time to handle the change process, creating room for flexibility within the project. Moreover he mentioned that there was a very good relationship with the client.

In the second phase, the project manager mentioned the absence of a designated scope. The client provided a fixed budget and insisted that the project be completed within that budget. The client preferred to work with a "plus-minus" approach, requesting additional deliverables while expecting the project to stay within the same budget. The client's dominant nature resulted in a lack of clear scope, which led to challenges within the project. The client consistently asked for more without being willing to pay for the additional work. "They (client) never settled for less, they always want more and that was the problem staying within the budget". This situation resulted in extra work being performed without compensation, leading to additional time being spent on the project without proper remuneration.

In the second phase an additional scope, for creating a walk-through file was incorporated into the project. These additional tasks were properly compensated, leading to profitable outcomes for the project. Also, since the project was not generating enough profit, the project manager tried to secure an additional project. They successfully obtained an extra assignment, adopting the mindset

of "if I am losing money here, I'll need more work." Thus, a new project was assigned during the ongoing project.

2. Decision making

In both project phases, the client's decision-making process was timely and thorough. In the first phase, there was a strong and collaborative relationship between the project team and the client. The project manager felt a sense of unity and alignment with the client's decision-making process.

In the second phase, the client's decision-making in the project was extremely thorough. The interviewee mentioned that "They (client) effectively collected feedback from multiple stakeholders within a week and considered valuable insights on various project aspects. The client consolidated the feedback into a comprehensive document, taking into account the different subjects and partners involved."

The project team was able to work efficiently and stay on schedule due to the timely decisions and clear information provided.

3. Communication

In both phases, the communication with the client was smooth and effective. The project team worked directly at the client's location, allowing for easy access to their feedback on the completed work. This not only facilitated efficient communication but also helped build strong relations with the client.

However, within the project team, communication was challenging due to team members working from different locations and not being appointed to this project on a full time basis. It was difficult to coordinate and gather everyone for team calls or meetings.

4. Bidding at low price

During the first phase, the bidding was done at a relatively competitive price. The engineering consultants knew that they were the only party that has the required expertise to finish the project. So after knowing the budget of the project, the consultants proposed to reduce the scope of the project at the same price. They also anticipated that the reduced scope would be awarded to them as an additional project, which indeed came to fruition. As a result, the second phase of the project consisted of the reduced scope as originally proposed by the consultants.

For the the second phase, the project manager (phase 1) and the client's project manager(phase 1) collaborated to define the project scope. The client had a limited budget for the second phase, and upon sharing the budget, it was accepted by the engineering consultants without extensive discussion. The client also mentioned that if the bid was submitted before the summer holidays, they would award the contract on time. Thus efforts were made to stay within the budget because the consultants were motivated by an attractive incentive provided by the client to submit the bid before the holidays and get the project. Sweco successfully submitted the bid within the specified scope. However, there were identified risks associated with changes in project managers, particularly with the new project manager appointed by the client. Additionally, the lack of required resources posed a challenge in performing the work. These challenges were predicted, but still the bid was submitted.

The project manager of the second phase mentions that "the contract was not adequate. We shouldn't have made such a contract at the every first place."

5. Resource allocation

In both phases, the necessary resources were unavailable in the company, resulting in challenges for the project. The interviewees emphasized that having the required personnel would have saved both time and money.

6. Project Team Turnover

During the first phase, there was a high turnover of team members, with individuals frequently joining and leaving the project. The appointment of a team member would often be followed by their reassignment to another project within a few weeks. This constant rotation caused significant chaos and discontinuity within the project, impacted the stability in the team, which also affected the cost and schedule performance. The interviewee further mentioned that "A 3d modeller required for one project who joined a week earlier had to leave the project because he was required in another project. The incidents like these happened a several times and this was not anticipated during

contract preparation." A lot changes in the team led to discontinuity in the team.

In Phase 2, there was a significant number of experienced team members falling ill, leading to uncertainties and changes in the project. The project manager of the first phase also fell sick after the bidding phase of the second project and then the new project manager was assigned to the project.

Moreover, the project manager from the client also changed in the second phase. This added to the discontinuity in the second phase.

7. Team efficiency
In the first phase, it took very long to get the right people in the project. The people that were involved didn't work as efficiently as required. This was the major reason that lead to cost and schedule overrun in the first phase. " It took a while before we had available for example 3-D modelling, it took me a lot of effort." There was a lot of trouble getting the people to do the job, the project manager had to take a lot of effort to find the right people in the project. "People were provided to the project team who were too junior to do the job, they did not really have mentorship. So that took us lot of time and money. A project manager takes a lot more time to do that". The same issue continued for the second phase as well.

8. External
The project involved numerous external stakeholders, although their involvement was within the client's scope. While the stakeholders played a critical role in the project, their influence did not impact the engineering consultants cost or schedule performance. "it was agreed at the start that if the stakeholders would resist it would be the clients problem ". "They didn't really influence the budget or schedule of the project."

5.5.3   Summary of Case 2

The project comprises of two phases, each directed by a separate project manager. Both managers were interviewed based on their involvement in the respective phases. The impact of leading indicators on cost and schedule performance in both phases is described in table 5.5

Table 5.5: Impact of leading indicators: Case 2

No.	Leading Indicators	PM-Phase 1	PM-Phase 2
1	Change Requests	Neutral	Negative
2	Decision making	Positive	Positive
3	Communication	Neutral	Neutral
4	Bidding at low price	N/A	Negative
5	Resource allocation	Negative	Negative
6	Project team turnover	Negative	Negative
7	Team efficiency	Negative	Negative
8	External	Neutral	Neutral

In the first phase there were very less change request, in the second phase there was no designated scope because there was a cost neutral arrangement but there was always over asking by the client, which had a negative impact on the project. It can be observed that the decision making in the project has a had a positive impact in both the phases. The client's effective decision-making positively influenced project cost and schedule. Timely and precise decision was taken that facilitated project team productivity. Communication and external had a neutral impact.

In the second phase, the project was bid at low price, thus it negatively impact the cost and schedule performance of the project. Subsequently, resource allocation, project team turnover and team efficiency also had a negative impact.

5.6 Case 3: N-59

The N59 motorway serves as a vital link between Serooskerke on Schouwen-Duiveland and the Hellegatsplein junction, connecting the provinces of South Holland and Zeeland. The project involves collaboration between the provinces, Rijkswaterstaat, and the municipalities of Goeree-Overflakkee and Schouwen-Duiveland. The primary objectives of the project are to improve safety, traffic flow, and sustainability, aiming for efficient travel and enhancing the natural environment in the area. Sweco, appointed by the province of Zeeland, is responsible for the conceptual and preliminary design of the project. Their involvement is denoted by the green color in Figure 5.3. The project falls under classification A.
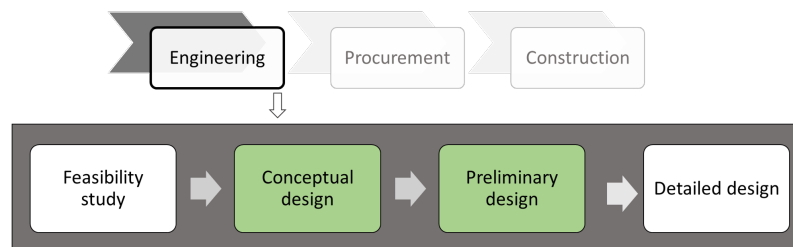
Figure 5.3: Project Phases N-59

5.6.1 Current Cost and Schedule performance

The project has a cost overrun of more than 35% and schedule overrun of more than 50%.

5.6.2 Effect of leading indicators on cost and schedule

1. Change request
The client's change requests, in the project manager's view demonstrate a realistic understanding of the project's needs. To manage any additional change requests that may affect project costs, the client requests an analysis of what can be omitted from the original scope. The objective is to maintain a cost-neutral approach. The interviewee emphasizes that the client is averse to incurring extra costs and aims to complete the project within the allocated budget, which has proven to be successful. To align with the client's limited budget, proposals are made to exclude specific elements from the original scope, ensuring cost neutrality for the change requests. The client had an allergy for extra cost.

2. Decision making
The client showcases timely decision-making, driven by two key factors as identified by the project manager: maintaining a positive relationship with the client and presenting an adequate proposal. In this particular project, the client had a limited budget and aimed to complete the project within that financial constraint. To accomplish this, they agreed to remove certain elements from the project scope while incorporating essential ones, employing a cost-neutral approach. The project manager believes that clients are more inclined to make swift decisions when a cost-neutral agreement can be reached.

3. Communication
The impact of communication on the cost and schedule of the project was neutral. It was identified that the project. However, it observed that building frequent communication instances helped foster a strong relationship with the client.

4. Bidding at low price
The project was bidded at an adequate price according to the project manager.

5. Resource allocation

90% of the personnel are required, while the remaining 10% do not possess the necessary qualifications. However, this has a limited impact on the project's performance.

6. Project Team Turnover

The project team turnover had a negative impact on both cost and schedule performance. Initially there was different project manager appointed for the project, but early on in the project, they were replaced with a different project manager. This change occurred due to a misalignment between the project manager of the client and the engineering consultants. The current project manager was appointed subsequently. The interviewee also highlighted that employee turnover is expensive as it significantly affects data management within the company, and finding experienced individuals is always challenging. It takes time to locate suitable personnel and it also impacts the cost.

7. Team efficiency

According to the project manager, 90% of the team members are efficient, and the remaining individuals can be trained. As a result, the impact on cost and schedule performance is considered neutral. Educating junior team members is an unspoken guideline, allowing them to learn while working on the project. However, in certain situations, external parties need to be brought in. The response time to change requests is also positive, with a typical duration of 2 to 3 weeks for approximately 80% of the changes, depending on the complexity of the problem.

8. External

The stakeholders undeniably have an impact on the project. However, in this particular case, the client is effectively managing and protecting the stakeholders. The project team maintains a positive relationship with the external stakeholders, resulting in minimal resistance from them. As a result, the effect on the project's cost and schedule is neutral.

5.6.3 Summary of case 3

It can be observed that the client's decision-making had a positive impact on the cost and schedule performance of the project. Timely decisions made by the client, coupled with a strong client relationship, helped expedite the project progress. Additionally, the agreement for a cost-neutral contract further improved decision-making efficiency. However, the project turnover became a major contributing factor to the project's problems. The main reason for these issues was the change in project managers, particularly the challenges associated with finding and appointing a new project manager. The other indicators did not impact the cost or the schedule performance of the project as described in table 5.6.

Table 5.6: Impact of leading indicators: Case 3

No.	Leading Indicators	PM-Phase 1
1	Change Requests	Neutral
2	Decision making	Positive
3	Communication	Neutral
4	Bidding at low price	N/A
5	Resource allocation	Neutral
6	Project team turnover	Negative
7	Team efficiency	Neutral
8	External	Neutral

5.7 Case 4: TiWa

The Rivierenland Water Board is strengthening about twenty kilometers of dikes between Tiel and Waardenburg because it does not meet the legal standards for flood protection: the dike is too low and has insufficient stability. The manager of the flood defence, Water Board Rivierenland, has therefore been commissioned by the Flood Protection Program (HWBP) to reinforce the dike (Province of Gelderland, 2023).

The dike will be raised, berms will be built, and sheet piles will be installed. The dyke reinforcement is being carried out by the Mekante Dike construction consortium (Ploegam, Van Oord, and Dura Vermeer) (Rivirenland, 2023). The construction is expected to be finished by the end of 2026, after which the dike will be safe for the future.

Sweco has been appointed by Waterschap Rivierenland to oversee the entire engineering phase of the project, starting from the feasibility study and extending through the detailed design as described in figure 5.4. The engineering phase of the project has been completed, and the project is currently in the construction phase. Additionally, Sweco has been entrusted with the responsibility of monitoring the construction activities of the project.
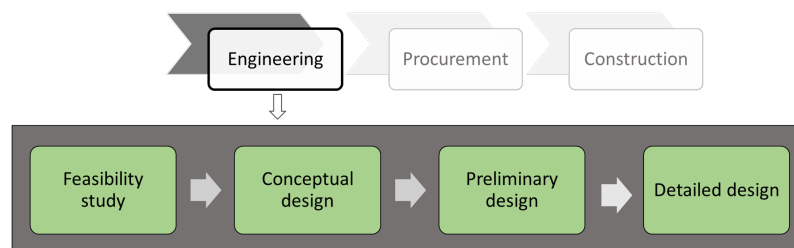
Figure 5.4: Project Phases TiWA

5.7.1 Current Cost & Schedule Performance

The project had cost and schedule overrun of more than 200%.

5.7.2 Effects of leading indicators on cost and schedule performance

1. Change request
The effect of change requests had a neutral impact. This was because for each change request, the team was compensated for the extra time required. However, it did have an impact on the overall schedule of the project, although the responsibility for the schedule did not lie with Sweco.

2. Decision making
The project encompassed a mix of positive and negative incidents. The involvement of the client was deemed essential, particularly during the initial design phase, as it had cost implications but ultimately contributed to an improved project outcome. However, the presence of indecisiveness, primarily resulting from a lack of expertise, had a detrimental effect. Delays occurred due to prolonged decision-making, and frequent client interventions further exacerbated the impact on project cost and schedule.

3. Communication
The project manager emphasized that communication did not pose any challenges regarding cost or schedule issues in the project. The presence of effective communication is regarded as a positive aspect. Given the project's five-year duration, the influence of communication was substantial. He believes that "Communication, in general, is viewed as a positive factor, while the absence of communication can result in problems". They actively pursued efforts to enhance our communication practices, although not all aspects unfolded as intended. However, it is important to acknowledge that certain instances where communication could have been different were beyond our control, and their resolution couldn't be solely achieved through improved communication.

4. Bidding at low price

The price of the project was adequate.

5. Resource allocation

The project manager strongly believes that when a project carries a strong appeal, it becomes easier to attract and retain the required people. He mentioned " For large projects, attracting people to work on the project is not very difficult as it is highly desirable. In our case, we had the necessary expertise readily available for the project."

6. Project Team Turnover

In this case, the changes in the project team had a positive impact on the project. Both on the client side and the employer side, there were significant personnel changes over a five-year period, but these changes were beneficial for the project. The quality of the project improved as a result. "Although the process of these changes might not have been pleasant during the project, ultimately, it proved to be advantageous for the project", says the project manager. However, it's important to note that this is not always the case. Typically, the best individuals are usually involved at the beginning of the project, and such beneficial changes in the team composition may not occur frequently.

7. Team efficiency

The project manager mentioned that because most times the best people were employed, the team was efficient.

8. External

The external stakeholder in the project tried to impact the project but it did not effect the cost or schedule of the engineering consultants.

5.7.3   Summary of Case 4

It can be observed that two key factors had an effect on the cost and schedule performance of the project: project team turnover and decision making by the client. The project team turnover had a positive effect as individuals who joined or left the project did so in the best interest of the project's improvement. Conversely, the client's decision-making process had a negative impact on the cost and schedule performance due to time delays. However, it was also evident that an additional team was required as not all decisions could be made in a timely manner. Table 5.7 depicts the impact of leading indicators.

Table 5.7: Impact of leading indicators: Case 4

No.	Leading Indicators	PM-Phase 1
1	Change Requests	Neutral
2	Decision making	Negative
3	Communication	Neutral
4	Bidding at low price	N/A
5	Resource allocation	Neutral
6	Project team turnover	Positive
7	Team efficiency	Neutral
8	External	Neutral

5.8 Cross Case Analysis

In this section, a comparison will be made regarding the impact of leading indicators in different projects. This analysis will assist in understanding the broader context and the impact of leading indicators in various scenarios, beyond just a single case. Table 5.8 provides an overview of the impact. It can be observed that decision making by client and project turnover have the most impact on the cost and schedule of the project. While the impact of externals and communication was neutral on the cost and schedule performance of the project. The indicators are discussed in detail below.

Table 5.8: Cross-Case Analysis of the impact of Leading Indicators

No.	Leading Indicators	Case 1 (i1)	Case 1(i2)	Case 2 (i1)	Case 2 (i2)	Case 3	Case 4
1	Change Requests	Negative	Negative	Neutral	Negative	Neutral	Neutral
2	Decision making	Negative	Negative	Positive	Positive	Positive	Negative
3	Communication	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
4	Bidding at low price	N/A	N/A	N/A	Negative	N/A	N/A
5	Resource allocation	Negative	Neutral	Negative	Negative	Neutral	Neutral
6	Project team turnover	Negative	Neutral	Negative	Negative	Negative	Positive
7	Team efficiency	Negative	Neutral	Negative	Negative	Neutral	Neutral
8	External	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral

1. Change Request

Change request has a negative effect primarily when extended discussions arise regarding the payment of the extra cost. The impact of change requests heavily relies on the reimbursement process. In Case 4, despite a significant number of change requests, the project's cost was not affected because the changes were agreed upon and promptly paid for, leading to a smoother process. Additionally, the change requests were made in a timely manner. In contrast, Case 1 experienced a large number of change requests, but prolonged discussions on payment have become the main concern, hindering the change process.

In Case 2 and Case 3, a cost-neutral arrangement was made. This arrangement worked well in Case 3 but not in Case 2. The client requested additional work but was unwilling to pay for the extra efforts in case 2. It can be observed that Case 2 is completed and case 3 is an ongoing project. It may happen that as the project progresses, there remains the possibility that the client may continue to prioritize cost considerations. Opting for a cost-neutral arrangement also introduces additional time requirements to assess what elements can be removed from the scope to accommodate new additions. A comprehensive analysis is essential in such scenarios. While building a good relationship with the client is beneficial, it does not always guarantee that the same scope will be achievable without additional costs.

The occurrence of change requests impacts negatively to the project cost and schedule. when the reimbursement for the change request depends on the type of contract in place. In a lump sum contract, it can be challenging to claim compensation. On the other hand, in a cost reimbursable contract, it is relatively easier to request financial reimbursement. The process of change request and contract type plays a vital role in change requests.

2. Decision making

The decision-making by the client was found to have a negative impact in two projects. Positive impact in two projects. The main reason for the negative effect was the lack of critical information provided by the client, resulting in significant delays. On the other hand, in cases where the project had a positive impact, it was observed that clear and timely decision-making played a crucial role. Such efficient decision-making can positively impact the cost and schedule of the project by minimizing delays and avoiding additional effort over an extended period.

Therefore, the three primary factors influencing decision-making are the time taken to arrive at a decision, the clarity and precision of the decision itself, and the provision of essential information necessary to execute the decision.

3. Communication

The case study also revealed that communication does not have a direct impact on the cost and schedule of a project. However, it is important to note that the absence of communication can significantly affect project performance due to its impact on team relations and information flow. Based on the analysis of the case study, it can be concluded that, in the context of cost and schedule performance, communication can be considered a hygiene factor. This is because the presence of communication may not directly affect cost or schedule, but the absence or deficiency of communication can have adverse impacts on project performance.

4. Bidding at Low price

Bidding at a low price was observed in the second phase of C2. This decision was primarily driven by the strong desire to secure the project. The challenges although were encountered but there was a strong optimism bias that the team will be able to finish the project in the allocated budget. Conversely, in other projects, project managers were confident that they could successfully complete the project within the assigned budget if there were minimal changes. As a result, the budget set during the bidding process was considered adequate in those cases.

5. Resource allocation

It was observed that team efficiency and resource allocation are closely correlated. The scarcity of available resources in a project contributes to inefficiencies, while projects with improper resource allocation also tend to have less efficient teams. The case study indicates that resource allocation is determined based on project priority and resource availability. In 3 out of 6 projects, resource allocation had an impact on the cost and schedule performance. This could be attributed to the availability of people within the organization or the overall scarcity of skilled labor in the Netherlands.

Resource allocation is generally done in three ways, firstly the expertise are hired from the NL office. Secondly, the expertise are hired from Sweco Poland/Finland. Thirdly, the expertise are either hired from an external party/secondment.

6. Project Team Turnover rate

The project team turnover rate, influenced by factors such as unavailability of resources and illness, is an external factor beyond the control of the project manager. It is important for projects to account for these costs in contingency planning. The turnover rate can also be influenced by the type of project and the project environment. In the case of the A9 project, the project team expressed satisfaction with leaving, while in other cases, individuals are eager to be associated with the project. This perception is often influenced by the client's involvement. Projects with frequent change requests and delays in decision-making can create a stressful environment for team.

7. Team efficiency

Team efficiency is influenced by three factors. Firstly, the availability of the required expertise in the team. In every case, it was observed that having the right person with the necessary skills in the team was a challenge, leading to chaos and difficulties in the team dynamics. Secondly, an enthusiastic designer can positively impact the team's performance. These designers exhibit a high level of passion, eagerness, and excitement for their work. However, at times, their ambition to create the best solution may lead them to overlook the time and cost constraints required to complete the design. While their drive for excellence is commendable, it can also result in longer design times, making it challenging to stay within the assigned budget. Thirdly, effective communication plays a vital role, particularly in projects that involve numerous interfaces. Regular communication within the team is crucial for better understanding and coordination.

8. External

In the case study, it was observed that the cost and schedule performance of the project, from the perspective of engineering consultants, were not directly affected by external factors. The management of external stakeholders was not a problem for the project as it was not in the

consultants' scope and was the responsibility of the client. However, it is important to note that external stakeholders may indirectly impact the work of the consultants. While this did not occur in the identified case study, it is crucial for consultants to be aware of the potential influence and interests of external stakeholders and consider their implications for the project.

5.9   Conclusion & Next Steps

The leading indicators identified during the initial two phases were validated by conducting a case study analysis across four distinct projects. This validation process also helped in understanding the impact of these leading indicators on the cost and schedule performance of each project. In total, six interviews were conducted. The impact of these leading indicators on the cost and schedule performance of the project is illustrated in Figure 5.5. It is evident that neither external factors nor
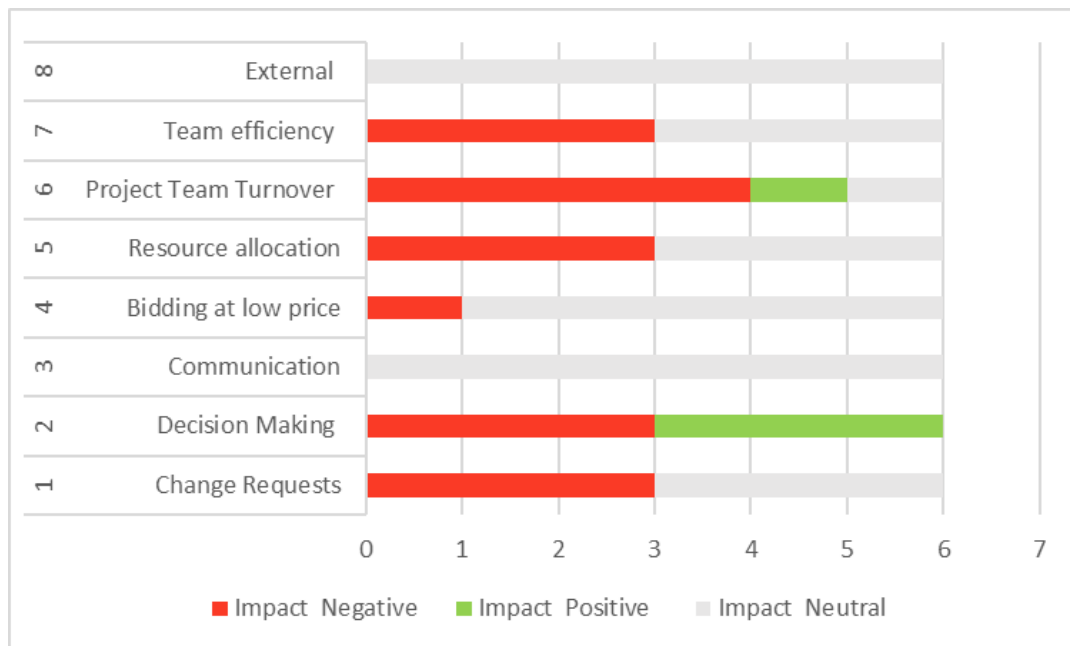

Figure 5.5: Impact of leading indicators

communication had an impact on the cost or schedule performance of any project. External had a neutral impact because most of the time the external scope was managed by the client and the consequences are also borne by them. Figure 5.6 provides an overview of the projects that were impacted by each leading indicator.
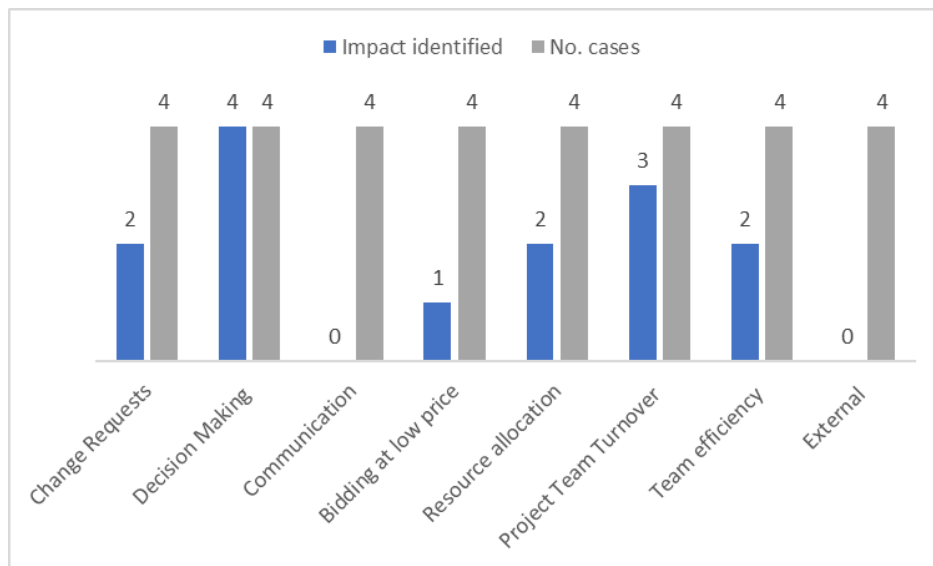
Figure 5.6: Impact identified in projects

Change request is termed to have negative impact when there are a lot of discussions regarding the payments. Especially when the lump sum contract is in place. The factors that influence change requests are the contract type and the change management process.

The impact of decision making by client was identified in all the projects. It had negative impact on two projects and positive impact on two. The factors influencing decision making are time taken to reach a decision, clarity/precision of the decision and the provision of essential information required for the effective execution of the decision.

Bidding at low price was observed to have a negative impact on the cost and the schedule because in the second phase of a project, the main reason was over optimism during the bidding phase.

Resource allocation had a negative impact on two projects and remained neutral in the others. This negative effect occurred because the required expertise for those projects was not available within the company. To address this issue, resource allocation was based on the availability of individuals, with priority given to billable employees.

However, this approach also affected team efficiency. The primary reason behind the impact on team efficiency was the inadequacy of resource allocation. Projects that received poor resource allocation also experienced lower team efficiency. Throughout the observation, resource allocation either had a neutral or negative effect on the projects, never yielding a positive impact. This highlights that resource allocation is indeed a significant problem within the organization.

Project team turnover was observed to be of highest significance. The turnover rate had a negative influence when individuals left or joined the company, leading to discontinuity within the team. People left the project team for various reasons, such as being assigned to a different project, falling sick, or departing the company. Conversely, new team members joined to contribute their expertise or to replace those who left for the mentioned reasons. Project team turnover was assumed to have a positive impact because the new team members joined with the intention of enhancing the project. The change in the project team was perceived as beneficial for the project's improvement. Thus, the main factors influencing project team turnover are members leaving or joining the project team because of the need for expertise, members falling sick or are appointed in a different project with high priority. Team efficiency had a negative impact on two projects. The factors that influence team efficiency are availability of the required expertise, enthusiastic designers and communication.

The case study analysis led to the confirmation and compilation of a comprehensive list of key indicators. An understanding was gained regarding both positive and negative effects of these indicators. The next essential step is to aggregate this information and formulate a framework to monitor these leading indicators.

Chapter 6

Framework Development

In this chapter, a framework for monitoring leading indicators is developed based on the results of the literature review, expert interviews and case study analysis. The framework is developed in consultation with experts. This corresponds with phase 4 of this research. This chapter aims to answer the final sub research question

SQ4: How can the identified indicators be monitored?

The chapter is constructed as follows. Section 6.1 provides an overview of step-by-step process of building the framework. The subsequent section 6.2 illustrates the proposed framework followed by framework implementation in section 6.3. Additionally, section 6.4, 6.5, discusses the expert validation and impact of expert validation respectively. Finally in section 6.6 conclusions are drawn, The next step is to see how these indicators can be monitored. This chapter focuses on suggesting how the identified indicators can be monitored in a project.

6.1   Constructing the Framework

The research began with a comprehensive literature study aimed at exploring and analyzing existing literature on leading indicators. Based on the insights gathered, a theoretical framework was developed. Additionally, expert interviews were conducted to identify leading indicators in practice, in the engineering phase. The outcomes of the expert interviews and the theoretical framework were then compared, leading to the creation of an exhaustive list of leading indicators. The next step involved testing these leading indicators in various project to assess their impact on cost and schedule performance.

The case study findings indicate that not all indicators have a significant impact on the cost and schedule of the project. **Bidding at low price** was found to be applicable in only one phase of the project. Furthermore, the case study revealed that **Externals** had a neutral impact on the project.

Similarly, Communication was identified to have a neutral impact. However, it is considered a crucial factor since its absence can significantly affect the project, as it is regarded as a hygiene factor. The interviews highlighted that absence of communication can result in problems, as mentioned in section 4.2.2, 5.7.1, 5.8. Therefore, it will be regarded as a relevant indicator. The number of indicators relevant to the engineering phases has decreased from eight to six. The most significant indicators in the engineering phase, whether impacting cost and schedule performance positively or negatively, are outlined in Table 6.1.

It's important to note that the identified leading indicators such as Change Requests, Team Efficiency, Project Team Turnover, and Decision Making evolve over the course of the project. Conversely, resource allocation is established at the start of the project. Therefore, monitoring of the leading indicators should begin from the start of the project.

Table 6.1: Most relevant indicators in the engineering phase

No.	Leading Indicators
1	Change Requests
2	Decision making
3	Resource Allocation
4	Project team turnover
5	Team efficiency
6	Communication

6.2 Proposed Framework

Based on the evolving nature of leading indicators, they are categorized into two phases, as depicted in Figure 6.1.
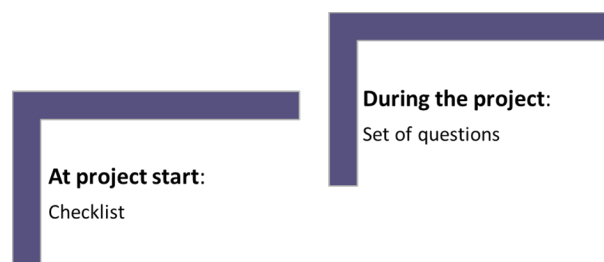
Figure 6.1: Phases of monitoring leading indicators

The first part of the framework entails a checklist exclusively with yes or no type questions, which should be monitored at the start of the project, which is phase 1. The second part consists of a set of questions that should be used at frequent intervals throughout the project, which is phase 2. Each of these phase is explained in detail in the following sections.

Framework Part 1: Checklist

The case study interviews and expert interviews emphasized inadequate resource allocation to projects, which subsequently impacted team efficiency. It was observed that when external parties are hired, their project objectives often differ and are not consistently aligned with the project's goals. Their primary focus tends to be on completing hours rather than project alignment. Likewise, challenges arise when expertise is sourced from Sweco Poland/Finland, as it can be difficult to align with their work culture. Therefore, it becomes crucial to establish a clear understanding of how and where resources will be hired right from the beginning of the project. This awareness will enable project managers to proactively plan the project's course based on these considerations.

Additionally, it was mentioned in the expert interviews, (as mentioned in section 4.2) instances of communication should be planned in a project, it keeps the project team align. It was also observed that having a proper communication helps in building trust between the client and the project managers. Therefore it is essential to have a communication plan set with the project team and also with the client. Moreover, it was observed in the case studies that communication becomes challenging when the project team are working in different locations and are not working on a full time basis, thus coordination becomes challenging. Therefore, in order to tackle this problem, having a communication plan at the start of the project is beneficial.

Furthermore, the case study revealed that change requests were a common occurrence across all projects. Although their impact was neutral in some cases, the likelihood of change requests highlights the importance of having a well-defined change management plan in place.

Thus at the start of the project it is important to know about the availability of the required

expertise in the project and from where the expertise are hired. For this purpose the first three statements are added in the checklist, as described in figure 6.2. Secondly, it is important to have a change management plan. Therefore, it is included as the fourth checklist point. Lastly, having a communication plan is necessary this leads to inclusion of the last two statements in the checklist.

Checklist: At Project Start

1. The required expertise are present in the project.

2. Expertise are hired from a different location.

3. Expertise are hired from an external party/secondment.

4. The procedure and timeline for responding to design change is defined.

5. Communication plan with team is made.

6. Communication plan with the client is made.

Figure 6.2: Framework Part 1: Checklist

1. The required expertise are available in the project.

Having the required expertise allocated to the project is an indicator that the team composition is strong. Conversely, if the required expertise is unavailable, it is an indicator for inefficiencies in the team. From the case studies it was observed that the inadequate resource allocation has a negative impact on team efficiency. Thus, the project completion may take longer than expected. Therefore a project manager should take the following actions inorder to make sure that the impact of lack of expertise is minimised on the project:

1. Reevaluate the project plan and timeline to accommodate any adjustments needed due to the skill gaps. Realistic planning will help to set achievable goals and will prevent potential bottlenecks.
2. Team members should be encouraged to seek help and advice from colleagues or mentors when facing challenges beyond their expertise, fostering a culture of continuous learning and improvement (Hansman, 2002).
3. The project manager should conduct a risk assessment to identify potential challenges related to the lack of expertise and develop contingency plans with alternative approaches and solutions.
4. It was mentioned in the interviews that transparency and open communication helps build trust and ensures that they are informed about the project's progress and challenges. Therefore a clear communication with the client about skill gaps should be made.

2. Expertise are hired from the same company but different location.

It was mentioned in the interviews that if the required expertise is hired from outside the Netherlands, it indicates potential differences in work culture between the Netherlands and other countries. Communication can also become more complex when team members are located in different parts of the world. In-person meetings might be difficult due to time zone differences and/or in person communication is almost impossible, making virtual meetings essential. Misunderstandings due to language nuances or varying communication preferences can arise, potentially affecting the clarity and efficiency of project-related discussions.

Addressing challenges associated with hiring expertise from different locations and managing cultural differences requires an all round approach. On organization level, a cultural diversity training to foster awareness and respect for varying work styles. On the project level, establish transparent

communication channels and hold regular virtual meetings to bridge geographical gaps.

3. Expertise are hired from an external party/secondment.

As mentioned earlier that external parties are hired to provide the required expertise, the project should be cautious because an external party may not share the same project objectives as Sweco. Therefore, if there is an involvement of an external party the project manager should make sure of the following to secure the availability of required expertise with minimal challenges:

1. Draft comprehensive contractual agreements that outline the scope of work, timelines, deliverable, and any specific terms and conditions. This will help protect both parties' interests and ensures clarity in the collaboration.
2. Establish a conflict resolution mechanism to address any disputes that may arise during the collaboration. Having a predefined process will ensure issues are resolved efficiently.
3. Develop a risk management plan that identifies potential risks associated with the involvement of an external party and outlines strategies to mitigate those risks.

4. The procedure and timeline for responding to a change proposal is defined.

The presence of a change management plan implies that the process for managing changes is clearly laid out. Without a change management plan in place, when changes inevitably occur in a project, it may lead to chaos as the project team won't know how to handle them.

In cases where a change management plan is lacking, it's essential to create a well-defined change management plan, that has clear protocols for response times, escalation procedures, and guidelines for handling urgent matters should be set. Furthermore, team members who oversee changes can be assigned as "Change Champions."

5. Communication plan with the team is made.

Communication is one of the most crucial and unique indicators. As mentioned earlier, it is considered a hygiene factor, implying that its presence does not directly impact project outcomes. However, the absence of communication can lead to significant problems. Therefore, it is essential to ensure that a communication plan is in place. If it is not, the project manager should make sure that a communication plan is created that describes the frequency of communication and agenda. Clear guidelines for sharing information, reporting progress, and addressing concerns should be included. The regular communication meetings will enable to review project progress, discuss challenges, and ensure everyone is on the same page.

6. Communication plan with the client is made.

Similarly, it is crucial to establish a communication plan with the client as well. Effective communication with the client is essential in a project, this was acknowledged by all the interviewees. The same actions discussed previously for the project team should be taken to develop and implement the communication plan with the client as well.

By systematically checking off these items, the project manager can effectively address potential resource gaps and communication challenges. Additionally, adhering to established procedures for design changes will promote consistency and efficiency throughout the project. In simpler terms, the checklist acts like a map guiding project managers to avoid problems before they become significant. By reviewing each item on the checklist, project managers can identify and resolve issues early, leading to smoother project progress and fewer unexpected surprises.

Framework Part 2: Set of questions

The second part of the framework consists of the indicators that evolves as the project progresses. This consists of the the leading indicators change requests, decision making, team efficiency and project team turnover. Additionally, it is crucial to regularly monitor communication. While the first part ensured the communication plan's establishment, the second part evaluates whether the plan is being executed as intended or not.

1. Change Requests

Starting with change requests, which are inevitable in projects, it is important to have a solid change

management process. Therefore, a change management plan needs to be defined at the project's outset. In the case study analysis, as mentioned in section 5.8, it was identified that the factors affecting change requests included client approval for additional time and incurred costs. Similarly, in cases of extra work, the approval for the extra work is important. Therefore, to effectively monitor change requests, two essential questions need consideration: Has the client approved the extra time and costs due to the change? And is there an agreement for the extra work?

The interviews uncovered that the change itself isn't the primary issue. Instead, obtaining approval and agreement on changes takes a significant amount of time and involves extensive discussion. These two questions, therefore, will allow the project manager to gauge the smoothness of the change request process. Furthermore, project managers possess extensive experience, which empowers them to also rely on their intuition. Experienced intuition is commonly reported by individuals with deep expertise in the respective field where they are receiving intuitive insights (Roeder, 2010). According to Roeder (2010), a, "If your intuition tells you to take the project in a certain direction, check the data to see if it supports your intuition. Also, you may want to have a conversation with a few stakeholders to uncover their perception of reality. Intuition works the other way around too. Spend a lot of time studying the data, then let your unconscious mind sort it out while you go for a walk, sleep, or engage in something unrelated to work. You may find moments of intuition after your full body has had time to process the data." The importance of intuition, is thus very important when it comes to experienced project managers. Therefore, a question related to intuition is also added and the project manager should take actions as suggested by Roeder (2010). The questions are described in figure 6.3.

If the client has approved the extra time and cost due to the change, it indicates that the change request process is progressing smoothly. On the other hand, if it is not approved, it is an early warning, and the project manager should proactively respond in this situation. Similarly, if the agreement for extra work is not presented, the project manager should first ensure if the work has been initiated. As mentioned in Case Study A9, in certain cases, the work is delivered even before receiving the agreement or assignment for the extra work. This situation creates a false perception of project performance. Thus, the absence of an agreement is an early warning of such a scenarios and there is a need to take prompt action. Lastly, since project manager has extensive experience, based on his experience, he should acknowledge and reflect on his intuitions.

2. Decision making by client

The case study, as discussed in section 5.8, highlights three principal factors that influence client decision-making: decision clarity, the time taken by the client to decide, and the availability of necessary client input. These factors form the basis for the formulated questions. Just as the importance of intuition was previously emphasized, project managers should similarly rely on their intuition when it comes to client decision-making based on their own experience. Thus the four questions based on decision making are listed in figure 6.3.

The case study indicates that decision-making has a negative impact in the absence of one out of three factors. Therefore, if there is no clarity in decision-making, an absence of timely decisions, and if the project team has to frequently go to the client to clarify decisions, then it is an early warning that the cost and the schedule performance of the project are going to be negatively affected. Thus the aim of the question to make the project manager aware of a potential problem in the project due to decision making.

3. Team efficiency

Similarly, team efficiency is influenced by factors identified in the empirical data, such as enthusiastic engineers and the expertise available in the team. Expertise available is checked at the start of the project, but it should also be assessed during the project to ensure that the required expertise is still available. Lastly, a question about team performance is included to understand the project manager's instincts. The questions are listed in figure 6.3.

If the team members are unable to meet the project requirements within the internal deadlines, it serves as an indication that there are issues within the project team. In such cases, the project manager needs to focus their attention on addressing these matters. Likewise, if the necessary expertise is unavailable, it signifies that the cost and schedule performance of the project will be impacted.

4. Project Team Turnover

As discussed in the previous chapter, project team turnover creates instability in the team. People leaving or joining the team can disrupt team dynamics. Therefore two questions are added along with the intuition question described in figure 6.3.

People leaving or joining the project team isn't necessarily a problem, especially if it contributes to the project's improvement, as observed in case 4. However, it's important for the project manager to comprehend the underlying reasons for the addition or departure of a new member. To achieve this, the project manager in case 4 mentioned that he ensures each new team member undergoes an introduction session upon joining and an exit session upon leaving. He explained that although this process takes time, the project has witnessed more favorable outcomes as a result.

5. Communication

The questions for monitoring communication will help to understand if the communication plan is taking place as planned.

List of Questions: During the Project

1. How is the change request process?

1.1 Has the client approved of the extra time and cost incurrerd due to the change?
1.2 Agreement for extra work is present?
1.3 What is your intuitive sense about the process?

2. How is the decision making by client in the project?

2.1 Is it required by the project team to frequently go to the client to clarify decisons?
2.2 Is the client making decisions in time?
2.3 Is the client providing the essential information requested in time?
2.4 What is your intuitive sense about the process?

3. How efficient is the project team?

3.1 Are the team members able to deliver the requirements as per the internal deadlines?
3.2 Is the required expertise avaliable in the team?
3.3 What is your intuitive sense about the team performance?

4. How is project team turnover in the project?

4.1 Are the project members leaving the project?
4.2 Are new members joining the project?
4.3 What is your intuitive sense about the turnover?

 5. Is the communication taking place as planned?

Figure 6.3: Framework Part 2: List of Questions

The objective of this research is to identify and monitor most relevant leading indicators. Project managers bring extensive experience to the table and inherently understand which actions are necessary based on their expertise. The primary goal is to enhance their awareness of a potential problem in the project. The questions will make them aware and provide an indication of a future probable problem and help them to take proactive measure accordingly.

6.3 Framework Implementation

The framework is made up of a series of questions that are designed to be user-friendly in terms of understanding the indications and minimizing the time necessary for implementation. As a result, the next step is to determine how this framework should be utilized, including implementation guidelines and suggesting target users.

Target users

The Project manager and Project controls should be the intended users of the proposed framework. This is due to their capacity to respond proactively to project-related challenges and risks.

Project controls are in charge of closely monitoring and managing the cost and the schedule of the project. Project managers, on the other hand, are responsible for planning, execution, and control. The project manager is also actively in contact with the client. Therefore, these personnel are in the right position to take proactive measures.

In the company, there is a different department for project controls. The project controls are hired in complex projects. In other projects, the project manager is responsible for project controls as well. In the former case, a crucial aspect in ensuring successful implementation of the framework involves fostering close collaboration between project controls and project managers. There should be open and honest communication between the two, and the project manager should answer these questions openly.

Implementation Guidelines

The framework's foundation is established through the integration of leading indicators and a set of monitoring questions. Complementing the leading indicators, the set of monitoring questions offers a practical means to assess and monitor the corresponding indicators. These questions are thoughtfully crafted based on the positive and negative impact of the leading indicators on the cost and schedule performance of a project, as identified from empirical data collection. They will play a crucial role in obtaining qualitative information, enabling the evaluation of overall performance and identification of areas that require attention or improvement.

The most crucial aspect is implementation. It is critical that the framework is used on a regular basis to monitor project performance. The following steps should be carried out to ensure an effective framework implementation.

To facilitate implementation when a project controls department is involved, the framework can be applied using a survey or Google Form, which can then be shared with the project manager. This is because, the project controls is not in direct contact with the client. Therefore, the project manager also has an overview of the project team. Therefore, project controls can use the framework to get early feedback on the project.

A meeting should be scheduled at two instances. The first meeting should be within the first two weeks of the start of the project to discuss the checklist. The schedule for other meetings should be discussed in this meeting. The other meeting instances should be fixed in the first meeting. The meeting instances should be based on the delivery phases, if that takes too long, the monitoring should be conducted once in every two months. This will allow project controllers to receive regular input on the project. On the other hand, the brevity of framework will allow the project manager to answer the questions quickly.

In cases, where the project controls department is not involved. The framework can also be directly employed by project managers themselves. They can pose these questions to themselves. The framework is structured with highly generic questions, making it applicable to a wide range of projects.

Furthermore, the leading indicators should be incorporated as Key Performance Indicators (KPIs). As a result, the framework should be deliberated in conjunction with the cost and schedule progress. This integration will guarantee that, in addition to cost and schedule, the leading indicators are considered during progress meetings.

6.4 Expert Validation

6.4.1 Expert Review Process

Two project controls department managers, who were external to this research and had not been interviewed previously, were selected for expert validation. Their opinions offer an unbiased perspective on the research findings. The identified experts have extensive experience as project controls managers in large and complex projects within the company, where there is a separate department dedicated to project controls. Their insights were best suited to validate the research findings, as the project controls department plays a significant role in monitoring project performance.

6.4.2 Expert Feedback

The experts agreed that the framework's questions were "on point," but they also cited a frequent issue: project managers are incredibly busy, and as a result, there's a good chance they won't complete out the form. This is because, when meetings with the project manager or design leads are scheduled, they are not very interested in conversations concerning cost and schedule. Furthermore, these meeting instances are not prioritized on their schedule because they are preoccupied with the main content of the project.

They also mention that within a project team, the positions of the project manager and the design leads hold higher authority than project controls. As a result, the opinions of the project controls department are not always prioritized. Furthermore, the experts revealed that scope-related matters are often discussed between the design lead and the client directly. The design lead, having direct contact with the client, agrees to additional scope because they consider it important, but they do not prioritize project constraints, particularly with respect to cost. While considering these suggestions, opinion from the project controls department is not considered essential.

Generally, project managers in a project do not prefer to have project controls appointed in their projects. The project team perceives them as imposing restrictions on the project.

Finally, the experts approved the framework's contents, but they are skeptical that the project managers will be willing to fill out the form. They say it's in the company culture to provide the best possible solution to the client, yet project restrictions are frequently overlooked while working on this solution.

6.5 Impact of Expert Validation

The impact of expert validation on the suggested framework itself is not much. The major concern that arises is the implementation of the framework.
It was mentioned in the interviews, that the project manager do not have sufficient time to do this formalities. In a practical world they may end up not filling the form and providing solutions.

The most serious problem emerges during the framework's implementation. Perceiving project controls as restrictive reveals a lack of urgency understood by project managers. Project controls are vital in project management (Regmi et al., 2019); senior management must recognize their importance. Implementing project controls is crucial for on-time, on-budget project completion (Marks, 2012). Addressing this, the organization must prioritize their role, and project controls should escalate the issue to senior management for action.

The project manager's time constraints, client communication, the positioning of project controls in the project hierarchy, and insufficient focus on project controls stand out as the main concerns. Project managers and designers frequently underestimate the urgency of implementing robust project controls. Consequently, taking effective actions in these areas is crucial for successful framework implementation. The following actions should be pursued:

- In order to tackle the time restrictions of the project manager, an associate project manager should be appointed in every project; this will relieve the project manager's workload and

allow him to focus on the project management side of the project.

- To incorporate the significance of project controls, altering the mindset of project managers is a challenging endeavor. However, if senior management acknowledges the necessity of these measures, project managers will be compelled to adhere to these standards. Secondly, create awareness about project controls in the company by conducting seminars, webinars and workshops.
- While project managers might perceive project controls as imposing restrictions, the framework's questions do not encompass financial or schedules. This framework resembles storytelling, which project managers might feel inclined to share, without creating a sense of restriction.
- To address decisions related to additional scope, establish a collaborative decision making platform that should consider the inputs form the design team, the project manager and the project controls. A decision should be processed further only after taking everyone's opinion in the discussion.

6.6 Conclusion

The framework, illustrated in Figure 6.4, allows for monitoring the leading indicators. It's split into two parts: a checklist for project initiation and a set of ongoing questions due to the dynamic nature of leading indicators.

Both project managers and project controls should use this framework. Project managers can use it independently as a quick performance check, while project controls can pose these questions to the project manager.

Checklist: At Project Start

1. The required expertise are present in the project.

2. Expertise are hired from a different location.

3. Expertise are hired from an external party/secondment.

4. The procedure and timeline for responding to design change is defined.

5. Communication plan with team is made.

6. Communication plan with the client is made.

List of Questions: During the Project

1. How is the change request process?

   1.1 Has the client approved of the extra time and cost incurrerd due to the change?
   1.2 Agreement for extra work is present?
   1.3 What is your intuitive sense about the process?

2. How is the decision making by client in the project?

   2.1 Is it required by the project team to frequently go to the client to clarify decisons?
   2.2 Is the client making decisions in time?
   2.3 Is the client providing the essential information requested in time?
   2.4 What is your intuitive sense about the process?

3. How efficient is the project team?

   3.1 Are the team members able to deliver the requirements as per the internal deadlines?
   3.2 Is the required expertise avaliable in the team?
   3.3 What is your intuitive sense about the team performance?

4. How is project team turnover in the project?

   4.1 Are the project members leaving the project?
   4.2 Are new members joining the project?
   4.3 What is your intuitive sense about the turnover?

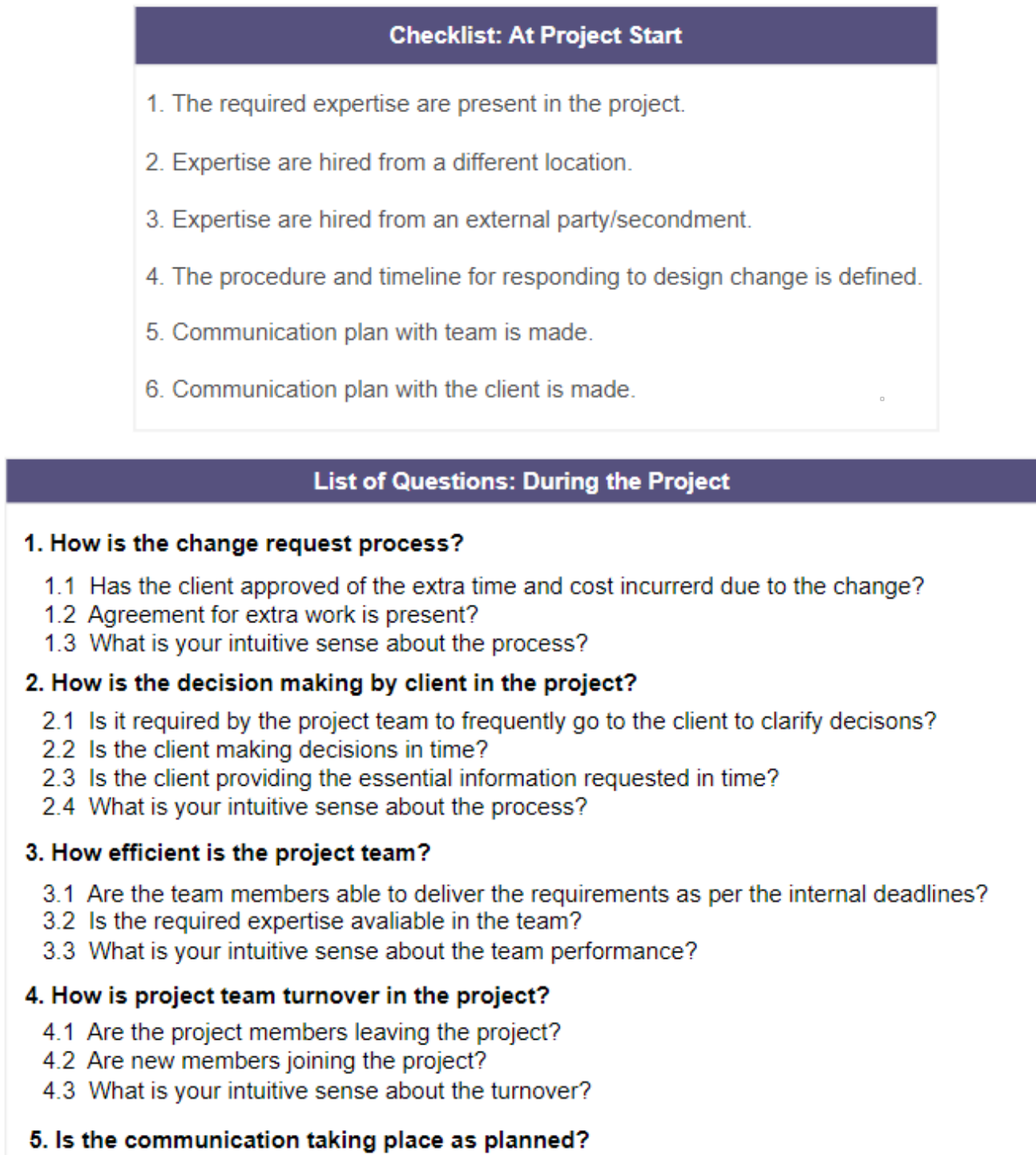**5. Is the communication taking place as planned?**

Figure 6.4: Framework

Chapter 7

Discussion

This chapter examines the findings of the research. It begins with a discussion of the scientific implications in section 7.1. Following that, the practical application of the findings is explored in section 7.2, and the limitations of this research are discussed in section 7.3.

7.1 Scientific Implication

The research on leading indicators is quite limited, with a scarcity of articles found in the literature. Additionally, the engineering phase has been given relatively less attention, resulting in fewer studies conducted in this area. This research is distinctive as it centers on these two relatively rare and under-researched domains.

The literature that exists on leading indicators heavily relies on review papers, and lacks empirical data gathering. However, research conducted in this thesis incorporates expert interviews and case study analysis, which enhances the validity of the study. The indicators in the literature are compared with the practise two times, once in the expert interviews and then in case study interviews.

The literature primarily defines leading indicators in the context of negative project outcomes. However, this research also emphasizes leading indicators with a positive impact. The indicators are phrased in a neutral manner to consider both the negative and positive effects of the indicator.

Furthermore, this research goes beyond mere identification; it has developed a framework for monitoring the identified leading indicators.

7.2 Practical Implication

This research plays a crucial role in identifying the most relevant leading indicators during the engineering phase of projects. Through comprehensive expert interviews and rigorous case studies, this research provides a robust foundation for determining which indicators reliably correlate with cost and schedule performance. By leveraging this research-backed framework, project managers will gain the confidence to recognize the early warning signs of potential problems. They can then respond proactively, ensuring that necessary actions are taken promptly to mitigate any negative impacts and influence the positive impacts on the project's cost and schedule. In essence, this research equips project managers with a powerful framework to navigate project challenges with greater foresight and effectiveness.

7.3 Limitations of the research

Like all research, this study has certain limitations. Based on these limitations future research recommendations are provided in section 8.3. This section outlines those limitations as follows

- The research is highly based on the perspective of project managers in the engineering phase, resulting in a limited number of interviews per case study. However, as the project manager

holds a prominent position in the project hierarchy, they have an overview of every discipline involved in projects. Therefore, the research findings are reliable.

- The recommendations given in the expert validation, as outlined in section 6.5, suggest proposing to senior management that they establish these recommendations as formal rules. However, project managers in this scenario might view them as obligations and may only complete the formalities for the sake of compliance, without investing their full attention and concentration.

- All the interviews are conducted with the project managers from the same company; therefore, the research findings may be aligned with the company culture and can be biased.

- All the expert interviews are conducted solely with the perspective of project managers, the perspective of other participants are not taken into consideration.

- The research focuses only on identifying and monitoring the indicators, how the project managers should react in every situations is not covered in the research.

- The research doesn't explore response strategies to leading indicators due to time constraints.

- The framework is validated from the perspective of project controls, the perspective of project managers is not taken into consideration due to time restrictions.

Chapter 8

Conclusion & Recommendations

As this study on identifying leading indicators in the engineering phase of infrastructure projects comes to an end, the following sections in this chapter will provide a concise summary of this research. In section 8.1 the research questions will be answered. In the subsequent section 8.2 recommendations for the company are provided, followed by recommendations for future research in section 8.3.

8.1   Answering the Research Questions

The sub-research questions are answered first, and based on these findings, the main research question will be addressed.

SQ 1: What are the most relevant leading indicators in literature?

A total of three articles were found in the literature that identified the leading indicators based on which the theoretical framework was created. Two out of the three articles are literature review papers that considered more than 100+ and more than 200+ articles, respectively. One of the three also involves empirical data collection from 90+ organizations, including companies and government agencies. Thus, these articles provide validity and credibility to the framework.

The three articles, when combined, form the theoretical framework as described in the table 8.1. The overlapping indicators were merged together and a total of 19 leading indicators were identified

The importance of using leading indicators in monitoring project performance was identified in the literature. Leading indicators help in taking proactive measures; they can predict potential performance variances before they cross the tolerance threshold. They also assist in predicting the likelihood of future leading indicators.

It was also observed in the literature that the engineering phase has the highest influence on the cost of the project when compared to procurement and construction phase. Despite of its importance, the phase is not given much attention in the literature.

Table 8.1: Theoretical Framework

No.	Leading Indicators
	Alignment
1	The project team has the necessary expertise, experience, breadth, and depth to successfully execute the project.
2	Business goals, project objectives and priorities, and critical success factors are consistently used by project team members and key stakeholders to guide decisions.
3	The level of maintenance and reliability personnel involvement in detailed design is low and the personnel lack alignment with other project team personnel with respect to maintenance issues for the facility.
4	The project team members are from different cultures.
5	Communication within the project team and key stakeholders.
	Change Management
6	The responsiveness of the project team to Requests for Information, questions, and changing events that can significantly impact the project.
7	Change in client/contractor requirements.
8	The ability of the project team to identify and/or address missing requirements during detail design reviews.
9	Time taken to process design change.
	Contracting
10	Significant project scope items are inadvertently omitted from bid packages.
11	Financial stability of the project participant companies.
	Quality
12	A project specific quality plan is defined and used in the project.
	Team Building
13	Project Team Turnover rate.
14	Relationship between key project stakeholders
15	Effective coordination between project team and key stakeholders.
	Client Related
16	Time taken for Decision making.
17	Time taken for approval stage
	Organization Based
18	Resource management .
19	Project Size

SQ 2: What are the most relevant leading indicators in practice?

A total of 8 experts with over 10 years of experience in the engineering phase of infrastructure projects were interviewed to identify the most relevant leading indicators. It was observed that the indicators mentioned by the last two experts coincided with the indicators identified by the initial six. This led to the conclusion that a saturation point in the interviews is reached.

It was observed that not all indicators identified in the theoretical framework were identified in the interviews. The primary reason for this is the perspective and the phase of the project. The literature did not clearly mention to which phase the indicators belong to and it also consist of multiple perspectives. So the indicators that were not identified in the interviews were excluded from this research. Moreover some additional indicators were also identified, as described in the table 8.2. The interviews also revealed that the current monitoring system heavily emphasizes lagging indicators. Interestingly, the project managers were not familiar with the term 'leading indicators,' but they did understand the rationale behind it.

Table 8.2: Indicators identified in practice

	Leading Indicators	
No.	Indicators	Description
1	Change request	Change in client requirements and the time taken to process design change.
2	Decision making	The precision and duration of decision making by the client.
3	Communication	The frequency of communication and the clarity in the delivered message.
4	Project size	Project size in terms of budget, cost, and number of stakeholders involved.
5	Bidding at low price	Submitting the bid at a price lower than expected.
6	Resource allocation	The basis on which resources are allocated to the project team.
7	Project team turnover	The number of people leaving or joining the team during the project.
8	Team efficiency	The ability of the project team to complete tasks within the given time.
9	External	The degree to which stakeholders are identified and managed. Changes in rules and regulations, Politics, Media.

SQ 3: How do the identified leading indicators affect the cost and the schedule performance of a project?

In order to identify the impact of the leading indicators on the cost and schedule performance, case study analysis was conducted. A total of 4 cases were selected and the project manager from each case was interviewed. The impact of each leading indicators in the project was asked and additionally a question was asked if there are any other challenges in the project that is having an impact on cost and schedule performance of the project. But the answer was always a no, this also validated the identified leading indicators. The impact of each leading indicator on the project is described in table 8.3. Change request had a negative impact because it involved a lot of discussions

Table 8.3: Impact of leading Indicators on cost and schedule of the project

No.	Leading Indicators	Case 1 (i1)	Case 1(i2)	Case 2 (i2)	Case 2 (i2)	Case 3	Case 4
1	Change Requests	Negative	Negative	Neutral	Negative	Neutral	Neutral
2	Decision making	Negative	Negative	Positive	Positive	Positive	Negative
3	Communication	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
4	Bidding at low price	N/A	N/A	N/A	Negative	N/A	N/A
5	Resource allocation	Negative	Neutral	Negative	Negative	Neutral	Neutral
6	Project team turnover	Negative	Neutral	Negative	Negative	Negative	Positive
7	Team efficiency	Negative	Neutral	Negative	Negative	Neutral	Neutral
8	External	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral

with client for the extra cost incurred due to the change which impacted the cost and the schedule of the project. Decision making by client had a negative impact when the decisions made by client were not clear or the key inputs were not provided to the project team or the client took a lot of time to take a decision. It was positive when the decisions made by client clear and accurate and this helped the project team to work on the project and it helped the project team to effectively respond to the projects. Bidding at low price had a negative impact because the project budget and timeline was underestimated due to over optimism during the bidding phase. Resource allocation had a negative impact because the right expertise was not present in the team same is the case for team efficiency.

SQ 4: How can the identified indicators be monitored?

A project manager typically handles a substantial workload, making it crucial to create an easily manageable and monitorable framework. To achieve this, a framework was developed by incorporating a checklist and a set of questions designed specifically for the project manager's use. During the case study, it was observed that external factors and communication had a neutral impact on the project. External was thus not included in the framework. Communication although does not directly impact the cost and the schedule of the project but the absence of communication will highly impact the project. Therefore, communication is included in the framework.
The checklist is intended for use at the start of the project. And the set of questions should be used at the end of every delivery stage or once in two months. This division of framework is because of the evolving nature of the leading indicators, where not everything is evident at the start of the project.

MQ: How can leading indicators be used to monitor the performance of an infrastructure project during the engineering phase?

This research identifies leading indicators that hold relevance within the engineering phase of an infrastructure project. These indicators are derived from comprehensive literature review and empirical data collection, rendering them reliable.

To monitor these identified leading indicators effectively, a framework has been developed, which should be regularly utilized. Similar to lagging indicators, these leading indicators should be discussed during the update meetings with the project team and the organization. Monitoring of leading indicators should begin from the start of the project and it should be a continuous process.

The proposed framework will be valuable for project managers to enhance their ability to predict and manage potential problems within projects. By implementing a system of regular monitoring, the framework aims to make projects more predictable in terms of their cost and schedule performance. This proactive approach empowers project managers to identify emerging issues at an early stage, enabling them to take timely and informed actions.

An essential feature of the framework lies in the design of the questions. These questions are intentionally framed in a generic manner, ensuring that they can be applied to a wide range of projects. This universality enhances the framework's adaptability across different projects. Furthermore, the framework emphasizes conciseness, with a limited number of questions. This deliberate choice enables project managers to quickly review these questions, fostering efficiency and allowing them to integrate the predictive assessment seamlessly into their workflow.

8.2 Recommendations for the Company

The recommendations for the company stems from the interviews. These recommendations will enhance the applicability of the framework and the ability of the project manager to predict potential problems in a project.

- Lessons learned from every project should be prepared. This enables the project manager to revisit the project later. These lessons learned should not be seen merely as documentation; they should be detailed and act as a comprehensive project diary. Everything, from change management to escalations, and all meetings, should be mentioned in this record. Both the positive and negative aspects of the project should be considered. A standardized format should be adopted for consistency and effectiveness.
- Similarly, the minutes of the meeting should be prepared after every meeting by adopting a standard format.
- A document controller can be hired to maintain and update these documents in consultation with the project team.
- It was observed in the expert interviews and also in the case study interviews that the project manager had to invest a lot of time to have the right resource in the team. Therefore, a dashboard should be created with the availability of the project team members and their

experience. This dashboard will enable the project manager to understand the availability of the required personnel, saving them time in searching for the needed expertise.

8.3 Recommendations for Future Research

In conclusion, this study has highlighted the key relevant leading indicators in the engineering phase of infrastructure projects and has crafted a framework for their ongoing monitoring. While the findings offer valuable insights, several unexplored directions for future research exist. The following are the recommendations for future research. Some of these recommendations stem partly from the limitations of this study as discussed in section 7.3.

- Assess the effectiveness and practicality of the framework through a comprehensive case study analysis during the entire engineering phase, utilizing the framework from project initiation to its completion.
- Verify the identified leading indicators by incorporating the perspective of the designers during the engineering phase.
- Identify the response strategy to the leading indicators in various scenario. This would contribute to a more holistic understanding of how to proactively address potential challenges in various project scenarios.
- Identify the leading indicators in the engineering phase from the perspective of client and contractors.
- Conduct a study to examine the correlation between the identified leading indicators, assessing the mutual influence of these indicators on each other.
- Conduct a similar research in a different country, allowing for cross-country comparisons of the research outcomes.

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Appendix A

Leading Indicators

Table A.1: Leading Indicators identified by (Choi, 2007)

Groups	Leading Indicators
Alignment	The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project.
	Business goals, project objectives and priorities, and critical success factors are not being consistently used by project team members and key stakeholders to guide decisions.
	The level of maintenance and reliability personnel involvement in detailed design is low and the personnel lack alignment with other project team personnel with respect to maintenance issues for the facility.
	The project manager (or team leader) is lacking in the required level of experience and skills.
	Commitments are increasingly made with the intention of not being met and are almost always not met.
	The project is frequently asking vendors, suppliers, service providers, and contractors to perform functions outside their areas of expertise and experience.
	The project is experiencing difficulties due to the lack of understanding cultural differences.
	The client and/or upper management is frequently making unreasonable requests (includes setting unrealistic goals.)
Change Management	The project team's response to Requests for Information, questions, and changing events that can significantly impact the project results is slow, inadequate, or incomplete.
	Owner and/or contractor is requesting an excessive number of contract changes and/or scope changes during project execution (detailed design, procurement, construction, and start-up).
	The project team is failing to identify and/or address missing requirements during detail design reviews.
	Project changes are not being processed in a timely manner for decision making (includes defining cost and mark-up rates, evaluating schedule impact, obtaining appropriate approval authority, and initiating dispute resolution procedures.)
Constructability	The project lacks sufficient skilled craft and is experiencing high craft turnover due to competition from other projects, low wages, and/or undesirable work schedules.
	The project lacks sufficient staff, bulk materials, small tools, and construction equipment to adequately support planned construction activities.
	The project is using new technology or construction practices that are unproven in commercial or industrial use.
	Material and/or equipment prices are increasing rapidly for certain types of materials/equipment that represent a high percent of the project cost.

Groups	Leading Indicators
Contracting	Construction is awarded before adequate completion of project design, including discipline design packages, resulting in an incomplete scope definition at time of award/start of construction.
	Significant project scope items are inadvertently omitted from bid packages.
	Some project participant companies become financially unstable.
Quality Management	The project is experiencing a high level of engineering/design/specification errors and scope changes.
	A project-specific quality plan is not consistent with the contract documents (plans and specifications.)
	The project fails to follow the quality plan for construction in relation to the roles and requirements of those who are responsible for that plan.
	The project is experiencing an above normal level of construction rework hours and costs when compared to target levels of rework included in the total budget on schedule.
	Project quality control results are reflecting high rejection rates for equipment and materials under fabrication in the factory and/or materials in place through testing in the field.
Safety Practices	The project is experiencing a high level of safety incidents.
	Design reviews fail to include qualified personnel who can analyze safety ergonomics, and/or loss prevention features of plans and specifications.
	The project team personnel lack involvement in safety inspections, awareness of safety issues, and education in safety practices.
	Potential safety related problems are not being resolved in a timely manner.
	The project is experiencing an increasing level of worker non compliance in safety practices.
	The project is not following the requirements of a project specific safety plan during construction.
	Process Hazard Analysis (PHA) is late and/or is experiencing an excessive number of operational/support items that are not complete during the design phase.

Groups	Leading Indicators
Project Control	The project team is losing confidence in the accuracy and validity of the schedule.
	Project milestones are not being met and are consequently jeopardizing future project milestones.
	The level of detail and the scope covered in the funding authorization estimate are not per estimating guidelines.
	The project is experiencing difficulties in integrating schedules between project participants.
	Actual installed bulk material quantities are greater than estimated or forecasted total bulk material quantities (e.g., steel, concrete, straight run pipe, electrical wire and cable.)
	Float for project activities is being used up at an increasingly high rate.
	Actual schedule activities are lagging behind planned scheduled activities over several reporting periods.
	Forecasts-to-complete based on actual project experience, actual commitments, and actual expenditures are projecting overruns.
Team Building	The project team is experiencing a high turnover rate and instability in team membership.
	Owner and contractor project personnel are not properly aligned.
	Key project stakeholder(s) is (are) exhibiting poor relationships and pursuing private agendas.
	The project team is not being realistic and truthful when project circumstances are unfavorable.

Appendix B

List of Interviewees

Ref.	Name	Current function	Department	Experience
1	Teunis Louters	Project Director	Transport & Mobility	30+
2	Marco Mijnders	Project Director	Transport & Mobility	25+
3	Robert Coffeng	Team Manager	Mobility	25
4	Robert Dwars	Project Manager	Roads	25
5	Geert Kervliet	Team Manager	Roads	10+
6	Pieter van der Knaap	Team Manager	Water	15+
7	Stephan Laaper	Project Manager	Water	20+
8	Gijs Kreike	Project Manager	Rail & Stations	15

Appendix C

Expert Interview Questions

A) **Research Context**
   The focus of the research is to create a performance measurement framework with a balanced set of leading and lagging indicators. Leading indicators are the project events/characteristics that proactively predicts potential problems in projects before it affects the project baseline. On the other hand, lagging indicators are the project events/characteristics that reflect the performance of a project after they affect the project baseline.

B) **Experience**

   (a) How long have you been Project Manager? / Involved in construction projects?

   (b) What kind of projects have you been involved in?

C) **Cost Performance**

Negative

1. Can you give an example of a project where there were major cost overrun?

2. What were the major reasons that contributed to project overrun? (If necessary ask Why questions to understand the root cause of the problem)

3. Can you describe any challenges or obstacles that arose during the project that impacted the cost?

4. How and when did you come to know about the cost overrun?

5. When was the first time you realized there is going to be a cost overrun?

6. How did you monitor cost performance? (ask explicitly if qualitative measures were used, if it is not mentioned) (ask monitoring also)

7. What were the KPI's used in the project ? Why?

8. How did you and your team respond to the cost overrun? What strategies did you use to address them?

9. Can you share any lessons learned from this experience that you have applied to subsequent projects?

10. In the hindsight do you think you could have anticipated the project overrun earlier based on certain events or project characteristics?

11. Looking back on the project, is there anything you would have done differently to avoid or mitigate the cost overrun?

12. Have you observed any common causes of cost overrun in projects?

Positive

1. Can you give another example where in the project was completed in/under budget?

2. What were the major reasons that contributed to completing the project within budget?

3. Can you describe any challenges that were encountered during the project that could have impacted the cost, and how those challenges were addressed?

4. Was there anything in the project management approach that contributed to the positive cost overruns? For example, was there a particular tool or technique that was used that helped manage costs effectively?

5. When was the first time you realized there is going to be a cost overrun?

6. How did you monitor cost performance? (ask explicitly if qualitative measures were used, if it is not mentioned)

7. How did you measure cost performance?

8. What were the KPI's used in the project ? Why?

9. Looking back on the project, what was done differently that contributed to finishing the project in budget?

10. In the hindsight do you think you could have anticipated the positive project overrun earlier based on certain events or project characteristics?

11. Can you share any lessons learned from this experience that you have applied to subsequent projects?

12. Have you noticed any common causes of why projects are completed within budget?

D) **Schedule Performance**

Negative

1. Can you tell me about a time when you experienced schedule overrun on a project you were working on?

2. What were the major reason that contributed to the delay?

3. Can you describe any challenges or obstacles that arose during the project that impacted the schedule?

4. How did you and your team respond to the schedule overruns? What strategies did you use to address them?

5. When was the first time you realized that there is going to be a schedule overrun?

6. How did you monitor schedule performance? (ask explicitly if qualitative measures were used, if it is not mentioned)

7. How did you measure schedule performance?

8. What were the KPI's used in the project ? Why?

9. How did you measure schedule performance? (ask explicitly if qualitative measures were used)

10. Looking back on the project, is there anything you would have done differently to avoid or mitigate the schedule overrun?

11. In the hindsight do you think you could have anticipated the overrun earlier based on certain events or project characteristics?

12. Can you share any lessons learned from this experience that you have applied to subsequent projects?

13. Have you observed any common causes of schedule overrun in projects?

Positive

1. Can you tell me about a time when you managed to finish on/before schedule?

2. Why do you think the project was completed within the timeline?

3. Can you describe any challenges that were encountered during the project that could have impacted the schedule, and how those challenges were addressed?

4. Was there anything in the project management approach that contributed to avoiding the delay? For example, was there a particular tool or technique that was used that helped manage schedule effectively?

5. How did you monitor schedule performance? (ask explicitly if qualitative measures were used, if it is not mentioned)

6. How did you measure schedule performance?

7. What were the KPI's used in the project ? Why?

8. Looking back on the project, what was done differently that contributed to finishing the project in time?

9. In the hindsight do you think you could have anticipated the positive project overrun earlier based on certain events or project characteristics?

10. Can you share any lessons learned from this experience that you have applied to subsequent projects?

11. Have you observed any common causes of finishing a project in time?

12. How did you measure schedule performance?

E) **Leading Indicators**

1. Are you familiar with the phenomenon of leading indicators?

2. Do you make use of leading indicators in projects?

    i. If yes, how and when do you make use of these indicators?
    ii. If no, why?

3. Do you make use of qualitative methods to measure project performance? If yes, which ones? If no, why?

4. In general, what factors do you consider crucial for measuring project performance?

5. What are some of the client-related factors that affect project performance?

6. What are some of the project team-related factors that affect project performance?

7. What are some of the external stakeholder-related factors that affect project performance?

8. Are there any additional factors that affect project performance?

9. Is there anything else you would like to share?

Appendix D

Case Study Interview Questions

- Decision Making

  - What is the effect of decision making on the cost/schedule of the project?
    * Positive
    * Negative
  - Why do you think so?
  - When and how did you come to know about it?
  - What reactions were taken?

- Change Request

  - What is the effect of change request on the cost/schedule of the project?
    * Positive
    * Negative
  - Why do you think so?
  - When and how did you come to know about it?
  - What reactions were taken?

- Bidding at Low Price

  - Do you think the project was bidded at a low price? Why?

- Resource Allocation

  - Do you have the required expertise in the team?
  - How does it affect the cost/schedule of the project?
    * Positive
    * Negative
  - Why do you think so?
  - When and how did you come to know about it?
  - What reactions were taken?

- Turnover Rate

  - Is there a change in the project team, people leaving or joining the project team? (Yes/No)
  - How does that affect the cost and schedule of the project?
    * Positive
    * Negative

- – Why do you think so?
- – When and how did you come to know about it?
- – What reactions were taken?

- Communication

  - – How does communication affect the cost/schedule of the project?
    - ∗ Positive
    - ∗ Negative
  - – Why do you think so?
  - – When and how did you come to know about it?
  - – What reactions were taken?

- Team Inefficiency

  - – Do you think the project team is inefficient?
  - – How does that affect the cost/schedule of the project?
    - ∗ Positive
    - ∗ Negative
  - – Why do you think so?
  - – When and how did you come to know about it?
  - – What reactions were taken?

- Stakeholder Management

  - – What is the effect of external stakeholders on the cost/schedule of the project?
    - ∗ Positive
    - ∗ Negative
  - – Why do you think so?
  - – When and how did you come to know about it?
  - – What reactions were taken?

- **Are there any additional challenges in the project?**

- **Is there any other aspect that you would like to mention that had an impact on the project's cost and schedule?**