Early Warning Signals: A Strategy for Reducing Schedule Delays in Infrastructure Projects During the Design

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Ivan Dimitrov

Executive Summary

The scale and complexity of projects in the construction sector have grown significantly in recent years. Larger projects typically result in worse performance, including overspending and delays in the calendar (Luo et al., 2017). These delays can often be attributed to various factors such as design flaws, inadequate planning, and unforeseen site conditions. Traditional project management approaches, which tend to be reactive, have proven insufficient to address the complexities of modern infrastructure projects. This thesis explores the concept of Early Warning Signals (EWS) as a proactive strategy to identify and mitigate potential schedule delays during the design phase of infrastructure projects.

The primary objective of this research is to understand how Early Warning Signals (EWS) can be effectively utilized during the design phase of infrastructure projects to identify potential issues early in the project lifecycle. By doing so, the study aims to develop strategies that can be employed to minimize schedule delays, thereby improving overall project outcomes. The main research question to be answer is as follows:

> *How are Early Warning Signals (EWS) related to the control and reduction of schedule delays in the delivery of the design phase of Dutch Infrastructural projects?*

The focus is on Dutch infrastructure projects, with the research being conducted in collaboration with Sweco Netherlands.

Early Warning Signals (EWS) are subtle signs or indicators that suggest potential future problems in a project. The concept of EWS was first introduced by Igor Ansoff in 1975, who emphasized the importance of detecting these weak signals early to prevent crises. In the context of construction project management, EWS can manifest as various indicators, such as unclear scope definition, delays in decision-making, inadequate staffing, and procurement issues. These signals, if identified and addressed timely, can prevent minor issues from escalating into significant problems that could derail the project timeline.

The proactive identification and management of EWS are crucial for the success of infrastructure projects, especially during the design phase. The design phase is where most critical decisions are made, and any delays at this stage can have a cascading effect on the entire project.

Despite the recognized importance of the early project stages in determining project success, there is a notable gap in the existing literature regarding the identification and measurement of EWS, particularly during the design phase of construction projects. This thesis seeks to fill this gap by developing a framework for the identification, monitoring, and prioritization of EWS.

To identify the most relevant EWS, the study combines insights from existing literature with practical experiences shared by Sweco experts. This process involves creating a comprehensive list of potential EWS, which is then narrowed down and prioritised based on their perceived impact and likelihood. The prioritisation is similar to a risk assessment method, considering both the probability and potential impact of each signal.

The literature review conducted as part of this research identified a total of 87 potential EWS relevant to construction projects. These signals were further refined into 25 distinct indicators by combing the results from the interviews and literature and asking the participants to score them. In the end, by prioritising the signals, six of them were selected to continue the research. These were the top three identified from practice and top three from the theory namely “client makes slow decisions”, “scope

creep", "unclear scope definition", "high level of engineering/design errors", "poor quality of the reports, preliminary plans, and documentation" and "consultants making continuous attempts to redesign the project".

The research highlights the importance of both formal and informal methods for the identification of EWS. Formal methods, such as structured assessments and technical analysis, provide a systematic approach to identifying risks, while informal methods, often based on intuition and communication, can capture subtle signals that might be overlooked by formal assessments.

Through exploratory interviews with project managers, directors, and controllers at Sweco Netherlands, the research validates the practical relevance of the identified EWS. The interviews reveal that while project leaders are generally aware of the concept of EWS, there is a need for a more structured approach to their identification and management. The experts provided real-life examples of how EWS have been used in practice to mitigate schedule delays, further emphasizing their importance in project management.

One of the significant challenges identified in the research is the measurability of EWS. While some signals, such as delays in decision-making or cost overruns, are relatively straightforward to measure, others, like poor communication or lack of motivation among team members, are more subjective and harder to quantify. The thesis proposes various metrics and strategies for monitoring these signals, highlighting the need for a balanced approach that combines quantitative and qualitative data.

The research concludes by proposing a framework for the integration of EWS into project management practices. This framework includes the identification of key EWS, the development of monitoring tools, and the implementation of strategies to address identified risks proactively. The goal is to create a system where project managers can detect potential issues early, assess their impact on the project schedule, and take corrective actions before they escalate.

This thesis contributes to both the academic literature and the practical field of construction project management by providing a comprehensive analysis of Early Warning Signals. The research emphasizes the importance of a proactive approach to managing schedule risks during the design phase of infrastructure projects.

The study concludes with several recommendations for future research, including the need for further exploration of EWS in other phases of construction projects and the development of more refined tools for measuring and monitoring these signals. The findings of this research are particularly relevant for project managers, controllers, and other stakeholders involved in the planning and execution of infrastructure projects, providing them with valuable insights and tools to enhance project outcomes.

Contents

1. Introduction

1.1. Background

In recent years, the construction industry has witnessed impressive growth in projects that are getting bigger and more complicated. Poor performance outcomes, such as cost overruns and timetable delays, are often associated with large projects (Luo et al., 2017). Due to issues like design faults, inadequate planning, unanticipated site circumstances, increases in project scope, weather conditions, and so on, this is a recurring problem for the construction industry. As a result, it is critical to identify the elements that lead to cost and time overruns and offer strategies for systematically addressing the primary factors in order to avoid and mitigate problems (Borse & Khare, 2016).

The quality of the execution of the early project stages in the construction industry may significantly influence the project performance. Despite this, early project phases have received little attention in previous studies (Kolltveit & Grnhaug, 2004). Furthermore, according to the Chartered Institute of Building (CIOB) (2008), complex projects are failing more frequently due to the traditional project management technique's inability to handle their complexity. Therefore, it is crucial that those involved in the construction sector move past the conventional approaches to project management and adopt more contemporary and successful ones, like the Early Warning Signal (EWS) strategy, which takes a more proactive rather than reactive approach to resolving project failure (Adebisi et al., 2020). Consequently, early in a project's lifecycle, the EWS method to project management often reveals subtle behaviours, occurrences, traits, etc., that raise the possibility of a crisis later on. To ensure project success, however, it is essential that project parties are able to read these warning signs correctly and take prompt action (Kappelman, 2010).

According to Meng (2014), early warning signals are critical throughout the design phase of building projects, assisting in the identification of possible problems and the implementation of corrective measures before they worsen. Construction projects are anticipated to show warning signals before facing crises, much like a patient showing symptoms of an illness (Adebisi et al., 2020). This is the fundamental reason why early warning has acquired growing attention and appeal in recent years.

The majority of essential decisions are taken in the early stages of projects. This is owing to the high degree of ambiguity at this stage (both negative and positive uncertainty) as well as the significant possibility for corrective measures and mitigating the consequences of any negative impacts (Hajikazemi et al., 2013). This is further confirmed by Othman et al. (2018), who claim that the best time to identify early warnings is during the design phase.

1.2. What are Early Warning Signals?

The general concept of Early Warning is broad. It applies to nearly any activity, industry, or region where it is advantageous to acquire early signs of a future development, often of a negative kind. The word Early Warning is used in a variety of fields, including health, meteorology, natural catastrophes, military, and cost control (Haji-Kazemi, 2015).

Ansoff (1975) proposed the concept originally, arguing that even unanticipated discontinuities could be detected by certain warning indications. He claims that strategic surprises provide advance information about themselves; they do not arise out of nowhere; and their appearance may be predicted using clues known as weak signals. This information is first imprecise: the signals are hazy, fuzzy, and difficult to comprehend; but, they eventually grow more definite and less complicated to

understand (Nikander, 2002). The definition of weak signals, according to Ansoff and McDonnell (2019) is:

> *"…imprecise early indications about impending impactful events…all that is known is that some threats and opportunities will undoubtedly arise, but their shape, nature, and source are not yet known"*

However, not everyone agreed with the claims of Ansoff (1975). The hypothesis of weak signals has proven disputed. Critics include Webb (1987), who stated that such messages or knowledge about the future could not be gained and that Ansoff's study lacked a prior foundation to support its claims of such weak signals. Others, such as Makridakis and Hea´u (1987) and Åberg (1993) stated that the concept of weak signals has remained a largely academic theory, and they are frequently so ambiguous that they are easily ignored, making it impossible to believe in them (Haji-Kazemi, 2015).

Nevertheless, Ansoff's theory later found support. One of them was in the face of Nikander (2002), who wrote a dissertation on the topic of early warnings phenomena. He defined early warnings as:

> *'An early warning is an observation, a signal, a message or some other item that is or can be seen as an expression, an indication, a proof, or a sign of the existence of some future or incipient positive or negative issue. It is a signal, omen, or indication of future developments'.*

According to the definition, Early Warning indications are observations that can be understood as potential future difficulties. This implies that interpreting these indications in projects might provide insights into future developments (Wijtenburg, 2018). Nikander (2002) developed a model to illustrate the nature of EW observations. This is a time-bound current that is analysed by the observer or that "sends" a message to it. When these occurrences are seen, signals can be discovered and interpreted as early warning indicators. Figure 1 depicts the phenomenon's two-part structure as well as the elements that influence it. The phenomena may be split into two phases: communication and decision-making; nevertheless, it is difficult to fully distinguish them (Nikander, 2002).

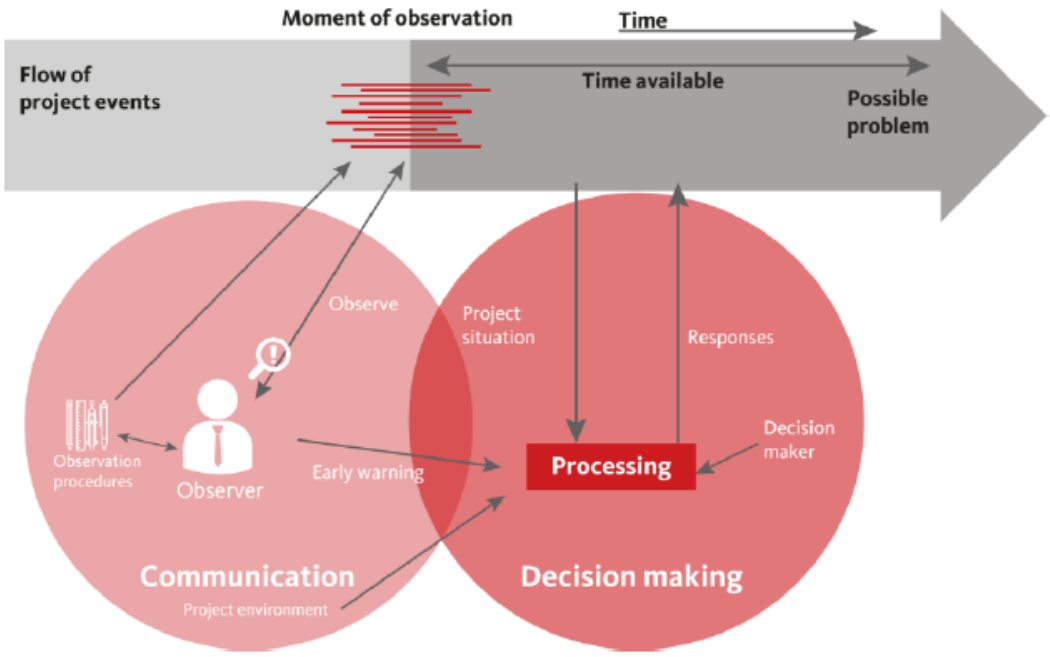

Figure 1. The character of Early Warning Signals (Nikander, 2002; Wijtenburg, 2018)

The communication phase include the detection, interpretation, and acceptance of Early Warning indications (Wijtenburg, 2018). The observer plays an important role in discovering early warnings, using the study's categorizations and typologies to identify patterns and symptoms of possible concerns. Then, knowing the relationships between early warnings, project difficulties, and their causes aids in determining the relevance of discovered warnings. Finally, after discovering and analysing the early warning, the observer must determine whether to accept its importance for the project (Nikander, 2002). This decision is impacted by a variety of elements, including the observer's communication procedures and the project setting. Once accepted, the observer proceeds to the decision-making step, taking into account the warning's impact. During the decision-making phase, the emphasis switches to understanding the relevance of the early warning for the project and developing appropriate responses (Nikander, 2002).

Another study done by Haji-Kazemi (2015) defined early warning signals as:

> *'…a specific element, happening or event which shows that the risk event will actually realize. The EW sign does not provide information on the exact time of the materialization of risk; neither does it reveal its expected magnitude. Rather it acts as an alarm which triggers action in order to either prevent the realization of the potential problem or possibly lessen the undesired consequences.'*

Overall, all of them emphasize on the existence of such early warning signs and the need to take them into account. A management team looking to prepare for strategic surprises has two alternatives. The first goal is to create a competence for successful crisis management—quick and efficient after-the-fact response to unexpected discontinuities. The second method is to address the issue before it arises, so reducing the likelihood of strategic surprises. Both techniques require managerial attention (Williams et al., 2012). These two approaches are also recognized as reactive and proactive approach.

Reactive management is all about dealing with problems as they emerge. Proactive management, on the other hand, involves anticipating issues and taking efforts to prevent them from occurring in the first place. Reactive management approaches may be effective, especially when there is little time to spend. If a firm is experiencing a crisis, a reactive manager may be the ideal candidate for the job. They will swiftly analyse the situation and take whatever steps are required to remedy the problem (Mäki-Marttunen et al., 2019).

In contrast, proactive management focuses on prevention. A proactive manager anticipates issues and takes actions to prevent them from occurring. This management style is frequently more effective in the long run since it allows you to avoid possible difficulties (Mäki-Marttunen et al., 2019). Early Warning Signals as such are considered as a more proactive rather than reactive approach to resolving project failure (Adebisi et al., 2020).

Another annotation of early warning signals that could be recognized in literature is "leading indicators". According to Zheng et al. (2019), leading indicators are essential project features and/or occurrences that reflect or anticipate project health; if detected in a timely manner, leading indicators enable for proactive management to impact project results. This explanation comes very close to the definition of early warning signals and they are considered to be the same. The terms will be used interchangeably.

1.3. Examples of Early Warning Signals

In order to better understand the definition of early warning signals and their application, a few examples will be included prior the start of the research. According to Adebisi et al. (2020), one

possible warning indicator in the construction industry is "*Lack of clear scope definition*". This would mean that the consultants are continuously attempting to reassess the project and change its scope. This would translate later into schedule delays, cost overruns, poor quality, etc.

Another example would be when people work too much or too little. This would mean that the organisation of man power is inadequate for the specific project. Either the project team is understaffed, which would translate into exhaustion, poor quality and schedule overrun, or there are too many people for too little work, which would reflect negatively on the budget (Williams et al., 2012). One suggestion for avoiding this problem would be to monitor on a regular basis the progress reports of the project and check the ratio between "work done" and "money spent". In this way, for 10% complete work there must be 10% money spent. If this ratio is not matching, then an issue with the project could be expected.

One more example given by Abotaleb et al. (2019) is the delay in procurement of special equipment. In this way, specific construction works cannot be executed, which would naturally lead to schedule delays of following up phases. Such delays might occur when there is poor planning and there are no set deadlines for the procurement of special construction equipment. However, if this problem is identified on time in the early stages of the project, the problem would be mitigated as much as possible and no serious delays would be expected.

1.4. Research Gap and Objectives

As previously stated, building projects are getting increasingly complicated and difficult to complete on time. Construction sector is responsible for a wide range of incredible accomplishments, including gorgeous cityscapes and vast infrastructure, as well as persistent innovation. However, in recent decades, it has also suffered from poor performance. The construction sector's poor performance is a direct outcome of the underlying norms and features of the construction market, as well as the industry dynamics that emerge in reaction to them. Traditional project management strategies are unable to keep up with the changing environment, which includes new technologies, greater regulations, digitalization, new materials, and so on (Ribeirinho et al., 2020). Therefore, it is critical that individuals working in the construction business move beyond the traditional techniques to project management and embrace more proactive ones, such as early warning systems, in order to minimize future interruptions (Adebisi et al., 2020).

However, in project management literature, the idea of early warning is often underrepresented (Haji-Kazemi et al., 2015). According to Williams et al. (2012), 'we are not very good at picking early warning signs.' In many circumstances, project managers fail to respond appropriately.

The literature review reveals a research gap in the identification and measurability of early warning signs, specifically in the construction industry during the design phase and their effectiveness. As mentioned previously, in the construction sector, the quality of early-stage project execution can have a substantial impact on project performance especially in term of delay. Despite this, past research has given little emphasis to the early stages of a project (Kolltveit & Grnhaug, 2004). It is unknown how to identify the early warning indicators and what is the impact/effect of EWS over minimization of schedule delay. What is more important, it is unknown how the theory of EWS translates into practice.

The majority of studies conducted on the subject of early warning in projects concentrate on projects in general rather than construction project management in particular (Othman et al., 2018). Other research on Early Warning relies heavily on data from project management methods across different fields, such as IT, oil and gas, and shipbuilding. Research in the field of construction from the

standpoint of a consultancy firm can bring new perspectives. The reason for this is the key position of the consultancy company between the client and the contractor.

As a result, the goal of this study is to have a deeper knowledge of the EW phenomena and how it might be applied practically. Investigate the effectiveness of early warning signals (EWS) in identifying and mitigating schedule delays during the design phase of infrastructure projects. By examining the influence/impact of EWS on schedule performance, identifying effective implementation strategies, and evaluating different detection methods, this research intends to contribute to improved project management practices and enhanced project outcomes in terms of schedule adherence. As an overview, this research aims at offering approaches for identification and monitoring of EWS, analysing the impact of EWS over time delays and proposing a framework for the successful application of EWS in following up projects.

1.5. Research Questions

Following the identified problems and research objectives the main research question is identified:

> *How are Early Warning Signals (EWS) related to the control and reduction of schedule delays in the delivery of the design phase of Dutch Infrastructural projects?*

This question aims to give an answer on how to use EWS in the design phase of a infrastructural project and provide with information in order to limit schedule delays during this front-end project phase. In order to answer this question, the following sub-questions are given:

> *SQ1: What Early Warning Signals are identified in the literature, what are the identification approaches, and what are the limitations associated with them?*
>
> *SQ2: What Early Warning Signals are identified in practice by the managers of Dutch Infrastructure Projects, and how do they act upon them?*
>
> *SQ3: Which of the Early Warning Signals have the highest influence on schedule delay from an expert's point of view?*
>
> *SQ4: How can the Early Warning Signals be measured?*
>
> *SQ5: How should the prioritised Early Warning Signals be handled by the management?*

1.6. Thesis Structure

The thesis starts with Chapter 1, giving an introduction to the topic and the current problems. Chapter 2 presents the research methodology which is applied. Then, Chapter 3 presents the results from the literature review. Chapter 4 focuses on exploratory interviews with company experts, which aim to get practical information relevant to the study. Chapter 5 discusses the measurability of the proposed Early Warning Signals and proposes strategies for acting upon them. Chapter 6 carries the evaluation of the previously proposed strategies. Chapter 7 provides a discussion of the limitations of the research, and finally, Chapter 8 contains conclusions and recommendations for future research.

2. Methodology

In this chapter, each of the previously identified research questions will be linked to one specific method in order to be answered. First, the scope of the research will be identified, then different methodological approaches are discussed and in the end a figure is presented showing the relation between each question and method.

2.1. Scope of the Research

The thesis is focused on investigating Early Warning Signals during the design phase of Infrastructure projects (roads, tunnels and bridges) carried out by consultancy company Sweco located in the Netherlands. Furthermore, the provided projects are mid-large to large in scale to depict the complex system in which Early Warning Signals are usually difficult to detect. The design phase includes multiple steps on different levels, therefore, this research will be focused on investigating the involvement of EWS more specifically during the Conceptual Design and the Detailed Design. It is very important to note that the research is focused specifically on Schedule Delays during the Design Phase.

Conceptual Design generally takes place after the feasibility studies. The design team will develop the outline specifications, planning strategy and schedules, cost plan, procurement options, phasing strategy, etc. After that, the Detailed Design follows. As the name suggests, this phase of the design goes into more detail and makes final adjustments. Here the boundaries need to be clearly defined, road and landscape layouts, detailed cost plan and schedule, risk assessment, specific materials to be used and potential suppliers, safety strategy, access for maintenance etc. The information provided by the detailed design should be sufficient for getting the required permits based on the requirements for example, from the building regulations in that area. The overall defined scope characteristics are visualised in Figure 2.

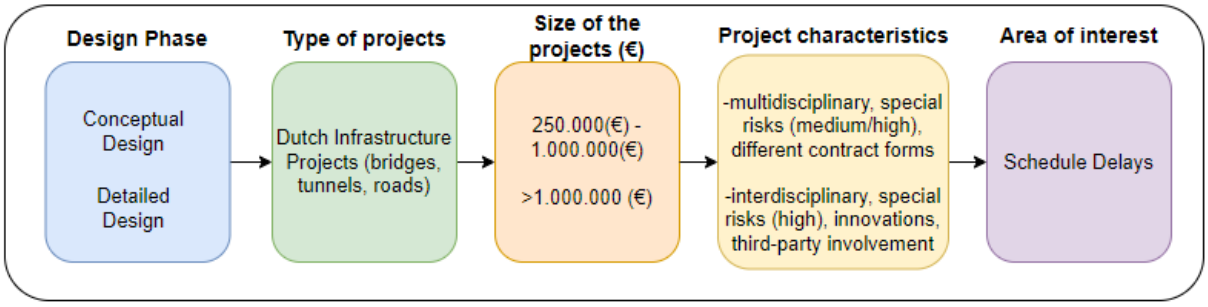

Figure 2. Scope of the research topic

2.2. Research Methodology

This research would be using both inductive and deductive approaches. Based on Mauldin (2020), inductive approach means moving from specific to the more broad. It is also known as theory-building research, which collects data and helps develop new theories. Deductive is the opposite, from broad to more specific. Based on hypothesis, different observations are made to check it. For example, the literature review about the Early Warning Signals is used as fundamentals for the following up questions and can be classified as deductive approach. On the other hand, the exploratory interviews with experts from the company can be associated with an inductive research approach. Conducting interviews with experts helps gather firsthand insights and observations about EWS, which can lead to the identification of new information that might not be covered in the existing literature.

The study primarily relies on exploratory interviews with experts from Sweco, which are classified as qualitative data gathering and analysis. Additionally, the research incorporates surveys wherein the interview participants provide scores to specific statements, allowing for quantitative analysis to draw conclusions.

This approach combines qualitative and quantitative methods, leveraging the strengths of both to provide a comprehensive understanding of the research topic. The qualitative interviews offer in-depth insights, while the quantitative surveys enable the measurement and comparison of responses. In order to answer each of the sub-questions, different methods will be used. The research approach is visually presented in Figure 3.

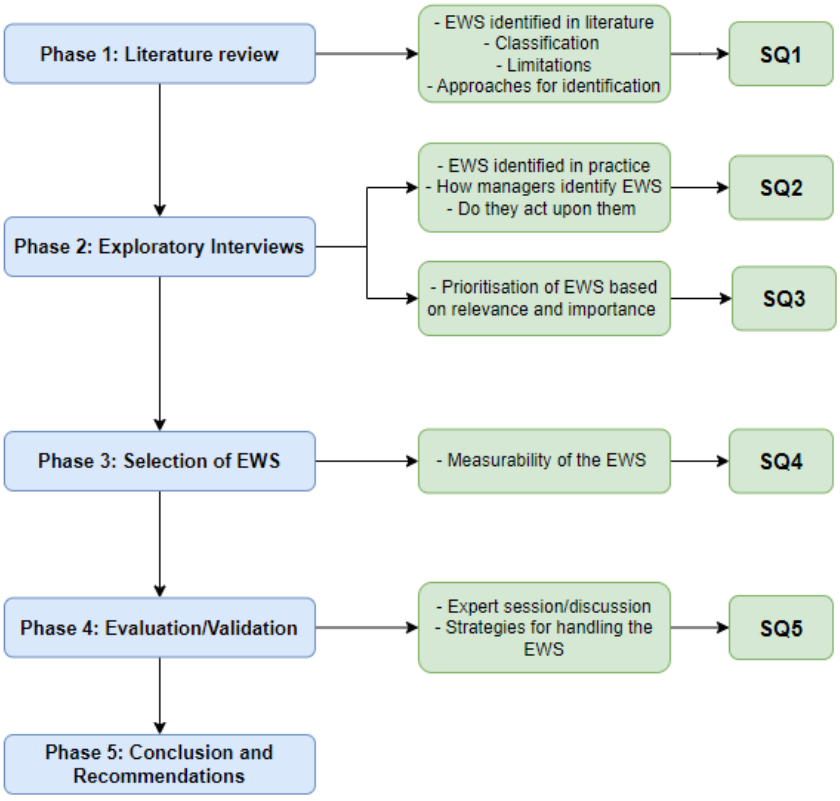

Figure 3. Research Approach

2.2.1 Phase 1: Literature Study

For the first question a literature study was made. It was used to give an overview of EWS, how to identify them, what are the limitations and applications, and provide with better understanding of the whole subject. The gathered information serve as foundation for the following up questions. In order to find reliable information, articles were retrieved via Google Scholar, Scopus, Elicit, Research Gate, Science Direct, TU Delft library and similar thesis from TU Delft repository. The key words that were used to find relevant articles were: ‘Early warning’, ‘early warning signs', 'warning indicators’, ‘early warning systems’, ‘response’, ‘barriers’, ‘limitations’, ‘early warning identification’, ‘design phase’, ‘signs of project failure’, etc. The articles need to be relevant for the construction industry, in particular infrastructure projects. This was assessed based on the title, abstract and context of the source and used only if there was further relevant information to the topic.

2.2.2 Phase 2: Exploratory Interviews

After the literature study, exploratory structured interviews and semi-structured interviews were made which gave valuable input data for the research (Bhat, 2023). Questions regarding the identification, monitoring and use of EWS during the design phase were asked to experienced project managers and controllers from the company. The full list of questions can be seen in Appendix B. With their help, the limitations were identified, the future usage opportunities, what could be improved based on their experience with EWS in construction projects and why in the first place problems occur. It is important to understand whether the employees want to use such warning systems and what is their perception about them.

The initial list was then refined by asking the experts who will take part in the interviews to evaluate the already identified EWS from the literature review. If the indicators on the list were important to infrastructure projects, the interviewers would be questioned about it. They had the option to respond to each indication with a "No," "Maybe," or "Yes."

A participant who answers "No" with 0 points has expressed a definite and unambiguous dislike. The signal has no bearing since it is irrelevant or the expert has not used it. The rating of zero points denotes this lack of importance or occurrence.

The one-point response "Maybe" implies uncertainty or perhaps a hint of importance. The signal is not conclusive, although it may be useful or experienced in specific circumstances. A score of one point indicates some potential, but it also indicates lack of confidence or lesser influence than a certain "Yes." By giving "Maybe" one point, it avoids completely discounting signals that could be meaningful.

A strong, certain confirmation that the signal is meaningful or has been experienced is indicated by assigning three points to the "Yes" response. Three points are awarded for the signal's strong relevance and application, which emphasizes the importance of unambiguously affirmative reactions.

With this system, the score for each indicator was calculated and the list was reduced based on predefined criteria. The most common threshold value to define consensus is 75-80% agreement between the experts (Barrios et al., 2021; Diamond et al., 2014).

After that, the list of Early Warning Signals was prioritized based on their importance for projects. To do so, similar method to the risk assessment was employed. The participants of the exploratory interviews were asked to assign a value between one and six for the impact and probability of each warning signal. Further explanation of the approach is given in Chapter 4.3.4.

2.2.3 Phase 3: Selection of the Early Warning Signals for further analysis

In this stage, six warning signals were selected. Three of them were the ones that scored the highest from the previously identified prioritised list. It is logical to assume that the participants from the interviews would score higher on indicators that are already known to them. This, however, might exclude highly important signals, but they were identified only in the literature, and the experts are not familiar with their application. For this reason, the three highest-scoring indicators identified only in the literature were also selected be examined further. In summary, the indicators that were selected are those most relevant from practice plus those most relevant from theory, if not overlapping. The analysis consists of a discussion about the measurability of those indicators. More precisely, to what extent can they be measured, are they being measured by the company, and how can they improve on that? Finally, recommendations are given on how to handle the indicators better.

2.2.4 Phase 4: Evaluation of the results

In this phase, the results of the study need to be evaluated. In particular, the proposed strategies for acting upon the Early Warning Indicators are discussed with two company experts who are external to the study. This was done in 1-hour session with both of them together. They had to give their opinion on the feasibility of the proposed recommendations and whether they think the suggestions are relevant to the presented problem.

2.2.5 Final Phase: Conclusion and Recommendations

Finally, recommendations were given on how to employ Early Warning Systems in a way that informs the project managers on time about potential progress issues and reduces schedule delays in the delivery of projects during the design phase. A theoretical framework would be served which indicates the most important warning signals that need to be monitored and their impact on the schedule delays. An overview of the research questions and the methods attached to them is given in Figure 4.

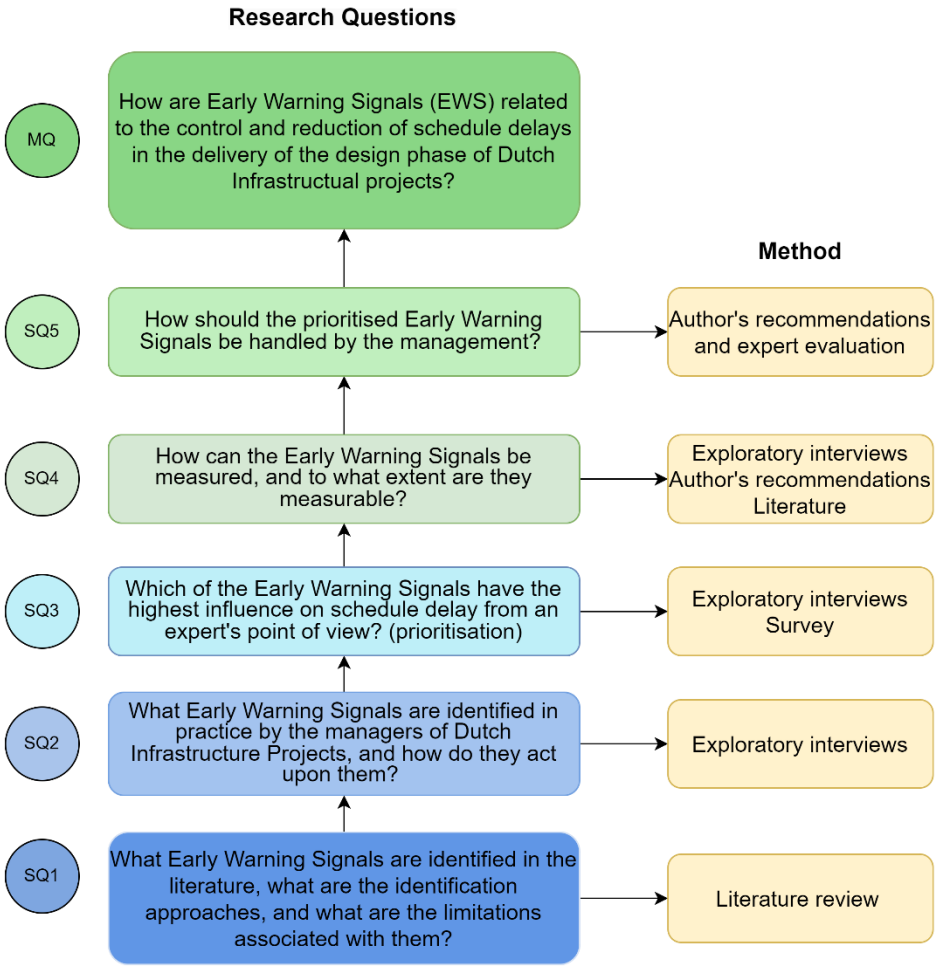

Figure 4. Overview of the Research Questions and the Methods related to them

3. Literature Review

In this chapter, the Early Warning phenomenon will be explained further. The aim is to make a review of the current indicators identified in literature and previous studies. In this way, an answer to the first sub-question will be given:

> *SQ1: What Early Warning Signals are identified in the literature, what are the identification approaches, and what are the limitations associated with them?*

More information will also be provided related to different methods for the identification of early warning indicators and limitations related to Early Warning Signals in order to prevent from occurring problems in the future. With the help of previous master student research done by (Wijtenburg, 2018) and (Stolk, 2022), as much as possible, relevant information will be gathered and presented.

In Chapter 1, Section 1.2, early warning signs were explained. As an overview of the findings until now, it can be said that early warning signs are indications of future positive or negative issues that trigger action (Nikander, 2002; Haji-Kazemi, 2015). Since the goal of the research is to reduce schedule delays brought on by unforeseen events, the focus of this study is on identifying unfavourable concerns.

Management teams can adopt reactive or proactive approaches to deal with strategic surprises. Reactive management focuses on dealing with problems as they arise, while proactive management anticipates and prevents issues. Early Warning Signals are considered a proactive approach for preventing project failure (Mäki-Marttunen et al., 2019; Adebisi et al., 2020).

Leading indicators, as described by Zheng et al. (2019), are closely related to early warning signals, reflecting or anticipating project health for proactive management. Even though the definitions of leading indicators and early warning signals are slightly different, in their essence, they have similar functions in project management practices. Therefore, the terms can be used interchangeably.

3.1. Early Warning Signals Identified in Literature

After the introduction of “weak” signals by Ansoff (1975), this wide topic was examined further and elaborated on by Nikander (2002). He named his PhD dissertation “Early Warnings; A phenomenon in Project Management” and dived deeply into the topic. For that reason, this literature review will start by examining the findings of Nikander (2002) and Nikander & Eloranta (2001) and use them as a reference point.

Nikander & Eloranta (2001) conducted research at the Helsinki University of Technology. The field of examination was the industrial construction projects, which might be relevant to the Dutch infrastructure projects, and therefore, their results are considered. Their research involved 17 professionals who were interviewed and four case studies. As a result, 68 warning indicators were identified, which were distributed in 11 different group types. Stolk (2022), with the help of the research done by Nikander & Eloranta (2001), identified the most common Early Warnings encountered in industrial construction projects. The list is presented in Figure 5. However, the list includes signals which are encountered not only during the design phase, which is the objective of this master thesis, but also includes early indicators in the construction and delivery phase. For this reason, the EWs will be sorted further in a later stage of the research.

Early Warning signs
Inconsistent behaviour of the contractor/supplier
A mood of non-satisfaction among personnel
Weak commitment to the project expressing itself
Bad quality of preliminary plans
A contract consciously drawn up to have little room for changes
Lack of speed and quality of work at the site
Being late is typical in the project
Same things come up again and again in meetings
Messages get lost along the way
Decisions are delayed
Quality of the reports is unsatisfactory
Old drawings are used at the construction site

Figure 5. Early Warnings encountered in industrial construction projects by Nikander & Eloranta (2001)

The study of Nikander & Eloranta (2001) also emphasizes on the importance of linking the early warning phenomenon with the appropriate project problems and their causes. In this way, a bigger number of early warnings can be identified and used effectively. In Figure 6, the hypothetical dependencies between early warning indicators, project problems, causes and responses are shown (Nikander & Eloranta, 2001).

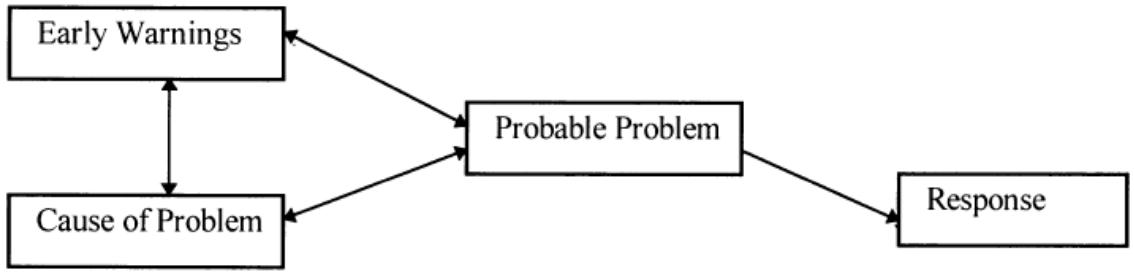

Figure 6. Hypothetical dependencies between early warning indicators, project problems, causes and responses

Nikander (2002), in his detailed research, examined more than 90 different documents, and with their help, he managed to classify the early warning signals in different groups. As a result, he came up with a table consisting of eight main categories with 21 different sub-categories. From there, the greatest number of examples, almost 41%, are referred to early warnings expressed by the personnel. Then it is followed by warnings related to project control and reporting with 19%. The overall result is shown in Table 1. Taking into account these categories and the importance of each one would be helpful for the author of this thesis to identify early warning signs of his own at later stages.

Table 1. Main Group Types of Early Warnings (Nikander, 2002)

	Literature references
Warnings expressed by personnel, project group	**40.6 %**
Interpersonal behavior	
Non-verbal information	
Concealing difficulties	
Attitudes and commitment to the project	
Turnover rate of personnel	
Professional competence of personnel	
Personnel resources	
Project manager, management	10.9 %
Project manager as a person	
Management	
Insufficient management resources	
Project planning and objectives	8.8 %
Preliminary planning, errors made during the brainstorming phase	
Ambiguous objectives	
Project planning	
Observations in the bidding phase	
Project control, reporting	**18.7%**
Progress of the project, quality level	
Labour effectiveness	
Delay monitoring systems	
Changes in the cost estimate	
Working on the project	5.5 %
The character of the work initiation	
Changes and disturbances in workflow	
Repetition of the same work	
Organization	
Communication	4.4 %
Expressed by the project parties	6.6 %
Participation of the client	
Support of the upper management, CEO	
Contractor's problems in devising a schedule	
Documents, reporting	4.4 %
Quality of the reports	
Delay of the project	
Total quotes	91 + (Honko)

Another study conducted by Williams et al. (2012) examined 8 projects with high complexity, both in the public and private sectors. Most of them were related to the construction industry. As a result, he identified 56 warning signals. He noted that it is important to look specifically at signals based on "gut feeling", because it is unlikely to be detected unless *'very much aware of their potential as early warning signs'.* In the end, he presented a table, which classifies the indicators according to the stages of the project and the way they could be identified. In this case, either through "assessments" or "gut feelings" (Williams et al., 2012).

As this thesis is mostly interested in the front-end stage of a project, the indicators falling in this criteria are marked in green and the rest – in red. The results are derived from the empirical studies of the 8 projects and are shown in the table below. As a result, a list of 36 indicators is left, which will be reduced further into the research because indicators such as "the need for development of new technology" are not related to schedule delays in the design phase; therefore, it will not be taken into consideration further in the analysis.

Table 2. Early warning signals extracted from the empirical studies conducted by Williams et al. (2012)

	Project setup	In front-end stage	Project execution
Assessments	• Sponsor(s) with unclear role • Lack of an implemented governance framework • Poor project definition • Lack of clarity in rationale, goals, and benefits • Poorly developed business plan • Poor definition of scale and what resources are needed • Unclear what assumptions are valid about the project • Lack of relevance of the proposed solution compared with the needs • The need for development of new technology • Main risks not identified	• Lack of a good business case • Deterioration of relations between the participants • Lack of a common definition of roles and responsibility • The project team over relying on the consultant/ contractor's people to "fix it" • Numbers/information missing in documents • Assessments not performed • Documentation not completed • Inappropriate quality of information and documentation produced • Missing competence in the project team • Guidelines for early phase assessments and "behaviour" not followed • Disputed major decisions and complications arising from these • Main risks not identified	• People in "acting positions" with no authority to recommend action • Lack of documentation • An excess of "no cost/no time" effects leading to optimism bias • Contractor unfamiliar with domain responsibility • High level of subcontractors' claims and extension of time claims • Plans and reports too late and/or not clear • Contract obligations not fulfilled • Milestones/activity definitions unclear or missing • Missing competence in the project team • Remaining risks not identified
Gut feeling	• Sponsor(s) having unclear expectations • Vague or unclear reasons for undertaking the project (unclear thinking) • Needs considered not real • Inconsistent arguments about agendas • Uneasy comments and body language • The way questions are asked and how answers are given • Specific conditions exist that will make cultural aspects important	• Leadership issues • The way answers are given to critical questions, when the answers are vague • Strained atmosphere • Lack of a culture of openness and good communication between the actors • Confusing or wavering changes in position over time • Uneasy comments and body language • Stating uncertainty, unwillingness to conclude • Parties unwilling to share relevant information • Parties voicing reservations and politically hedging their positions	• Leadership issues • Lack of commitment to make decisions • Frequently changing decisions • Continually unfulfilled promises • Vague answers to critical questions • When people work too much or too little • Uneasy comments and body language • Not showing trust in the project organization

Next in the literature list is Habibi et al. (2018), who discusses the construction process in three main phases: Engineering, Procurement, and Construction (EPC). It highlights the importance of performance indicators in determining the success of building projects, with an emphasis on time and cost challenges. The goal of their research is to conduct a thorough review of related performance papers in order to address the inconsistent issue of time/cost overrun signs in construction projects, as well as to provide a comprehensive list of Leading Performance Indicators or in other words Early Warning Signals, based on related EPC phases (Habibi et al., 2018).

To do this, Habibi et al. (2018) found and compiled over 200 peer-reviewed journal publications, conference papers, dissertations, and research reports on cost overrun and delay. The detected scholarly sources were published during a 46-year span, from 1971 to 2017. As a consequence of this investigation, 115 journal publications have been discovered that examine LPIs in the construction business.

They then selected leading schedule and cost performance indicators by assessing them in accordance with their frequency of appearance in the publications. It is important to note that, as this master thesis is mainly focused on the design phase and schedule overruns, only the results related to that will be taken into consideration. Nevertheless, for comparison, the whole list will be given, and the appropriate indicators will be coloured in green, where the rest will be coloured in red. The list with the results found by Habibi et al. (2018) is shown in Table 3.

Table 3. Leading Indicators (Early Warning) identified by Habibi et al. (2018)

Category	Indicators	Frequency	Ranking
Indicators in Engineering Phase			
Schedule performance indicators			
Change	Design change	13	1
Client-related	Slowness in making decisions by owner	8	2
Client-related	Delay in approval stage	8	2
Management	Poor communication between stakeholders	5	3
Cost performance indicators			
Change	Design change	7	1
Project-characteristics	Project size	4	2
Management	Poor communication between stakeholders	4	2
Indicators in Procurement Phase			
Schedule performance indicators			
Material	Shortage of Material	16	1
Equipment	Equipment Shortage (Machinery and its parts)	14	2
Labour	Shortage of labour	13	3
Cost performance indicators			
External	Price fluctuations	14	1
External	Poor economic conditions (exchange rate, inflation rate, interest rate, etc.)	9	2
Material	Shortage of Material	9	2
Labour	Shortage of labour	8	3
Indicators in Construction Phase			
Schedule performance indicators			
Change	Design change	28	1
Management	Poor site management and supervision	18	2
External	Severe weather condition	17	3
Client-related	Financial issues by client	17	3
Cost performance indicators			
Change	Design change	14	1
External	Severe weather Condition	11	2
External	Laws and regulations	10	3
Consultant-related	Inaccuracy and deficiencies in cost estimates	10	3

Engineering is the process of identifying and designing the owner's requirements, including preferences, desires, and needs, before submitting them to contractors. During the pre-project planning and engineering phase, several significant decisions are taken to properly allocate huge amounts of money and other resources to the project. Although many academics have focused their efforts on identifying performance indicators in the building phase, the engineering phase has received the least amount of study (Yang and Wei, 2010).

As a result, the engineering phase has a substantially lower frequency of signs than the other stages, and this is due to the above-mentioned lack of consideration for this critical stage of the construction process (Habibi et al., 2018). The procurement phase is also considered in the information review, as it can be integral to the overall design phase examined in this study.

For instance, the issue of labour shortages is highlighted in green to denote its potential impact on the entire design phase. The absence of specific skilled labour required during the design phase can lead to substantial project challenges.

According to Safapour et al. (2019), rework orders are frequently issued throughout the design and construction phases of large-scale construction projects, which can result in significant cost overruns and significant schedule delays. It is estimated that major rework results in cost overruns and schedule delays on more than half of construction sector projects. The impact of this rework and the essential causes behind it are being evaluated by academics and practitioners throughout the globe. They are mainly concentrating on defining the entity-based rework indicators since it is critical to determine the essential project, human, and organizational elements that contribute to the rework (Safapour et al., 2019).

For this reason, the goal of the study is to present a list of indicators of human, project, and organizational rework and thoroughly evaluate relevant articles on the subject. For project managers and industry practitioners, anticipating possible reasons for rework early in the design and construction stages is quite beneficial (Safapour et al., 2019).

In order to accomplish their aim, Safapour et al. (2019) examined over 100 peer-reviewed research reports, dissertations, journal articles, etc., that concentrated on rework factors that belonged to the project, organization, and human categories. Of these, 57 journal papers published after the 2000s were considered the most relevant, and they underwent a thorough review process to get the necessary information.

As a result of their study, a list of indicators is presented and sorted into three different categories – project-based indicators, organisation-based indicators, and human-based indicators. The final selection can be seen in Table 4, where the frequency of mentioning the specific indicator in the literature review and their overall ranking is shown (Safapour et al., 2019).

Due to the nature of the author’s research, these rework indicators can be considered as early warning signals for schedule delay in the design phase of an infrastructure project. The green-coloured indicators could be applicable and relevant to the front-end stage of a project, whereas the red ones are more likely to occur during the construction phase, which is not the subject of this study.

From the table, it can be seen that the most frequently recognised indicators are inappropriate/poor design, unclear scope definition, ineffective coordination, lack of resource management, ineffective communication, lack of training and control, lack of experience and lack of skill whereas the least common are lack of motivation, quality issues and unclear task specification.

Table 4. Rework Indicators identified by Safapour et al. (2019)

Indicator	Frequency	Ranking
Project-based rework indicators		
Inappropriate/Poor design	38	1
Unclear scope definition	28	2
Site location issues	19	3
Material issues	14	4
Supervision related issues	12	5
Financial issues	11	6
Unclear task specification	7	7
Quality issues	7	7
Organization-Based Rework Indicators		
Ineffective coordination	37	1
Lack of resource management	20	2
Ineffective communication	18	3
Lack of training	18	3
Lack of design control and audit	16	4
Lack of documentation control	14	5
Poor management	12	6
Human-Based Rework Indicators		
Lack of experience	16	1
Lack of skill	15	2
Lack of knowledge	11	3
Lack of safety commitment	4	4
Lack of motivation	3	5

Choi (2007) conducted an extensive investigation on the issue of early warning signals. He sought civil engineering specialists from over 90 organizations and government agencies in the United States to identify potential leading signs based on their experience. At the beginning of the process, 181 indicators were identified. However, three surveys were carried out in order to narrow down the list and take only the most important of them. The participants in the surveys were asked to evaluate the negative impact of leading indicators on various project outcomes. For project outcomes, Choi (2007) considered cost, schedule, quality, safety and stakeholder satisfaction.

After completing all three surveys and reassessing the indicators, Choi (2007) compiled a final list of 43 leading indicators, categorized into eight groups: alignment, change management, constructability, contracting, quality management, safety practices, project control, and team building. The list with the final results is shown in Table 5. Additionally, Choi (2007) asked 84 experts to assign weights to each indicator based on its impact on the various project outcomes. For the purposes of this research, only indicators with a moderate to high impact on the project schedule are considered. Furthermore, due to the focus of this study, only indicators fitting into the design phase are deemed relevant.

One limitation of Choi's (2007) study is the lack of differentiation among the types of experts surveyed, such as contractors, consultants, and owners; all participants were considered as a single group. Therefore, the author of this study will make the selection based on reasoning. The indicators that meet the requirements and can be part of the design stage are coloured in green, and the rest of the list is in red colour. In this way, visual comparison could be made between the different stages, groups or indicators.

Table 5. Full list of 43 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.
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 Practice	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.
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 unfavourable.

The last study to be analysed, as part of this literature review, was done by Adebisi et al. (2020). It involved 134 participants, both consultants and contractors. A structured questionnaire had been used for data collection. The respondents were asked questions regarding different types of Early Warning Signals and how they make use of them. As a result, 30 EWS were identified, which were categorised into 6 different groups. The full list is shown in Table 6.

As was done in the previous analysis, the indicators relating to the design stage of a construction project are marked in green and the others in red. Some of the identified early warning signals represent the same problems, and for that reason, the lists will be made more concise and understandable. For example, in Table 6, client-related symptoms, the given list of indicators can be summarised as “poor scope definition, organisation and communication, and unclear goals”.

This refinement process will be further discussed in the subsequent sub-chapter, where an analysis of all presented tables will be conducted. As a result, the overlapping indicators will be combined and a comprehensive list of various warning signals will be given.

Table 6. List of EWS identified by Adebisi et al. (2020).

Category	Early Warning Indicator
Project/construction management-related symptoms	Management inability and incompetence to proactively detect and manage problems at early project stages.
	Difficulty in estimating project resources with practical foresight at the construction phase.
	Contractor's progress is greatly retarded by every little alteration in design or programme schedule.
	There are constant schedule slippages (along critical path) right from early project stages.
Project and construction work or task-related symptoms	Actual expenditure is constantly shooting beyond cost estimates at various project stages.
	Incurred costs on the project are already getting higher than the anticipated benefits from the project.
	Design problems often encountered at early period in the construction stage.
	High amount of rework being carried out on site.
	Project execution is constantly behind schedule.
	Major defects are identified during site inspection exercises at the early construction phase.
	Construction workers are indiscriminately paid for work not done or wrongly done/increasing levels of overtime.
	Too much work is being allocated to a worker (than he can reasonably perform).
	Site supervisors and construction workers are asking too many questions on new methodology introduced to project execution.
Client-related symptoms	Client's unresponsiveness, lack of seriousness and want of dedication to ensuring timely completion of projects.
	Lack of understanding between client and other project stakeholders at early project phases.
	Sponsor of project is anxiously demanding for project finishing time before scope and schedule are set (because of finance uncertainty).
	Client is making continuous efforts to redefine project after specifications are already set.
	Client does not want to meet with the construction team members.
Project stakeholders/ construction workers-	Fighting/quarrelling/conflict among stakeholders during project planning phase.
	Evident drop in morale of construction workers or site supervisors.
	Construction workers/site supervisors dragging their feet on tasks, hoping tasks will go away from them.
	Observation of constant stress in construction workers and site supervisors during operations.
Project goal-definition related	There is a large number of change requests or requirements fluctuations within the project right from early project stages.
	Consultants are making continuous attempts to redesign project and alter its scope.
	People are asking questions incessantly about the value of the project.
Project/site meeting related symptoms	Senior management of contractor's or client's organisation unusually begins to get involved in project and site meetings.
	Higher frequency of meeting with client to clarify problems.
	Tension increases in the atmosphere of project/site meeting.
	Some project stakeholders refuse to participate in important meetings.
	Notice of sudden or gradual reduction in attendance at project or site meetings.

3.2. Analysis of the Identified Early Warning Signals and Final List

Several authors have identified similar or identical early warning indicators in their studies; therefore, these will be merged to avoid repetition and ensure clarity. This process is inspired by the methodology employed by Singh (2023).

A vision board was created to organise and group together all identified warning signals systematically. This vision board helped the brainstorming and categorization process, resulting in the definition of nine distinct categories where early warning signals can be identified and effectively utilized. These categories were borrowed from the study done by Choi (2007) and are: Project Organization, Project Management and Control, Quality Management, Client/Stakeholder Related Symptoms, Project Changes, Professional based problems, Team Building, Documentation, and External Factors.

Each category covers a unique area of project management and control, resulting in a comprehensive framework for understanding and monitoring early warning signals. For example, the Project Organization category covers indications for the project team's structure and efficiency, whereas the Quality Management category concentrates on signals for project delivery standards and outcomes.

The Client/Stakeholder relating Symptoms category includes warning signs relating to communication and interaction with clients and stakeholders, while the Project Changes category collects symptoms of changes in project scope, timeline, or requirements. Professional concerns emphasize issues with the project team's abilities and competences, whereas Team Building focuses on the project team's environment, structure and cooperation.

Documentation includes warning signals linked to project record management and maintenance, whereas External Factors comprise signs that occur outside of the project context, such as legislative changes or market circumstances. In Appendix A the vision board and the brainstorming activities are shown.

The initial number of early warning signals (EWS) detected was 87. After sorting and combining overlapping indications, the total was decreased to 51. Although several indicators were not written exactly the same, they communicated very similar concepts and were thus merged. For example, phrases like "lack of skills," "lack of experience," "lack of knowledge," and "lack of expertise and competence" were combined into a single early warning signal.

One specific indicator needs further clarification. In the Project Management and Control category, the indicator “Incurred costs on the project are already getting higher than the anticipated benefits from the project” (Earned Value Management) is taken into consideration, even though initially it is connected to cost performance, which is not an objective of this research. However, by using Earned Value and comparing the money spent to the executed work, it is possible to identify schedule-related problems as well. The final table, which contains the whole list of 51 EWS, is shown in Table 7.

Table 7. Relevant Early Warning Signals identified from the literature

Category	№	Early Warning Signal	References
Project Management and Control	1	Supervision related issues	Safapour et al. (2019)
	2	Lack of resource management	Safapour et al. (2019)
	3	Leadership issues	Williams et al. (2012)
	4	Inconsistent arguments about agendas	Williams et al. (2012)
	5	Too much work is being allocated to a worker	Adebisi et al. (2020)
	6	Lack of design control and audit	Safapour et al. (2019)
	7	Poor management, inability to proactively detect problems at early stages, management is lacking required level of experience and skills	Safapour et al. (2019); Adebisi et al. (2020); Choi (2007)
	8	Incurred costs on the project are already getting higher than the anticipated benefits from the project	Adebisi et al. (2020)
	9	There are constant schedule slippages (along critical path) right from early project stages and milestones are not being met	Adebisi et al. (2020); Choi (2007)
	10	Consultants are making continuous attempts to redesign project and alter its scope.	Adebisi et al. (2020)
	11	The project is experiencing a high level of engineering / design / specification errors and scope changes.	Choi (2007)
	12	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.	Choi (2007)
	13	Float for project activities is being used up at an increasingly high rate.	Choi (2007)
	14	Poor communication and coordination	Safapour et al. (2019); Habibi et al. (2018)
	15	Main risks are not identified	Williams at al. (2012)
	16	Guidelines for early phase assessments and "behaviour" not followed	Williams at al. (2012)
	17	Lack of an implemented governance framework	Williams at al. (2012)
Project Organisation	18	Unclear scope definition including poor definition of scale, required resources, goals, tasks, assumptions, etc.	Williams at al. (2012); Safapour et al. (2019); Choi (2007)
	19	Lack of a common definition of roles and responsibility	Williams at al. (2012)
	20	Same things come up again and again in meetings	Nikander & Eloranta (2001)
	21	The project is experiencing difficulties in integrating schedules between project participants.	Choi (2007)
	22	Higher frequency of meetings with client to clarify problems.	Adebisi et al. (2020)
	23	The project team is experiencing a high turnover rate and instability in team membership	Choi (2007)
	24	Shortage of labour (skilled)	Habibi et al. (2018)
	25	Discussions are delayed/postponed	Nikander & Eloranta (2001)

Client/Stakeholder related symptoms	26	Client's and stakeholders'' unresponsiveness, lack of seriousness and dedication to ensuring timely completion of projects.	Adebisi et al. (2020); Choi (2007)
	27	Slowness in making decisions by owner	Habibi et al. (2018)
	28	Fighting/quarrelling/conflict among stakeholders and participants during project planning phase.	Williams at al. (2012); Adebisi et al. (2020)
	29	Poorly developed business plan	Williams at al. (2012)
	30	Some project stakeholders refuse to participate in important meetings.	Adebisi et al. (2020)
Project Changes	31	There is a large number of change requests or requirements fluctuations within the project.	Adebisi et al. (2020); Choi (2007); Habibi et al. (2018)
	32	Project changes are not being processed in a timely manner for decision making	Choi (2007)
Team Building	33	The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project.	Choi (2007); Williams at al. (2012); Safapour et al. (2019)
	34	Lack of motivation	Safapour et al. (2019)
	35	Lack of training	Safapour et al. (2019)
	36	Poor communication between stakeholders and participants	Habibi et al. (2018)
	37	Parties unwilling to share relevant information	Williams at al. (2012)
	38	Notice of sudden or gradual reduction in attendance at project meetings.	Adebisi et al. (2020)
	39	Commitments are increasingly made with the intention of not being met	Choi (2007)
	40	A mood of non-satisfaction among personnel, strained atmosphere, uneasy comments, lack of cultural understanding, etc.	Choi (2007); Williams at al. (2012); Nikander & Eloranta (2001)
	41	The project team is not being realistic and truthful when project circumstances are unfavourable.	Choi (2007)
	42	The project team is losing confidence in the accuracy and validity of the schedule	Choi (2007)
	43	Weak commitment to the project expressing itself	Nikander & Eloranta (2001)
Quality Management	44	Inappropriate/Poor design quality	Safapour et al. (2019)
	45	Quality of the reports, preliminary plans, and documentation is unsatisfactory	Nikander & Eloranta (2001); Williams at al. (2012); Safapour et al. (2019)
Documentation	46	Documentation not completed	Williams at al. (2012)
	47	A project specific quality plan is not consistent with the contract documents	Choi (2007)
	48	Numbers/information missing, messages get lost along the way, lack of control	Nikander & Eloranta (2001); Williams at al. (2012); Safapour et al. (2019)
External factors	49	Some project participant companies become financially unstable, overall financial issues	Choi (2007); Safapour et al. (2019)
	50	Laws and regulations	Habibi et al. (2018)
	51	Delay in approval stage	Habibi et al. (2018)

3.3. Methods for the Identification of Early Warning Signals

This chapter seeks to describe approaches linked to the detection of early warning signals. The literature contains information on identifying project uncertainties, unhealthy project circumstances that may lead to future difficulties, and causes for project underperformance. Furthermore, there is a large body of literature on project risk and its identification. However, in the context of early warning indicators, the literature on identifying procedures is scarce (Wijtenburg, 2018).

Previously, a research done by Williams et al. (2012) presented a list of early warning indicators based on 8 case studies. They, however, also discussed different methods for identification of the warning indicators. These methods were categorized as identification “through assessments” and based on “gut feeling”. All of the organizations involved in the research underwent a variety of assessments, including stakeholder analysis, risk assessment, political assessment, technical analysis, cost estimation, and more. Documentation, reports, checklists, contractual requirements, and milestones all serve to support these evaluations. Some participants recognized the significance of interviews and discussions with key persons, peer evaluations, and observations in meetings as a tool for identifying early warning signals (Williams et al., 2012; Wijtenburg, 2018).

Williams et al. (2012) continued by explaining that building trust and effective communication is a good substitute for using assessments extensively. In particular, dialogue with stakeholders and technical observations made during a parallel development process were more important than assessments as a source of early warning signs. Regular communication and the work environment are better at identifying early warning signs than assessments.

Furthermore, the authors believe that many early warning indications are less quantitative, necessitating more "gut feeling" methods. The case studies and interviews demonstrated that conversation and company culture are critical in identifying early warning indicators. This demonstrates the importance of "gut feeling" techniques that might capture signals that more formal approaches may miss. Whereas formal assessment methods are effective for identifying EWS in the situations they are intended to address, informal "gut-feeling" approaches can be used to hunt for signals without a specific focus or concern in mind (Williams et al., 2012).

The article written by Haji-Kazemi et al. (2015) makes an overview of possible identification methods for early warning signals. The study relies on literature review, practices in the industry and authors’ own experience. As a result, they presented an illustration with different possible approaches for the identification of EWs, which can be seen in Figure 7.

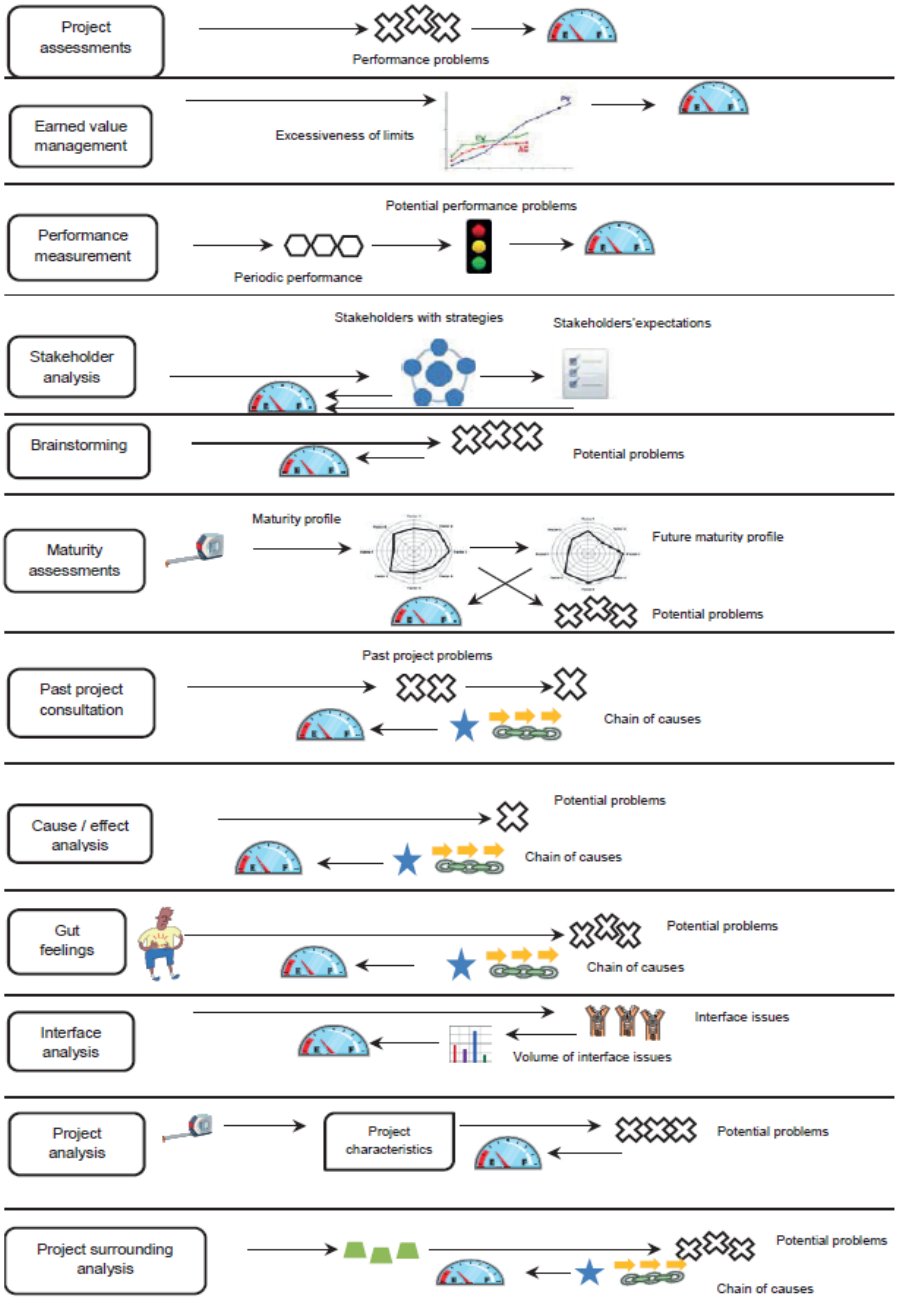

Figure 7. Approaches for identification of EWS (Haji-Kazemi et al., 2015)

Haji-Kazemi et al. (2015) also mention in which project phase the approaches are applicable, and it appears that they can be used in all project phases, including the design phase. However, it is interesting to note that some of them would work especially better in the front-end stage of the project which is very valuable for this thesis research. These methods are as follows: stakeholder analysis, brainstorming and maturity assessment. Using the findings of Williams et al. (2012) and Haji-Kazemi et al. (2015), a previous master thesis research done by Wijtenburg (2018) made a very valuable table including all of the identified approaches. The list can be seen in Table 8.

Table 8. Overview of EW identification methods from literature (Wijtenburg, 2018; Haji-Kazemi., 2015; Williams et al., 2012)

	Identification method	Description
1	Risk analysis	Identified risks can be monitored by the current risk management practice. However, it can be questioned if the ambiguous character of soft EW signs can be detected by risk management practices (Thamhain, 2013).
2	Earned Value management	EV method is set to measure the health of a project by a set of metrics. Since the main KPI's of the method are focused on costs and time, this is not the most suitable method to detect 'soft' type of EW signs. Nevertheless, it is a well-used method to track planning and cost deviations in an early stage.
3	Project assessments	Project assessments account for all sorts of reviews, audits and status check that are applied to the project. A problem Is that assessments can give a too optimistic view on the project. Project assessments can be used to acquire both hard and soft project data. However, most of the current used assessments focus mainly on hard KPI's.
4	Performance measurement	Performance measurement is a general term for approaches to periodically track progress of the project by means of KPI's or a balanced scorecard. most project performance measurement focuses on lagging KPI's, being mainly hard factors (Williams et al., 2012). To capture soft EW signs, it is necessary to monitor the KPI's that indicate the softer managerial issues of the project.
5	Stakeholder analysis	Stakeholder analysis is a tool designed to evaluate the stakeholders involved in the project, which is widely used in construction projects (Olander, 2007). According to Haji-Kazemi, stakeholder analysis can be used to identify EW signs by analysing the stakeholders involved in the project.
6	Brainstorming	Brainstorming can be periodically, evaluating, or non-systematic used as out-of-the-box reflecting on project issues. According to Haji-Kazemi, this is arguably the most used source for finding EW signs. Another strong advantage of this method is that it allows employees to ventilate their opinions more freely, creating a very realistic image of the project. This is important for soft EW signs.
7	Maturity assessments	Maturity assessments are used to evaluate the quality of the project organisation that is running the project. These assessments could function as a very EW, by assessing the quality of the project team that is assigned to the project.
8	Past project consultation	Evaluation of past projects in order to detect EW signs. While organisational learning is perceived as a problem in the construction industry, it is important in detecting EW signs.
9	Cause and effect analysis	Root cause analyses can be used to identify EW signs and their risk in projects, both systematic and non-systematic. The essence of these methods is to explain certain anomalies in the project, which makes it a good tool to detect 'soft' EW signs.
10	Gut feeling	Gut-feeling as described by Klakegg et. al (2010) is an important source of EW signs. Experts stress the fact that EW signs are mostly less measurable, making the detection of them depending more on gut-feeling than systematic approaches (Haji-Kazemi et al., 2013a).
11	Interface analysis	Interface analysis is used to detect problems with interfaces between technical systems, different actors, and people in the project that may arise in the project. It can be used to identify potential EW signs, both hard and soft signals.
12	Project analysis	Assessments used to examine the characteristics of the project, conducted in frond-end stage of the project. These kinds of frond-end analyses are tools that can present EW signs.
13	Project surrounding analysis	Analysis of project environment, made in frond-end stage of the project. Examines the external factors that could influence the course of the project. Issues related to political climate, market, financial climate, organisations can present EW signs for the course of the project.
14	Text mining	Scanning of management documents including meeting minutes in order to identify EW signs (Alsubaey, Asadi, & Makatsoris, 2015). Gives objective data, but can evoke strategic behaviour.
15	Project health checks	Type of project assessment. However, PHC's can be used explicitly to monitor soft EW signs. It is argued that PHC's should mainly focus on the managerial side. At the same time a PHC should be applicable at any time of the project.

3.4. Limitations to Early Warning Response

After identifying EWs and presenting the different approaches for doing so, the possible barriers or limitations need to be explored as well. For this reason, Ansoff and McDonnell (2019) established three distinct filters that an EW indication must travel through before reaching the organisation. Those filters are surveillance filter, mentality filter and power filter. The model was originally published by Ansoff (1984). This model is illustrated in Figure 8. For the purpose of this study, the updated version of Ansoff's book is used, the third edition of Ansoff and McDonnell (2019).

According to them, the surveillance filter processes the data that enters the company, and its properties are decided by the firm's forecasting/analysis procedures. To accurately depict environmental reality, a technology capable of capturing the main parts of that reality must be used. The approach must be increasingly extensive as the reality becomes more complicated.

Before data may influence judgments, it must first pass through two more filters. The mentality filter, which is based on managers' mental success models, selects relevant information. However, with abrupt environmental changes, ineffective success models may obstruct fresh useful data. It is critical to cultivate a mindset that is prepared to deal with future volatility. Diagnostic tools and treatments are available to help managers adopt this mentality (Ansoff & McDonnell, 2019).

The power structure applies a third filter to data. The power filter refers to the decision-making process that determines what information may be used to influence project decisions. If powerful managers lack the right mindset, they may prevent critical signals from affecting choices, resulting in procrastination. Novel knowledge will not be incorporated into management responses unless managers with strategic/creative mindsets have the authority to ensure its adoption (Ansoff & McDonnell, 2019). Overall, power constraints are one of the primary filters against acting upon early warning indicators. This impact can get stronger in large initiatives with extra complexity due to the variety of aims (Haji-Kazemi, 2015).

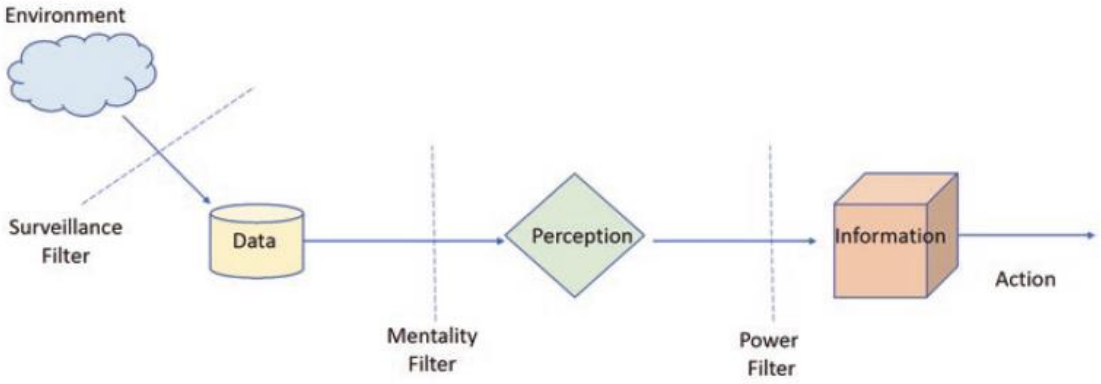

Figure 8. Management information (Ansoff & McDonnell, 2019)

Haji-Kazemi (2015) dissertation expanded on the model proposed by Ansoff (1984). The findings of the dissertation define the method by which information about a prospective EW sign should be processed in order for the appropriate response to be made before the potential problem occurs. In this approach, the mentality filter is divided into two independent filters to highlight the distinction between the observer and the decision maker (Haji-Kazemi et al., 2015). This was deemed important because the observer is usually not the same person as the employee making the judgment. Furthermore, a lack of communication among project staff might interfere with an efficient reaction (Wijtenburg, 2018). The model is illustrated in Figure 9.

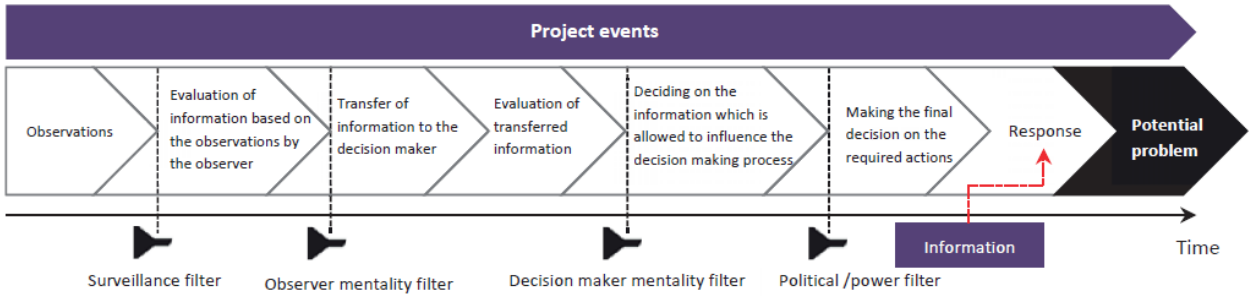

Figure 9. The EW procedure and the possible filters against flow of information (Haji-Kazemi, 2015).

Furthermore, Haji-Kazemi (2015) conducted a survey among the respondents included in her case study. Respondents were then questioned about the most critical reasons for failing to respond to EW indicators when they were discovered. The respondents were given many options and asked to score them on a scale of 1 to 5, with 1 being the least essential reason and 5 being the most important. The results with the highest scores are presented in Table 9.

Table 9. Reasons for not responding to Early Warning Signals (adopted from Haji-Kazemi (2015))

Reasons for not responding to EWs	Average rank (out of 5)
Poor management	4.1
Lack of effective communication among project members	3.2
Over-optimism	3.1
Political issues	3.1
Lack of time to respond	2.9

In another study, Williams et al. (2012) recognized over-optimism as a significant obstacle to reacting to EWs. Optimism will often cause actors to ignore potential warning signals. Other challenges include organisational, such as complexity in the project's environment, which makes it difficult to notice early warning signals, or simply not having a clear plan, or being unable to articulate and resolve arguments over goals or methods. Finally, Williams et al. (2012) addressed review process restrictions, such as predetermined presumptions in preset formal evaluations that impede openness to early warning indications.

Wijtenburg (2018), in his study, made a summarised table from the literature which presents most of the identified limitations/barriers related to early warning signals. The table has been adopted for the purpose of this study relating it to schedule overruns. The list can be seen in Table 10.

Table 10. Possible barriers to EWs response (adopted from Wijtenburg (2018))

Barrier	Description
Over-optimism / optimism bias	Benefits are exaggerated; expenses and time are minimized; and the possibility of issues and miscalculations is ignored.
Normalisation of Deviance	The unexpected becomes expected, which becomes accepted. Three types: strategic misrepresentation, client-contractor relation, planning-scheduling issues.
Fragmentation	Fragmentation of projects limits organizational learning
Uncertainty avoidance	The degree to which individuals of a society feel frightened by ambiguous or uncertain conditions.
Systematic fallacy (illusion) in decision making	People tend to underestimate the costs, planning, and hazards of a given activity while overestimating its rewards. Actors have a 'inner perspective', focusing on the elements of the particular intended action rather than the effects of previous acts.
Time pressure	Difficulties for acting due to lack of time to think ahead and question assumption
Effects of politics	Political pressure (exerted by the project owners) to implement a given solution
Poor Management	Poor management of the project
Project complexity	A situation involved with flux and unpredictability and large number of unknown unknowns
Management style	Leadership style by project manager influences project performance
Lack of communication	Lack of communication and coordination between parties in the project as cause for project issues

3.5. Conclusion and Next Steps

Chapter 3 was devoted to literature analysis of the Early Warning Signals identified in the literature, the used approaches for the identification and their limitations/barriers. The aim was to give an answer to the following sub-question:

> *SQ1: What Early Warning Signals are identified in the literature, what are the identification approaches, and what are the limitations associated with them?*

Early Warning signals, as identified in the literature, are indicators of potential future problems, allowing proactive management to prevent project failures. The review highlighted that these signals could materialise as "weak" indicators of both positive and negative future conditions, with the primary focus on negative indicators to mitigate unforeseen schedule delays. Management teams can adopt reactive or proactive approaches to deal with strategic surprises.

Reactive management focuses on dealing with problems as they arise, while proactive management anticipates and prevents issues. Studies by Mäki-Marttunen et al. (2019) and Adebisi et al. (2020) recognised Early Warning Signals as a proactive approach to preventing project failure.

Key studies, such as those by Nikander & Eloranta (2001), Williams et al. (2012), Habibi et al. (2018), Choi (2007) and Safapour et al. (2019), have provided extensive lists and classifications of EWS relevant to various project phases, particularly the design phase of infrastructure projects. These studies collectively identified numerous EW signals distributed across multiple categories, such as Project

Management and Control, Project Organisation, Client/Stakeholder related symptoms, Project Changes, Team Building, Quality Management, Documentation, External Factors.

As a result, the extensive literature review provided with a list of 87 early warning signals. However, some of them were either not applicable to the design phase in which this thesis is interested or they were repetitive. Therefore, after making a visual board which can be seen in Appendix A and illustrating all possible warning indicators, the list was narrowed down to 51 signals.

The analysis also highlighted the importance of both formal and informal methods for EW identification. Formal methods include structured assessments like stakeholder analysis, risk assessment, and technical analysis, supported by documentation and checklists. Informal methods, or "gut-feeling" approaches, rely on intuition, communication, and organizational culture, capturing signals that formal methods might overlook. This dual approach ensures a comprehensive detection of EWs. As a result, a total of 15 identification methods were discovered and presented. The final list can be seen in Table 8.

Finally, limitations to effective EW response were discussed, as elaborated by Ansoff and McDonnell (2019), who identified surveillance, mentality, and power filters as potential barriers. A previous master thesis written by Wijtenburg (2018) summarised the limitations/barriers from literature related to Early Warning Signals. The list can be seen in Table 10. With this, the chapter concludes and the next step of this research would be to conduct exploratory interviews and retrieve information on Early Warning Signals from industry experts.

4. Warning Signals Identified in Practice

In this chapter, the exploratory interviews related to the topic of Early Warning Signals take place. The aim of the exploratory interviews is to get more practical information related to the warning signals, get to know how the project involved people handle problems, what are the main challenges, why schedule delays occur. Getting to know better the company profile and gaining insight from experienced employees would help answer the second and third research question which are as follows:

> *SQ2: What Early Warning Signals are identified in practice by the managers of Dutch Infrastructure Projects and how do they act upon them?*
>
> *SQ3: Which of the Early Warning Signals have the highest influence on schedule delay from expert's point of view?*

The main goal at the end of this chapter is to be able to present a prioritised list of Early Warning Signals which are most relevant from a practical point of view in the design phase of a project and would serve Project Managers, Controllers and Leaders in such a way that schedule delays would be reduced to a minimum.

In order to do so, eight interviews were conducted and thereafter analysed. First, it would give an indication of how familiar the project leaders are with the concept of Early Warning Signals. Then, real life examples of warning indicators would be given. Finally, the warning indicator list from Chapter 3, Table 7 will be used and updated using the information given by the interviewees. For simplicity, each of the participants in the interviews will be named from P1 to P8.

The structure of this chapter is as follows. In chapter 4.1. the selection criteria for the interviewees are presented and explained. Then, the design of the interviews is introduced with some information about the participants. Chapter 4.3. is concerned with the actual interviews and is split into four steps.

The first step analyses the interviews themselves and presents the indicators proposed by the experts. Also, it gives a better idea of the understanding of project involved people with the Early Warning Signals concept. In the second step, the participants assess the previously identified indicators from the literature and refine the list further. In the third step, the information from the literature and the interviews is combined together, making the final comprehensive list of Early Warning Signals.

Finally, the indicators are prioritised based on their importance using the probability and impact matrix, similar to how risks are assessed. The conclusion and further steps are given in the last section.

4.1. Interviewees Selection Criteria

For the purpose of these interviews, different selection criteria were determined:

1. Active involvement in Dutch Infrastructure Projects and variations in their type.
2. Experience of at least 5 years.
3. Position in the company as Project Director, Project Manager/Leader or Project Controller.

Each of the selection criteria is explained further in the next sub-sections.

4.1.1. Active involvement in Dutch Infrastructure Projects and variations in their type

All of the interviewed experts need to be part of the Infrastructure department of Sweco because the topic of the thesis is focused on Dutch Infrastructure Projects. The main department consists of the sub-departments Transportation and Mobility, Water, Rail and Roads. By interviewing people from

different departments it would give a better understanding of the whole industry and the results would be more reliable. The Early Warning Signals' list needs to be useful to different variety of Dutch Infrastructure Projects.

4.1.2. Experience of at least 5 years

The interviewees need to have at least 5 years of experience which would mean they have participated in multiple projects which have finished. In this way, the practical examples would be valid and the knowledge they contained helpful. Most of the interviewed experts have 15+ years of experience, however, due to the subjectivity of the warning indicators' topic and their innovative character, it is critical to obtain the opinions of experts with varying degrees of competence.

4.1.3. Position in the company as Project Director, Project Manager or Project Controller

The reason for choosing experts specifically in these positions is because of their active involvement through the whole project cycle. They are the most familiar with the details and the progress made in a project combined with a vast knowledge in terms of organisation, resource allocation, scheduling, controlling, etc.; therefore, their input is the most valuable for this research.

4.2. Design of the Interview

The interviews conducted for this research were semi-structured. Each interview started with an introduction to the topic, providing the experts with essential background information about the research. This initial phase ensured that the specialists clearly understood the research's aim and scope, enabling them to respond to the questions appropriately.

The interview consists of 20 questions in total which are divided into 4 categories. The first one is *"General Experience and Understanding of Early Warning Signals"*, which aims at getting to know the interviewee better, their experience and their understanding of the concept of EWS. This is followed by *"Identification of Early Warning Signals"* which looks into monitoring, identification and specific practical examples. During this section, experts reflected on projects they had worked on that encountered scheduling delays, discussing the reasons for these delays and freely providing examples of warning indicators throughout the interview.

Then, the third section *"Actions Taken in Response to Early Warning Signals"* aims to find information about the decision-making process, responsibilities and prioritization. Finally, the *"Reflection and Improvement"* category summarises the findings and presents lessons learned and potential improvements. The full list of questions is provided in Appendix B.

At the end of each interview, participants are presented with a printed list (Table 7) containing indicators previously identified from the literature review. The interviewees are asked whether the indicators from the list are relevant to infrastructure projects. They can assess each signal by giving it a "*No", "Maybe"* or *"Yes*". In this way, after collecting information from all the interviews, the tables can be put together, and based on selection criteria, the most relevant indicators will be chosen and used further in the research. The whole interview lasts about one hour. Detailed explanations of the entire process are provided later in this chapter.

The list of the interviewed experts is presented below in Table 11, giving information about their positions, the infrastructure department they work in, and the years of experience they have. The average years of experience is 21.1. For simplicity, each participant will be referred to as P1 to P8 throughout the research.

Table 11. List of participants

Ref. №	Current Position	Department of Infrastructure	Years of Experience
P1	Project Director	Roads	30+
P2	Project Manager	Water	25
P3	Project Manager	Roads	30+
P4	Project Manager	Rail and Stations	20
P5	Project Manager	Rail and Stations/Water	15+
P6	Project Manager	Water	15
P7	Project Controller	Water	5+
P8	Project Manager	Transportation and Mobility	30

4.3. Analysis of the interviews

In this section the results from the interviews are discussed. First, a table is presented in which all warning indicators that were mentioned are presented. In front of each indicator, with a grey colour, it is marked which participant identified it. In this way, the frequency of appearance for each signal can be seen. Immediately after the table, the indicators are explained in more detail with examples, and the ones expressing the same idea will be put together under the same name. This would answer the first part of SQ2. Then, an explanation will be given about how the participants act upon the proposed indicators. This would give an answer to the second part of SQ2 (Step 1).

After that, as explained in Chapter 4.2., an analysis of the previously identified Table 7 with EWS will be made because the experts eliminated a big portion of them (Step 2). Then, both lists formed from Step 1 (exploratory interviews) and Step 2 (literature review) will be merged into one, giving the final Early Warning Signals which are important and relevant to the Dutch Infrastructure industry (Step 3).

Finally, the indicators will be prioritised by asking the participants from the interviews to give scores on the *"Probability"* and "*Impact*" of the Early Warning Signals. By multiplying both factors, the indicators can be compared and prioritized based on their score level. The higher the score, the more important the signal is (Step 4). Each step will be explained further in the relevant sub-chapter.

Before starting the analysis of the warning indicators, it is important to say what the project managers/controllers/directors currently know about Early Warning Signals and whether they are familiar with it.

Most participants reported that they had heard of it and had an idea about the concept and the rationale behind it. However, they are not explicitly using it or thinking about it. They do not know how to apply them and recognize them in the first place. Everyone reported that the signals in their mind come from gut feeling and vast experience in the field. None of the participants had a specific point of time devoted to the identification of EWS and, thereafter, the proper reaction to them.

4.3.1. Step 1: Analysis of the discussion with the participants

During this step, a complete table is created to record the indicators suggested by the respondents, which are expressed clearly as keywords or brief sentences. This strategy allows for a clear and structured summary of the signals that participants think are important and useful for monitoring.

In total, the interviewees identified 22 distinct signals. The results are shown in Table 12 and this gives an answer to the first part of SQ2. For each participant, the boxes corresponding to the indicators they identified are highlighted in grey. This visual representation provides an easy and intuitive overview

of the frequency and agreement among experts on various metrics. Examining the grey highlighted boxes for each participant reveals how many individuals identified the same signals. However, this information can just give direction but cannot draw conclusions based on it. On one hand, the higher frequency of mentioning the same signal might indicate how important it is. On the other hand, it might demonstrate that everyone has the same level of knowledge and understanding of Early Warning Signals and is equally capable of using them.

Table 12. Early Warning Signals identified by interviewees

№	Early Warning Signal	Experts who identified the signals							
		P1	P2	P3	P4	P5	P6	P7	P8
1	High turnover rate of people/ no stability in the team	■	■	■	■	■		■	■
2	Shortage of skilled labour -> Too many juniors		■	■			■	■	
3	Too much work is being allocated to a worker/ Working on couple of projects at the same time	■	■		■	■			■
4	High number of change requests/ Scope changes/ Scope creep	■	■	■	■	■	■	■	■
5	Lack of experience	■	■	■	■	■			■
6	People not aware what they are doing/ what they are required to do							■	
7	Incurred costs on the project are already getting higher than the anticipated benefits from the project (Earned Value Management)	■			■			■	
8	Not following the plan	■		■					
9	Poor organization and communication/ too many layers of communication	■	■	■	■	■	■	■	
10	Cultural/working differences	■		■			■		
11	Negative attitude/behaviour of people/lack of motivation	■						■	■
12	Unclear scope definition/starting point	■	■			■	■	■	
13	Lack of detailed specifications in contracts								■
14	Discussions/meetings are delayed/postponed (internally and externally)		■	■					
15	Poor quality of questions coming from people	■							
16	Time for decision making/ client makes slow decisions		■	■					■
17	Project location/ the nature of the project			■	■	■	■		
18	Use of untested tools/software for the project						■		
19	Unclear/vague instructions given by the client	■							
20	Lack of transparency	■							
21	Lack of responsibility		■						
22	Unpleasant working environment/ well-being of the team			■					■

As can be seen, a large number of the indicators are repeated multiple times by most of the participants. Explanations of the indicators will also be given here. Participant 1 (P1) identified scope creep as an indicator, which would mean increasing the number of requirements and work without adding additional time or resources. This is an early indicator of schedule overruns. The other participants called these “scope changes”. This can be closely related to another indicator referred to as “unclear scope definition”, which also includes what P1 called during their interview “unclear starting point”. All participants mentioned at least one of them. The requirements are unclear and changing a lot, which complicates the initially planned work and leads to overscheduling. Although scope extensions usually add more time to the planning, it is often impossible to finish the project within the specified time range. This is due to the lengthy procedure of obtaining additional work. In some cases, the job is even finished before obtaining all the required documentation for the assignment to be handed officially. As a consequence, when the task is formally assigned, the assignment has already been completed, resulting in a misleading sense of performance, which can generate challenges for resource management and organization, negatively influencing the final delivery point.

It is essential to monitor the number of changes made because this is an excellent indicator for future schedule delays supported by numerical (non-objective) data. Some examples included more than 100 modifications to the project, resulting in major design changes and rework, needing more hours than originally estimated. Participant 8 went a step further with his arguments, identifying "lack of detailed specifications in contracts" as a warning flag. They believe that the level of specificity in a contract indicates whether or not the demand will be satisfied on time. If the contract is poorly made and details/specifications are missing, then many change requests will come during the project slowing down the work, adding complications and leading to delays eventually.

Seven out of eight participants highlighted the "high turnover rate of people" as another sign, indicating that people participating in the project are departing for various reasons. The project managers recognize the harmful effects of team turnover, pointing out possible interruptions and knowledge gaps. This is a severe problem since it requires you to allocate new personnel, include them in previous work, allow them time to comprehend, and train them if necessary, all of which take time and may result in schedule overruns.

However, the impacts of employee turnover are not usually as large. It truly depends on when it happens. If personnel depart at the start of a project, they may be quickly replaced and the problem remedied. However, P8 emphasised that the influence on the project might be severe if it occurs near the conclusion of the project when everyone's familiarity and expertise of the project are critical. Therefore, if an employee leaves, it needs to be taken with caution, act on time and prevent others from leaving.

The same indicator was also identified as “resource management” problems or “changes in key personnel” and was mentioned by everyone. Additionally, some of the interviewees explained that problems in “resource management” also refer to having people but not the correct ones. This is very closely related to other indicators such as “lack of experience and expertise”. Therefore, these two will be united together as one indicator later in the research. Participants noted that they lacked the necessary competence for some initiatives. Mistakes were made, motivating the client to request rework, resulting in a considerable increase in the number of working hours necessary for the project.

Earned Value Management (EVM) is another warning indicator identified by P1, P4, and P7 because it checks the ratio between the progress made (in hours) and the money spent. In this way, if someone has spent 20% of the allocated budget, but the work progress is only at 10%, this would be an

indication of some delay, which might negatively affect the timely end of the project. P1 used an example to show how the design of a project took significantly longer than expected owing to factors such as a lack of competence, delegating too much responsibility to juniors, and so on. Despite spending more than half of the allocated funds, just 10% of the design was accomplished. The discrepancy was too large to compensate for. Therefore, if this indicator is monitored closely, project managers may respond on time and avoid deadline delays.

Working on more than one project at a time was identified by both P1 and P8. The reason for that is when someone is working on more than one project, they are not focused very well and start postponing and being late with their deliverables, and this causes issues. This is also the same as "too much work is allocated to a single person". Employees get overwhelmed, which in the end reflects on the project in a negative way.

Participants 1 and 3 also identified as important the indicator "not following the plan". They share from their experience that when you do the planning and later start deviating from it too much, it never ends well, and schedule overruns occur. This is valid for the more important and bigger steps/milestones, not for the small details, because they always get changed.

Then, P1, P3 and P6 identified as indicator "cultural differences". They gave some real life project examples where multiple companies from different countries were involved in very big infrastructural projects and due to differences in the culture and the way of working, multiple problems occurred leading to schedule overrun. For example, P3 worked with colleagues from Poland and at the beginning they had very hard time informing him of problems which were their responsibility. P3 continued:

> *"…the way of working and openness about problems differed greatly from ours. They had to report to me, and it took me some time to make them feel comfortable enough to disclose anything to me, including problems that were their responsibility and fault."*

Here, it can be closely related to another indicator identified by almost everyone, which is "communication", a very important aspect of every project. Poor communication among project participants inevitably leads to issues later in the project. For example, if you do not adequately notify a project participant about changes or communicate progress, needs, and expectations, a delay is quite possible. Also, if meetings are postponed and people begin cutting corners as a result of having too many meetings, this can lead to major communication issues. Nonetheless, the respondents acknowledge that they seldom experience serious communication issues or timetable delays as a result of this. Most of the time, the contact with the customer goes well and is successful.

In addition, P7 recognizes that having "too many layers of communication" can be very problematic as well. This is the case when representatives of the interested parties do not communicate directly with each other but use intermediaries. In this case, information is lost along the way or not represented in the correct way, causing errors and overall communication issues which once again might lead to schedule delays.

Attitude and behaviour of people could be another warning signal which was identified by P1 and P8. Very closely related to that is "lack of motivation" which was identified by P7. They explained that it gives an indication of their competence and how invested they are in a project. If someone behaves ignorant that could already be a sign of potential future problems. P8 gave an interesting example explaining that near deadlines, people usually start contacting them more, seeking information, advice, decisions, etc. However, if this is not happening, most of the time it means that too little work is being done, or people are too much behind and do not know what to ask. For them (project

managers), this is a good indication that they need to step in and steer the project in the correct direction.

Related to the attitude of people and the lack of experience is “quality of questions”. P1 gave an example of a project where the project leader was asking questions which were very simple, not strictly related to the job and not seeking for any relevant information. This was a signal for them being incompetent, ignorant and just trying to get around the work. As a result, later in the project this caused multiple problems and the project was massively delayed.

Participants 2, 3, and 8 identified "time for making decisions" as a very important early warning indicator in project management. This issue frequently manifests as a significant problem due to the sluggish decision-making processes observed on the client's side. Once consultants have identified issues or reached a critical point that requires a decision, it becomes essential for the client to step in and determine the next course of action. However, some clients have a noticeable tendency to postpone, thereby prolonging the decision-making process excessively.

Procrastination is frequently motivated by a desire to improve outcomes or eliminate certain design components in order to save money. Clients think that by carefully analyzing and modifying their selections, they may improve results and reduce costs. However, contrary to their intentions, such delays typically result in increased expenditures and extended project timelines. This paradox occurs because prolonged decision-making disrupts the project flow, leading to inefficiencies and the need for rework.

Consultants rely largely on the client's timely decisions and information to go on with the project. In the lack of prompt input from clients, consultants are frequently forced to make assumptions and proceed with their job accordingly. This method, although required to minimize immediate project delays, creates risks and uncertainties that could affect the project's eventual success, especially in terms of delays. For instance, in a lump sum contract, consultants are remunerated for the assignment and are obligated to complete the project within a specified timeframe. Any delays in decision-making can put at risk their ability to meet these contractual obligations and eventually delay the whole project.

Additional challenges arise when certain projects must be executed within specific periods of the year. For example, environmental considerations, such as the nesting periods of special breed birds, can impose strict time limitations on project activities. In such cases, clients' ability to make quick decisions becomes extremely important. Failure to make timely decisions can result in substantial delays, as project activities may need to be postponed to comply with environmental regulations, leading to significant disruptions. Therefore, it is vital to identify and address excessive delays in decision-making early in the project lifecycle. By proactively controlling the decision-making process, projects may avoid the problems associated with procrastination and ensure a smoother transition towards success.

Interviewee 2 described an intriguing approach in which the project is organised into so-called sprints. In this methodology, project participants focus exclusively on the deliverables for a single sprint within a specified timeframe. Upon completion of this period, regardless of the amount of work finished, the team moves on to the next sprint and its associated deliverables. This approach ensures continuous progress, though it necessitates that project managers make decisions regarding incomplete deliverables from previous sprints.

To implement this method effectively, it is essential to monitor the burn rate of tasks. The burn rate refers to the number of tasks assigned within a given timeframe. Based on experience, Participant 2

observed that a particular team is capable of handling a maximum of ten tasks at a time. For this reason, they said: “If you give them 11 or 12 tasks, they will not meet the demand, and you will get a delay”. In this way, the “number of tasks” assigned to a team could be used as an early warning indicator for the successful completion of those tasks.

Moreover, this indicator aligns with observations from other participants who identified that assigning "too much work to a person" could be used as a warning signal. Therefore, these indicators will be put together as one. This emphasizes the importance of balancing work assignments to avoid overwhelming team members.

Another interesting indicator that P2 identified is “lack of responsibility”. In a project that ultimately took twice the planned duration, key personnel failed to take responsibility from the beginning. During the initial planning phase, specialists were consulted regarding the time required to complete their tasks. After collecting their estimates and formulating the project plan based on their input, these specialists refused to put their signatures in the planning. They were unwilling to accept responsibility for the projected demand. Despite this refusal, the plan was adopted and implemented, resulting in significant delays and the project exceeding its original timeline.

The "project location" was identified by Participants 3, 5, 6, and 8 as an important early indicator of potential schedule delays in a project. Participant 3 noted that "…*the location of the project can indicate whether your scope is stable or not. If the environment is very complex, then you know your scope will always change*". In such complex environments, the expectation of frequent changes becomes manageable as actions can be prepared in advance. Thus, the location serves as a predictor of the likelihood of changes and deviations.

For instance, a project situated in an area with extensive subsurface infrastructure, such as oil and gas pipelines or electricity cables, is sensitive to additional work requirements. One would say that all of this is known before the start of the project, however, usually the underground plans are not absolutely accurate and unplanned objects might appear. These unforeseen factors can lead to scope changes/ scope creep. The need for additional work requires modifications in organization, planning, and resource allocation, ultimately resulting in schedule delays. Therefore, project location acts as a crucial indicator of the stability of the project scope and the potential for schedule disruptions.

“Wellbeing of the team” or “unpleasant working environment” is another signal identified by P3 and P8. They explained that the atmosphere where people work is very important for the success of their job. If people do not feel comfortable in the team they are placed in or the job they are doing, it is likely that they will not execute the work at a very high level. Participant 8 explained that it even happens for people to sabotage the project if the working environment is unpleasant. Also, they do not communicate as much which is closely related to the previously identified indicator “poor communication”.

Another indicator identified by P2 and P3 is when “meetings start getting postponed”. It is critical to have frequent meetings with the customer, and it may be an early warning sign if the client begins to postpone meetings, since this indicates that they do not prioritize the project. In this case, good communication is also affected by this; information gets lost or not shared at all, and the requirements are not discussed properly, resulting in an unsatisfactory product, which eventually leads to project delays.

Participant 6 identified the “use of untested tools” as a very interesting indicator for schedule delay. In a project, they were expected to do inspections, examine certain parts, determine whether they needed to be changed, and so on, and the city of Amsterdam had developed a digital/online system,

a tool that allows companies to work according to schedule and follow the progress. However, after one month, it became evident that the tool had never been tested or used before, and the system did not function properly. Although the method was first relied upon, it was found to be excessively time-consuming.

The consultants went to the client to discuss these issues and what they found was that internally people had different views and expectations regarding the project. This situation contributed to multiple problems and ultimately delayed the project by nearly two years. Several indicators could have been monitored in order to avoid the problem such as “poor communication”, “unclear scope definition”, “use of untested tools”, etc.

Participant 7 identified "employees unaware of their job" as an early warning indication. They explained that asking employees questions about their responsibilities on a regular basis can be a useful diagnostic tool. By evaluating their reactions and answers, project leaders, managers, or controllers can determine the need for intervention and take proactive measures before delays occur. These questions successfully check if participants in the project have a clear understanding of their duties.

In some cases, P7 noticed that when people react vaguely, demonstrating a lack of understanding of their roles, the project's progress, or the general situation, difficulties arise quickly after. Thus, the signal "employees unaware of their job" could be a useful predictor of possible problems. This indication may also be connected with previous signals such as "people's behaviour/attitude" or "lack of experience."

How is the current management acting upon the identified early warning signals?

As it was explained in Chapter 4.2. the interviews revealed that most participants have heard of the Early Warning Signal concept and have an idea about the rationale behind it. However, they are not explicitly using it or thinking about it. Everyone reported that the signals in their mind come from gut feeling and vast experience in the field. None of the participants had a specific point of time devoted to the identification of EWS and, thereafter, the proper reaction to them. Therefore, there was no clear answer or strategy about how most of the signals were handled.

Nevertheless, some of the participants gave some examples of acting upon the warning indicators, even though it was noted that these measures are not always very effective. For instance, when there is a high turnover rate of people or no stability in the team, the project managers first need to understand where the problem comes from. Usually, the employees either leave the company, or they are allocated to another project. In the first scenario, the project managers report that they cannot do anything about it, only make recommendations to team leaders or senior managers for the improvement of the working environment, which would minimise the turnover rate of people. In the second scenario, project managers can speak directly to the team managers who have relocated the employees to another project and explain the inconveniences that this creates for the project. Everything in this case is up to good communication and reaching a consensus. If the motivation of the project manager is valid, the employee can be returned back to work on the project.

In another example, where too much work is being allocated to a worker, similar measures are taken. First, the project manager speaks to the person of interest and seeks information on whether they are overwhelmed with the workload. If this is the case, to prevent issues from materialising, the project manager can speak to the team manager, who can ease some of the work or provide additional employees. It is important that the employees share information regarding their physical or mental health. Otherwise, the project managers will not know there are problems.

However, in order for the employees to share such information, there needs to be a pleasant and comfortable working environment. This is mainly the responsibility of the project manager (PM), who is the leader of their own team. This is done by organising regular meetings with the whole team, sharing information, seeking for opinions and feedback, doing various activities together, etc.

Participant 2 reported that sometimes there might be some cultural/working differences. This is possible to turn into a bigger problem for the project, therefore, actions must be taken. The employees in question, who might struggle due to some cultural/working differences, are put together in controlled situations. They have conversations and meetings or execute assignments, which are monitored by the project manager in charge of the team. In this way, either differences are resolved, and the work can continue without other issues, or the differences become even more evident, which indicates that these people cannot work together and should be put in different positions to prevent some future clashes that would negatively affect the project.

In some cases, cultural and working differences extend beyond the project team within the same company. Participant 3 described a large Dutch infrastructure project involving multiple companies from different countries. Initially, significant issues arose with communication and timely information sharing due to substantial differences in working styles. To address this, the main project manager from SWECO had to travel to Poland to meet with one of the involved teams. This in-person meeting was critical in underlining the importance of their position and aligning everyone's expectations, underscoring the seriousness of the issue and ensuring successful teamwork.

A significant factor contributing to project delays is the slow decision-making process by clients. Project managers report that in such cases, it is important to timely inform the client what would be the consequences of such actions. They need to be reminded to make decisions in a timely manner; otherwise, the whole project might be delayed, and then the responsibility is theirs.

In other situations, there are large number of change requests coming from the client. In such cases, it is important to communicate all the changes with the client before starting to work on them. The project managers assess what is the impact of those changes over the whole project in terms of money and execution time. This is explained to the client, what are the effects of the changes and they need to be taken into consideration when updating the initial planning. However, it is hard to foresee the full impact of a potential change, which is the reason for having big delays when the number of change requests increases.

Another example of a reaction related to the warning signal “Not following the plan” was given by P8. They explained that in such cases, the progress meetings are crucial. For instance, once a month there is a big progress meeting where team members discuss the work on the project. Questions related to the methods, execution, progress, etc., are asked, and in this way, the deviations from the plan can be traced and addressed. In the same way, the ratio between the spent money and the made progress is monitored. When there is a big difference, the project managers first speak to the team and try to address the issue internally. If the problem is caused by some of the members, the project manager makes sure it will not happen again and a strategy can be made for improvement in the next milestone. For instance, the engineers overdesigned something which in the end costs more money and takes more time, however, the client did not ask for it. In this situation, either the client accepts the additional work and allocates more money, or the project team accepts the consequences and continues to work strictly following the initial requirements.

In summary, most of the reported actions are related to improved communication and information sharing. The client needs to be well and timely informed about everything, the consequences of their

actions need to be explained carefully and clearly, and there must be constant information flow within the teams. This is all done by scheduling regular progress meetings, providing with comfortable working environment and involving the client when needed. However, these measures do not address sufficiently big portion of the identified Early Warning Signals, therefore, further analysis and recommendations will be given in the next chapters. This concludes the answer to SQ2.

4.3.2. Step 2: Analysis of the Early Warning Signals identified from literature

In this section, the previously created list of indicators with the help of literature (Table 7) will be revised and shortened. For this purpose, the participants from the interviews will take part and assess each of the signals. Based on that, the list will be updated. As it was explained at the beginning of Chapter 4, the concept is to review each of the EWS in the table and determine whether or not to respond with a "No", "Maybe" or "Yes" depending on their knowledge, assessment of the indicator's significance, and relevance to the projects they have worked on.

After that, in order to filter the indicators and exclude the least relevant ones, different scores were assigned to their opinion, so *"No"* equals 0 points, "Maybe" equals 1 point and *"Yes"* gives 3 points. Because this approach is logical and easy to comprehend, the author chose to utilize it. It is very similar to the three-points-for-a-win system in the football. By assigning three points, there are higher incentives for the respondents than giving only two points. This also can prevent signals to go through by scoring only one point consistently among the participants (Moschini, 2010). The rationale behind this system is explained further.

When a participant gives *"No"* – 0 points, this indicates a clear and unambiguous negative reaction. The signal is not relevant or has not been experienced by the expert, thus it has no influence. The zero point rating represents this absence of significance or occurrence.

The response *"Maybe"* which receives 1 point, suggests ambiguity or just some significance. The signal might be relevant or experienced under certain conditions but is not definitive. Assigning 1 point acknowledges the potential but low confidence or lower impact compared to a certain "Yes." Assigning 1 point to "Maybe" avoids dismissing potentially relevant signals entirely.

Giving 3 points to "Yes" indicates a strong, confident affirmation that the signal is relevant or has been experienced. Assigning 3 points reflects the high relevance and applicability of the signal, giving more weight to clear positive responses.

In order to exclude some of the early warning indicators and leave the more relevant, applicable or experienced by experts, some criteria need to be established. There are 8 participants in total which would result in the highest possible score of 24, when everyone gives "*Yes*" – 3 points.

This assessment process can be associated with the Delphi method, which has gained popularity in recent years and is now recognized in academic research as a useful strategy for establishing consensus on specific problems when empirical data is limited or contested. So, the primary goal of this strategy is to generate consensus on the issue under investigation by collecting opinions from a group of experts. Similarly, in this phase of the research, there needs to be a consensus about the most relevant indicators found in the literature. The most common threshold value to define consensus is 75-80% agreement between the experts (Barrios et al., 2021; Diamond et al., 2014).

For this reason, it is assumed that the results could be considered robust and valid if they are supported at 80% or more. In other words, the total score for each indicator needs to be 19 or higher, which would mean six out of eight experts selected "*Yes*" and one selected "*Maybe*". This high threshold ensures that the signals considered are those with substantial agreement, thus representing

a high level of confidence and agreement among the participants. As a result, 21 indicators from the initial Table 7 were excluded and are left with 30. The whole excel table with the scoring and calculation can be seen in Appendix C, and the list of the 30 indicators sorted also by score from higher to lower can be found in the table below.

Table 13. List of Early Warning Signals based on literature

Early Warning Signal	Score
1. Lack of resource management	24
2. Poor management, inability to proactively detect problems at early stages, management is lacking required level of experience and skills	24
3. The project is experiencing a high level of engineering / design / specification errors and scope changes.	24
4. 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.	24
5. Poor communication and coordination	24
6. Unclear scope definition including poor definition of scale, required resources, goals, tasks, assumptions, etc.	24
7. Shortage of labour (skilled)	24
8. The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project.	24
9. Lack of training	24
10. Documentation not completed	24
11. Inappropriate/Poor design quality	24
12. Too much work is being allocated to a worker	22
13. There are constant schedule slippages (along critical path) right from early project stages and milestones are not being met	22
14. Same things come up again and again in meetings	22
15. Client's and stakeholders' unresponsiveness, lack of seriousness and dedication to ensuring timely completion of projects.	22
16. Slowness in making decisions by owner	22
17. There is a large number of change requests or requirements fluctuations within the project.	22
18. Project changes are not being processed in a timely manner for decision making	22
19. A mood of non-satisfaction among personnel, strained atmosphere, uneasy comments, lack of cultural understanding, etc.	22
20. Quality of the reports, preliminary plans, and documentation is unsatisfactory	22
21. Incurred costs on the project are already getting higher than the anticipated benefits from the project	20
22. Lack of a common definition of roles and responsibility	20
23. The project is experiencing difficulties in integrating schedules between project participants.	20
24. The project team is experiencing a high turnover rate and instability in team membership	20
25. Discussions are delayed/postponed	20
26. Lack of motivation	20
27. Consultants are making continuous attempts to redesign project and alter its scope.	19

28. Float for project activities is being used up at an increasingly high rate.	19
29. Parties unwilling to share relevant information	19
30. Weak commitment to the project expressing itself	19

4.3.3. Step 3: Combining the results from the literature review and the exploratory interviews

In this step, a comprehensive list of Early Warning Signals (EWS) is constructed, combining insights from both the literature review and exploratory interviews. During the interviews, participants identified several indicators that, while expressed in different words, indicate the same underlying issues, for that, these overlapping indicators were combined. Some examples were discussed in Chapter 4.3.1.

Moreover, the interviews uncovered other signals that the literature review did not address, so they had to be included in the final table. As a result, there are a total of 25 indicators in the final table that combine signals from the literature and interviews. This total is achieved after eliminating duplicates and merging indicators that represent similar concepts.

For instance, "Negative attitude/behaviour of people," "Lack of motivation," "Weak commitment to the project," and "A mood of non-satisfaction among personnel, strained atmosphere, unpleasant working environment" were combined into a single indicator. Similarly, "Unclear scope definition including poor definition of scales, goals, tasks, assumptions" was merged with "Lack of common definition of roles and responsibilities," and "Discussions are delayed/postponed" was combined with "Client starts postponing meetings". The final list of Early Warning Signals is presented in Table 14 and with a cross sign, it indicates where the specific indicators come from (Literature, Interviews or both).

Table 14. Final list of Early Warning Signals combining results from the literature review and exploratory interviews.

Ref №	Early Warning Signals	Literature	Interviews
1	High turnover rate of people/ No stability in the team	✕	✕
2	Shortage of skilled labour -> Too many juniors	✕	✕
3	Too much work is being allocated to a worker/ Working on couple of projects at the same time	✕	✕
4	There is a large number of change requests or requirements fluctuations within the project/ Scope creep	✕	✕
5	The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project.	✕	✕
6	People not aware what they are doing/ What they are required to do		✕
7	Incurred costs on the project are already getting higher than the anticipated benefits from the project (Earned Value Management)	✕	✕
8	Not following the plan		✕
9	Poor organization and communication/ Too many layers of communication	✕	✕
10	Cultural/working differences		✕
11	Consultants are making continuous attempts to redesign project and alter its scope.	✕	

12	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	✕	
13	The project is experiencing a high level of engineering/ design/ specification errors	✕	
14	A mood of non-satisfaction among personnel, strained atmosphere, negative attitude, uneasy comments/ unpleasant working environment	✕	✕
15	Unclear scope definition including poor definition of scale, goals, tasks, assumptions, etc.	✕	✕
16	Lack of detailed specifications in contracts		✕
17	Same things come up again and again in meetings	✕	
18	Discussions/meetings are delayed/postponed (internally and externally)	✕	✕
19	Poor quality of questions coming from people	✕	✕
20	Time for decision making/ Client makes slow decisions	✕	✕
21	Project location/ the nature of the project		✕
22	Lack of training	✕	
23	Parties unwilling to share relevant information	✕	
24	Quality of the reports, preliminary plans, and documentation is unsatisfactory	✕	
25	Use of untested tools/software for the project		✕

4.3.4. Step 4: Prioritization of the Early Warning Signals

In this final step, the Early Warning Signals are prioritized based on the input given by the respondents. This is done based on the method for calculation of risk severity, however, in this case, the risks are substituted with warning indicators which are examined and assessed. To understand better the process, first the method for risk assessment will be explained.

The primary goals of project management, which includes risk management, are often controlling costs and schedules, quality and safety in the construction industry. The methodical process of comprehending these risks and their consequences through risk analysis enables decision-makers to prepare for risk mitigation as well as account for them in emergency plans. Identification, quantification (assessment), and response are the three general phases. The construction company can identify and prioritize different hazards in this way (Cirovic & Sudjic, n.d.; Dziadosz & Rejment, 2015).

The focus in this section is on the assessment part, or the creation of Risk Matrix. The method is chosen because it is relatively simple and understandable. It helps in prioritization of risks and attracts attention. After identifying the risk aspects, different scenarios for each risk element should be analysed. The worst-case or most pessimistic scenario, as well as the best-case or most optimistic scenario, should be regarded as the greatest and lowest consequences of risk aspects, respectively. An example of Risk Matrix can be seen in Figure 10. As it can be seen, there are two axes. One for the probability of occurrence of a risk, and the other for the impact of the risk on the project. Generally, the impact is in terms of money or time. This research is interested in schedule delay, therefore, impact would be in terms of time. The risk score/level is calculated by multiplying the probability value with the impact value. The higher the score, the more critical and important the risk (warning indicator).

			Impact				
			1	2	3	4	5
			0-50 tys.	50 tys.-500 tys.	500 tys.-2 mln	2 mln-5 mln	5 mln-20 mln
Probability	1	0 -5%	Low	Low	Low	Medium	High
	2	5-40%	Low	Low	Medium	Medium	High
	3	40-70%	Low	Low	Medium	High	High
	4	70-80%	Low	Medium	Medium	High	High
	5	80-100%	Low	Medium	High	High	High

Figure 10. Risk Matrix (Dziadosz & Rejment, 2015)

In the same way, as explained about the Risk Matrix, the Early Warning Signals will be prioritized. The final list of signals from Table 14 is used and ranked. To do so, the interviewees from before participate again and give scores to the probability and impact axis based on their experience and feelings.

The Likert scale is one of the most fundamental and widely used instruments in educational and social science research. The 5-point scale is one of the most often used. It provides five alternative options for responders to pick from. The possibilities are two extremes, two intermediates, and one neutral opinion. It's straightforward to understand and complete it. However, responders might excessively use the neutral point, producing less meaningful data. Additionally, because there are fewer categories, it could miss slight distinctions in viewpoints. As a result, the 6-point scale will be employed, which produces more consistent results and eliminates the neutral choice, pushing participants to thoroughly consider their alternatives and provide their opinions. At the same time, the 6-point scale cannot be really considered more complex than the 5-point scale (Chomeya, 2010; Joshi et al., 2015; Leung, 2011).

The question to be answered about the Probability would be: *"How often do you think the above mentioned indicators are present in projects, or how often have you encountered them?".* For example, how probable do you think it is to have "high turnover rate of people/ no stability in the team"? The scale is from 1 (lowest) to 6 (highest) and represents the following:

1. Highly unlikely (1%) - Very unlikely to occur. Probability is between 0% and 5%.
    a. The event is highly improbable and could happen only in exceptional circumstances.
2. Unlikely (10%) - Not expected to occur but possible. Probability is between 5% and 15%.
    a. The event could occur, but it is not expected under normal conditions.
3. Possible (30%) - Might occur at some time. Probability is between 15% and 45%.
    a. There is a chance that the event could occur at some point.
4. Likely (55%) - Will probably occur in most circumstances. Probability is between 45% and 65%.
    a. The event is more likely to occur than not under normal circumstances.
5. Very likely (75%) - Expected to occur in the majority of cases. Probability is between 65% and 85%.
    a. The event is very likely to happen.
6. Almost certain (90%) - Highly likely to occur. Probability is between 85% and 100%.
    a. The event is almost certain to happen.

The question to be answered about the Impact would be: *"How big do you think is the impact of the indicator over schedule delay?"* For example, how big do you think is the impact of having "high turnover rate of people/ no stability in the team" on the schedule? The scale is again from 1 (lowest) to 6 (highest) and represents the following:

1. Negligibly low - The event would have unnoticeable impact and would not require changes to the planning/organisation.
2. Minor - The event would cause low inconvenience and could be handled with existing resources.
3. Moderate - The event would require management attention and might lead to minor adjustments in operations.
4. Significant - The event would cause disruption and would need a coordinated response.
5. Major - The event would severely disrupt operations and would need serious resources/attention to manage.
6. Catastrophic - The event would be disastrous for the timely completion of the project.

After each interviewee carefully examines the list of early warning indicators, scores will be given to the Probability and Impact column of the table. In this way, the rank of the warning indicator will be calculated (*Probability x Impact = Rank*). Then, for each row (indicator), the average number from all participants will be calculated, and the final score will be given. The final results can be seen in Table 15 and this gives an answer to SQ3. The whole Excel table with the individual scores given by each participant can be seen in Appendix D.1, whereas the layout of the questionnaire is presented in Appendix D.2.

As a result of this analysis, the top three indicators will be selected and used further in the research. These are R1 - Ref №20, R2 - Ref №4, and R3 - Ref №15. From Table 14 it can be seen that these indicators were identified both from the literature and the interviews.

This research aims to give better insight into the topic of Early Warning Signals, their importance and how to use them. It is logical to assume that the participants from the interviews would score higher on indicators that are already known to them. This, however, might exclude highly important signals, but they were identified only in the literature, and the interviewees are not familiar with their application. For this reason, the three highest-scoring indicators identified only in the literature will also be examined further. These would be R11 - Ref №13, R13 - Ref №24, and R14 - Ref №11.

Table 15. Prioritization of the Early Warning Signals

Rank	Ref №	Early Warning Signal	Score
R1	20	Time for decision making/ client makes slow decisions	21.00
R2	4	There is a large number of change requests or requirements fluctuations within the project/ Scope creep	18.29
R3	15	Unclear scope definition including poor definition of scale, goals, tasks, assumptions, etc.	15.00
R4	1	High turnover rate of people/ no stability in the team	14.71
R5	16	Lack of detailed specifications in contracts	13.86
R6	3	Too much work is being allocated to a worker/ Working on couple of projects at the same time	13.57
R7	8	Not following the plan	12.43
R8	2	Shortage of skilled labour -> Too many juniors	12.14
R9	21	Project location/ the nature of the project	12.00
R10	7	Incurred costs on the project are already getting higher than the anticipated benefits from the project (Earned Value Management)	12.00
R11	13	The project is experiencing a high level of engineering / design / specification errors	11.86
R12	5	The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project	11.71
R13	24	Quality of the reports, preliminary plans, and documentation is unsatisfactory	11.57
R14	11	Consultants are making continuous attempts to redesign project and alter its scope.	11.57
R15	12	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	10.86
R16	9	Poor organization and communication/ too many layers of communication	10.00
R17	18	Discussions/meetings are delayed/postponed (internally and externally)	9.57
R18	25	Use of untested tools/software for the project	9.14
R19	14	A mood of non-satisfaction among personnel, strained atmosphere, negative attitude, uneasy comments/ unpleasant working environment	8.57
R20	22	Lack of training	8.00
R21	10	Cultural/working differences	7.71
R22	23	Parties unwilling to share relevant information	7.71
R23	6	People not aware what they are doing/ what they are required to do	7.43
R24	17	Same things come up again and again in meetings	7.29
R25	19	Poor quality of questions coming from people	6.71

The six EWS that will be used further in the research are coloured in green. The first column represents the Rank of the indicator starting with the most important and going to the least important one. The second column represents the Reference number of the indicator, which comes from Table 14. In this way both tables can be related to each other.

In order to understand better the scores of each indicator, all of them will be plotted on the Early Warning Signal Matrix – Impact/Probability. In this way it can be seen clearly how the factors (probability and impact) contribute to the final score. For example, signal R10 has a total score of 12, however, this could be a combination of probability = 3 and impact = 4, the other way around, or other

numbers. The graph which presents all warning signals can be seen in Figure 11. Both the horizontal and vertical axis goes from one to six, however, for better visualisation, the horizontal axis is cut at five.

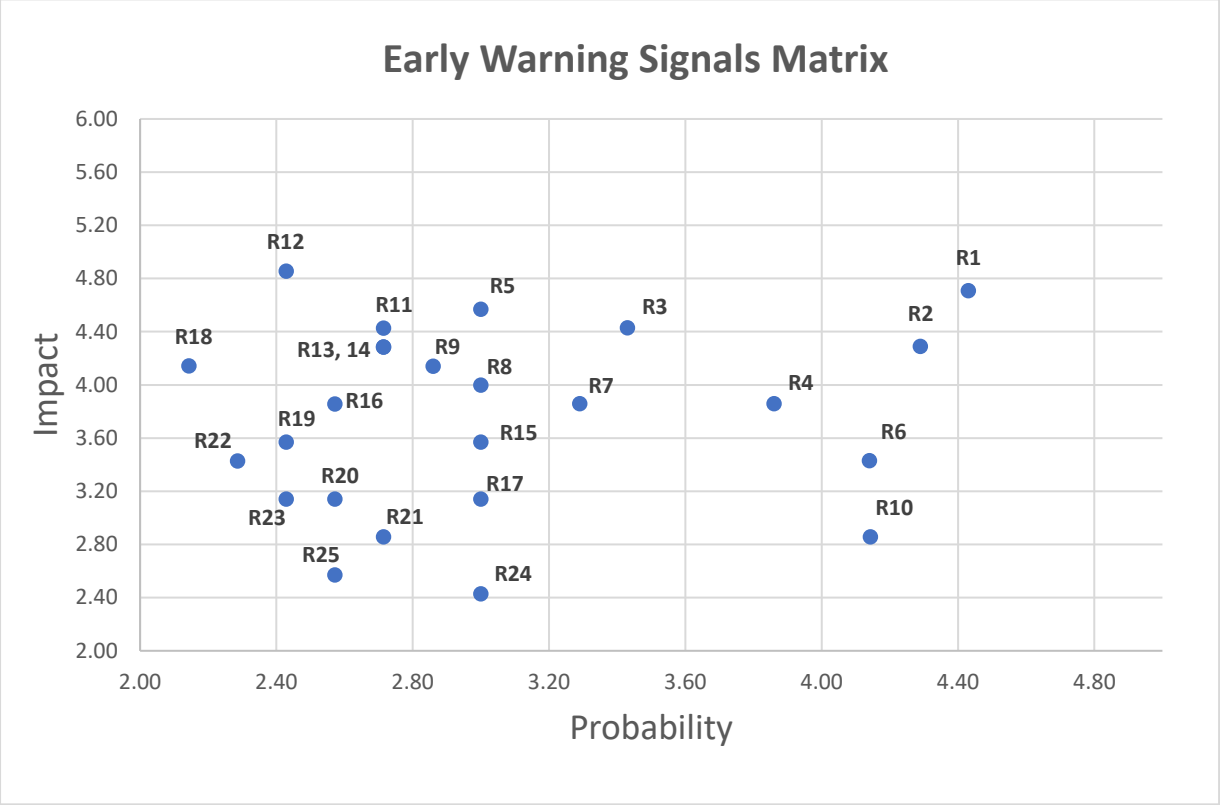

Figure 11. Probability/Impact graph

For instance, indicator R10 (Earned Value Management) has a much higher value for probability compared to the impact. This is because the probability of mismatch between the amount of money spent and the progress made is usually very high. However, the impact of it is not so significant in terms of schedule delay. It would have been different, if the graph was related to the effect of R10 on the budget. The results mean that the project manager can either decide to take measures which would lower the probability and minimize the chance of occurrence, or they can mitigate further the impact on the project and make it negligibly small. This would depend on the amount of resources required to do so.

4.4. Conclusion and Next Steps

The aim of this chapter was to give an answer to Sub-Question 2 and Sub-Question 3 which are as follows:

> *SQ2: What Early Warning Signals are identified in practice by the managers of Dutch Infrastructure Projects and how they act upon them?*
>
> *SQ3: Which of the Early Warning Signals have the highest influence on schedule delay from experts point of view?*

The first phase involved conducting exploratory interviews with eight industry experts from different Infrastructure departments such as Roads, Water, Rail and Stations, and Transportation and Mobility.

These interviews aimed to collect examples of Early Warning Signals from the experience of the participants and get to know how they act upon them. It was valuable to note which indicators come first to their mind and how many people identified the same indicators. As a result, Table 12 was created which shows all indicators identified from practice and the frequency of repetition of each one of them.

Chapter 4.2 found that, while most interview participants were aware of the notion of Early Warning Signals, they did not employ or consider them directly. Instead, they relied on experience and gut feelings to spot problems. None of the participants had a defined strategy for detecting and reacting to EWS. Therefore, there were no clear methods for dealing with the majority of signals.

Overall, improved communication and information sharing were identified as key strategies for managing Early Warning Signals. Regular progress meetings, a comfortable working environment, and timely client involvement were crucial. However, these measures were insufficient to address all identified EWS, necessitating further analysis and recommendations in subsequent chapters.

The second phase of the exploratory interviews aimed to refine further the initial list of indicators obtained from the literature. Participants were asked to assess each indicator's significance and relevance based on their professional experience. This process resulted in a revised list where each EWS was evaluated and scored as "No," "Maybe," or "Yes," with corresponding points of 0, 1, and 3, respectively.

The grading system was created to be simple and easy to grasp, reflecting the experts' belief in the importance of each indication. Indicators scoring 19 or above (out of a possible 24) were kept, indicating strong support at no less than 80% of the maximum possible result. This stage eliminated 21 signs, resulting in a revised list of 30 Early Warning Signals (EWS).

In the third step, the interview list was further examined to combine overlapping signs and integrate new signals discovered during the interviews that had not previously been addressed in the literature. This synthesis produced a final consolidated list of 25 EWS, which provides an exhaustive set of indicators relevant to Dutch Infrastructure projects. This list effectively combined theoretical information gained from the literature research with practical insights from industry specialists. A visualisation of the sieving process of the Early Warning Signals is shown in the figure below.

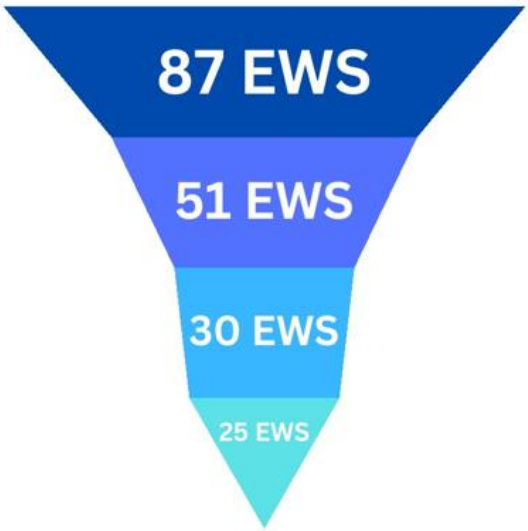

Figure 12. Funnel diagram illustrating the reduction in Early Warning Signals (EWS)

The final step involved prioritising the Early Warning Signals based on their probability of occurrence and impact on project timelines. The same participants were asked to score each indicator on these two axes using a 6-point scale. The probability axis ranged from "Highly unlikely" to "Almost certain," while the impact axis ranged from "Negligibly low" to "Catastrophic." The final scores were calculated by multiplying the probability and impact scores. Then, the average scores were used to rank the indicators. Finally, the top three indicators are selected which were identified by both literature and interviews. Additionally, the top three indicators identified only in the literature are also selected because the experts might not be very familiar with them, which does not mean they are not of high importance (Table 15).

This chapter's findings offer significant insights for construction project managers. By focusing on the highest-ranked Early Warning Signals, project managers may address potential issues before they develop, increasing the likelihood of project success. The selected warning signals are as follows: “client makes slow decisions”, “scope creep”, “unclear scope definition”, “high level of engineering/design errors”, “poor quality of the reports, preliminary plans, and documentation” and “consultants making continuous attempts to redesign the project”. Implementing frequent monitoring and mitigation techniques for these crucial indicators will assist in keeping projects on track and avoiding serious delays.

In the next step, the six selected indicators will be further examined. It will be checked to what extent they can be measured in order to be monitored efficiently. Furthermore, the current situation regarding acting upon those indicators will be discussed, and recommendations will be given on how it can be improved.

5. Measurability of the Early Warning Signals

In this chapter, the measurability of the six previously selected warning signals will be investigated. This would give an answer to the last fourth research question, which is as follows:

SQ4: How can the Early Warning Signals be measured?

First, it will be investigated whether the selected warning signals are measurable. After that, suggestions on further measuring the indicators will be given. Some of the indicators are closely related to each other, which means the measurements to be taken might be similar or interconnected between each other.

5.1. Measurability of the Early Warning Signals

Each of the Early Warning Signals will be investigated separately. Data from the participants of the exploratory interviews will be used to check whether the current organisation is measuring any data related to the indicators and how it is done. Also, additional questions will be asked to the available interviewees in case information regarding the measurability is missing. Finally, suggestions for each indicator are given on how they can be measured further.

Time for decision making/ Client makes slow decisions

This indicator scored the highest from all in the prioritization table and received rank one (R1). Both the literature review and interviews identified it. This issue typically develops as a substantial problem owing to the client's slow decision-making procedures. Once consultants have detected concerns or reached a key point that necessitates a choice, it is vital for the client to intervene and select the next course of action. However, some individuals tend to postpone, overextending the decision-making process.

As a result, consultants are usually obliged to make assumptions and carry out their tasks appropriately because the client also the planning to be met. Although this strategy is necessary to reduce immediate project delays, it introduces risks and uncertainties that may have an impact on the project's overall performance, particularly in terms of delays.

The interviews reveal that managers currently do not measure this indicator; however, some reported that it could be measured. For instance, when there is a request for change (could be both from the client or consultants), this needs to be written in the progress report, and the decision about that change and when it was taken must also be written down. This means that it can be measured how much time it took from the moment of request until the decision was taken. However, in the current situation this is not done.

Most of the time, the consultants work with an issue list, and a decision needs to be made for each element. The client, for example, goes through the list one by one and makes decisions. However, the available time is not officially specified, and the amount of time it takes to make decisions is not measured, and this is the main problem currently. Therefore, in order to make this indicator measurable, a recommendation for the consultants would be:

- Define important decision points: Identify and record all crucial decision points (milestones) in the project plan. These are the times when customer permission or input is necessary to proceed with the next phase or job of the project.

- Establish baseline timelines: Determine the expected durations for each decision based on the project plan and client agreements. These baseline timings are the criterion against which real decision times will be compared.
- Track the decision-making process: Implementing a system to track the time taken for each decision. There must be a description of the required decision, the date when the decision was formally requested, the date when the client provided their decision, and from there, the number of days/weeks it took the client to make the decision can be calculated.

In this way, a specific timeframe will be identified before the decision, and the client will be properly informed about the amount of time available for making the decision. As a result, whether the client was late could be monitored, with how much time, the frequency of the delays, and the further impact on the project could be estimated. After that, the planning could be adjusted accordingly. All of these need to be officially documented and communicated with the client. The ultimate goal for Sweco is to help the client stay on schedule and make them aware of the consequences of slow decision making.

There is a large number of change requests or requirements fluctuations within the project/ Scope creep

This is the second scoring indicator from the prioritisation list and has a rank of two (R2). It was identified by both the literature and the interviews. This indicator is related to the high number of changes made to a project/ scope creep, resulting in major design changes and rework, needing more hours than originally estimated. Changes usually come with some more time, but this is hardly sufficient because it is very difficult to anticipate the entire impact of a change over the project timetable, leaving less time for approved sections of the scope (Larson & Larson, 2009). Also, changes bring with them the relocation of budget, people, priorities, etc., which creates discontinuities in the work, which is why they must be avoided as much as possible and prioritised accordingly.

The interviews reveal that it is easy to document and track the number of changes made within a project, which makes them measurable. However, the problem is that in some projects, multiple changes have very little impact on the project, whereas, in other projects, only one change can have a significant impact on the project planning.

For this reason, when a change requests occur, the consultants need to estimate how many hours this would take and what is the effect on the rest of the project. Usually, when a new activity is introduced, another one is dropped, and it is possible that the total working hours stay the same or it is even reduced. However, most of the time, the changes contribute negatively to the project because of the resource allocation and reorganisation of the work.

Currently, when a change is introduced, Sweco first classifies it as a “need to have” or “nice to have”, which helps in the prioritisation. Then, the impact on the planning, budget, and scope is checked, and if everyone agrees, the change is adopted, and work starts. Overall, the consultants are handling change requests very well, but it is much work, which inevitably takes additional working hours, and therefore, it is good to avoid changes if possible. For instance, in some projects, the changes are so significant that there are people dealing only with them.

There must be clear documentation of the initial scope and planned work. In this way, the impact of the changes could be estimated more accurately using WBS, and the number of additional working hours can be measured with higher accuracy, which directly affects the project's schedule performance. This would be helpful when taking preventive measures to limit issues.

Another recommendation would be to use visualisation tools to monitor the change request data, such as the number of submitted changes, additional working hours, percentage of approved and

rejected changes, and differences in project schedules before and after the implementation of change requests. One suggestion for visualisation software would be Power BI, which is used widely for the analysis of data and, at the same time, is easy to comprehend. This would make it easier to communicate the impact of scope creep to stakeholders. For instance, the consultants can use Gantt charts to reflect the impact of potential change requests on the project timeline and then make final decisions with the client/stakeholders. All of that provides the opportunity to measure the indicator.

Unclear scope definition, including poor definition of scale, goals, tasks, assumptions, etc.

This is the third highest scoring Early Warning Signal, which, similarly to the previous two indicators, is also identified by both the literature and interviews. As the name suggests, it has to do with the unclear scope definition of the project, which is a serious problem because there are many unknowns and a high degree of uncertainty, which negatively affects the planning of the project.

In the current situation, the project managers report that they do not measure “unclear scope definition”, but some suggested that it could be possible to do so. Participant 2 explained that when defining the scope, once again, they make a Work Breakdown Structure (WBS) and based on that, it is decided what should be done, how many deliverables there are and how much time it would take. And in some projects, it takes them months to decide on the WBS because there are too many unknowns. In cases when there are extensive and repetitive discussions between the client and the consultants about the work that needs to be done and the number of deliverables, usually the scope is unclear from the beginning. This means that the amount of time required to make the WBS could be the measurable unit for “unclear scope definition”.

However, the problem with this suggestion is that “too much time” is a subjective matter. Based on the experience of the project manager, the complexity and the nature of the project, for one person, two months of time for making the WBS could be reasonable, and for another, this could be “too long”. Therefore, it is relatively easy to measure the time it takes to create the WBS and this could be a marker for the project manager. However, it is subjective, based on experience and gut feeling.

To support the decision of the project manager, another suggestion is proposed. For example, the use of a standardised document which describes all of the required points of attention when defining the scope of a project because currently there is no such standardised list. This could include project objectives, detailed requirements, acceptance criteria, assumptions, scales, involved stakeholders, project boundaries, milestones and deliverables, planning, potential risks, required resources, communication channels, roles and responsibilities of each party involved, etc. (A Guide to the Project Management Body of Knowledge, 2017). Before the project starts, it can be measured the number of specifically defined scope elements compared to the total number of scope elements from the list, and this can give an impression of whether the scope is clearly defined before the work starts. Additionally, Sweco has five different classes of projects which are based on the required budget. Similarly, for each class, the ”reasonable” amount of time that a Work Breakdown Structure should take could be defined.

Finally, after finishing the scope elements, the key stakeholders could be invited to complete a survey in which they can rate the clarity of each aspect on a scale and document the results. This would add some extra time to the project in the short term. However, analysing the scores and fixing unclarities early on would reduce the likelihood of having a large number of revisions and other difficulties that would have a negative effect on the project's long-term success. Combining together all of the mentioned measurable elements would support the project managers’ gut feeling and help them take the correct preventive measures. Nevertheless, it can still be said that it is hard to measure “unclear scope definition”.

The project is experiencing a high level of engineering/ design/ specification errors

This indicator is the highest scoring one from those identified only from the literature and is placed in 11th place from the whole prioritisation list. It has to do mainly with human errors/mistakes, and those are inevitable to happen. However, they can be reduced to a minimum by monitoring the correct data. One can argue that this is not really a warning indicator because nobody knows there is a mistake until it is found. On the other hand, it is important at what point in time the mistake is discovered and whether it is repeated. Usually, one design mistake would not turn around the entire project, but if there is a tendency to repeat it, this might have a significant negative impact. Therefore, this indicator can be considered as an early warning for potential long-term problems and delays.

Similarly to the previous indicators, this one is not measured by the interviewees, but it is possible to do so. The simplest thing to do is measure the number of errors made. Then, this can be used to calculate the error rate as the number of errors per, for example, working hours or submitted design pages. Prior to that, there can be a specific ratio which is acceptable, and everything above that can be considered as a red flag. For instance, it could be acceptable to have one mistake for every 120 working hours of engineering.

However, the number of mistakes alone would not be sufficient because sometimes there might be multiple mistakes which have a very small effect on the project and can be fixed easily. This is why it should also be measured what is the impact of the error over the project in terms of time and how much resources would be needed to deal with the issue. This is a measure of the severity of the problem which currently is not measured.

In addition, some experts report that a mistake would not be considered as such if it is found on time by the quality checks. This would mean before delivering the product to the client. Nevertheless, as explained above, if the frequency of mistakes internally becomes too high, this could be considered a big issue, and actions need to be taken before it starts affecting the long-term goals of the project.

Finally, the percentage/number of errors recurring in a project can also be measured and monitored. In this way, a list of the most common mistakes could be created and prevented from happening in future projects.

Quality of the reports, preliminary plans, and documentation is unsatisfactory

This is the second indicator in the list from those identified only in the literature and receives rank 13 from the full prioritization list. Currently, the participants report that they use systems engineering and WBS where the demands of the product/report are put, and in this way, it can be verified whether or not the document meets the requirements, which should be defined before that. For instance, a drawing should have some specific underlayer, scales, etc., which can be checked directly whether it was used the correct format or not.

Additionally, there are extensive internal quality checks of the reports before they are submitted to the client. Then, if there are problems, contradictions, or flaws in the format, remarks need to be made and returned back for improvement. One thing that can be measured is the number of comments/remarks made, which might indicate the quality of the documentation. However, sometimes the comments are very simple and related to, for instance, the colour that has been used. Therefore, it would only be fair to put the comments in categories and measure the number of remarks for each category and this is not done at the moment.

Another suggestion would be to strictly define within the team and with the client the completion rate of the reports and the mandatory sections before submitting them. For instance, the deliverables could be submitted at no less than 80% of the report being done, and this can also be measured.

Finally, the client satisfaction could be monitored by asking them to complete a feedback survey by assigning points/scores to different sections or categories of the report. Once again, the result would not act as an early warning for the current report, however, it would give an indication of where most problems come from. A project consists of multiple reports and plans that need to be submitted. Therefore, these measurements could be used as a warning indicator for following-up submissions.

Consultants are making continuous attempts to redesign project and alter its scope.

This is the final indicator of interest which receives a rank of 14 and was identified only in the literature. However, it has the same total score as rank 13, which makes it of similar importance. This signal has to do with the fact that sometimes engineers overdesign something and deliver products that were not requested. This is due to the nature of engineering and everyone involved trying to improve on a product "too much" just because they have an idea for it and know how to do it.

This indicator is not measured in any way within the company, and it is reported to be very hard to measure because it mainly relies on the gut feeling of the project manager and communication within the team. One thing that is done and gives more objective data (measurable) is during the monthly progress meetings, where the ratio between the spent money and the executed work can be compared. More specifically, there is an estimate for the design hours and the budget for the design work, and they can be compared. A big mismatch between those during the progress meetings could be an indicator of overdesigning and delivering products that the client did not ask for, and in this case, the project managers need to take action to prevent it from happening further in the project.

5.2. Conclusion

In conclusion, the measurability of the selected Early Warning Signals (EWS) has been thoroughly examined in this chapter, offering valuable insights into how these signals can be effectively measured to enhance project management practices. Through a combination of literature review and input from exploratory interviews, it has been established that while some EWS are currently not being measured within the organization, there are viable methods to begin doing so. Each indicator has been addressed with specific recommendations, ranging from the establishment of baseline timelines and tracking decision-making processes to the implementation of Work Breakdown Structures (WBS) and the use of visualization tools like Power BI.

The analysis highlights that while certain indicators, such as the time taken for decision-making or the number of design errors, can be quantitatively measured, others, like the clarity of scope definition or overdesigning by consultants, pose challenges due to their subjective nature. However, by employing standardized documents, conducting surveys, and monitoring progress meetings, even these complex indicators can be made more manageable and measurable.

Ultimately, the goal of measuring these EWS is to provide early indications of potential project risks, allowing for timely interventions that can prevent small issues from escalating into major problems. By systematically applying the suggested measurement techniques, the organization can improve its ability to detect and respond to early warning signals, thus enhancing project outcomes and reducing the likelihood of delays.

6. Strategy for Handling the Early Warning Signals and Evaluation of the results

This section will discuss further how currently the six warning indicators are handled within the organisation, and finally, potential improvements will be proposed and discussed. How the management acts upon these six specific signals will be analysed in more detail. In Chapter 4, a more general answer was given to the question related to handling the warning indicators, whereas here, the participants from the exploratory interviews will be asked specifically about those six Early Warning Signals and how they are handled within the company. Based on that an improved strategy can be proposed for future projects. In the next parts of this chapter, each warning indicator is discussed separately. Finally, the chapter finishes with evaluation of the proposed measures to be taken. This would give an answer to the last research question of this research:

SQ5: How should the prioritised Early Warning Signals be handled by the management?

Time for decision making/ Client makes slow decisions

When the client makes slow decisions, the consultants cannot proceed with their design and progress as they would like to. However, due to the relationship between the client and the consultancy company hired by the first one, it is hard to make them or force them to make timely decisions. Nevertheless, some measures can be taken to prevent or minimise the issues as much as possible.

Currently, one of the biggest issues is that the period for decision-making is usually not officially specified. The discussions are informal and the client is asked to make a decision about something. However, by not giving them a strict deadline to do so, they tend to take more time than needed, which automatically affects the project timeline. Therefore, it is advised that before the project starts, there should be clear working agreements between the client and the consultant, where specific timeframes are given for making decisions. For instance, it could be written down that an answer should be provided within two weeks of the request for technical questions. Also, the consequences need to be defined in case both parties do not meet their obligations.

On the other hand, there is a risk of becoming too formal with your client because then people start focusing too much on the reporting and documentation and whether everything was done as described in the working agreement. In such cases, both sides start pointing their fingers at the other one, and the project could be delayed heavily due to the focus on the documentation process and not so much on the work. Therefore, a balance between formal and informal communication needs to be found.

To do so, both parties need to focus on excellent communication. In this way, the consultants could properly inform the client what the consequences of the project's performance would be in case of slow decision-making. Organise workshops and meetings in which the impact of slow decision-making is properly explained to the client and presented with the help of visual tools such as Power Bi. Visualizations are effective tools for enhancing comprehension and exerting a positive influence on individuals. They have been shown to improve both the quality and speed of decision-making, although their effects on other variables, such as decision confidence, are more variable. Additionally, visualizations can enhance the efficiency of marketing managers, provide new insights, and contribute to increased customer satisfaction and loyalty (Lurie & Mason, 2007; Eberhard, 2021).

In some cases, the clients are not technically capable of making decisions. In such situations, the consultants must explain all possible decisions and scenarios carefully, educate the client and provide

their services accordingly. From the interviews, it became clear that Sweco managers usually provide a working hypothesis when a decision needs to be made. This means that they suggest different scenarios to the client and already have a preference for one of them. Explaining the different options and why one is better based on analyses makes it easier for the client to make a decision. This is a good practice and Sweco consultants should continue to employ it.

The focus needs to be on collaboration, openness and transparency. Both the client and the design team need to have the same objective and sit on the same side of the table. To do so, the scope needs to be clear from the beginning of the project, which, as explained in Chapter 5.1., can be done by using a Work Breakdown Structure (WBS). There must be clear working and communication agreements, which specify the time available for decision-making, roles and responsibilities, and the means of communication that will be used. This would guarantee the common goals and, most likely, the timely decisions of the client.

Finally, Sweco can keep track of the decision-making process of all their projects and record the results, which were explained in the previous "measurability" chapter. In this way, it can be noticed for what kind of decisions the clients usually take more time and procrastinate, and be more cautious in advance.

There is a large number of change requests or requirements fluctuations within the project/ Scope creep

In Chapter 5.1. it was explained that overall, Sweco is handling changes very well by first categorising the changes as "nice to have" or "need to have". Then, the impact on the planning, budget, and scope is checked, and if everyone agrees, the change is adopted, and work starts. All that is included in a Scope Change Log. Additionally, Sweco uses visualisation tools to keep track of the changes and their progress. These practices are affecting the project in a positive way, and Sweco should continue using them. However, there is still room for improvement.

Normally, in the contracts, there is a change procedure in case the client asks for changes, which leads to extra work. This includes proposal, discussion, revisions, approval, and then the work starts. However, this procedure never takes into consideration the time pressure of the project and usually, the consultants do not have the required additional time for the process itself. Therefore, the first suggestion for improvement is to start including in the contracts the time required for the process itself, which assesses the requested changes. Otherwise, every change will continue contributing to additional scope creep.

Another problem is that the contract is looking only into additional work. However, changes have an impact on previous work as well and sometimes lead to rework, and this is not considered at all. The consultants need additional time for the initial planning when rework takes place. Unfortunately, the clients are not always willing to give that time even though they requested the changes. Therefore, the second important suggestion is to include points (clauses) in the contracts dealing specifically with the rework of previous deliverables, which was caused by the change requests because they require additional time.

Another suggestion for improvement would be the use of simulation tools such as BIM (Building Information Modelling) and VR (Virtual Reality) during the process. The changes could be visualised first in a digital model, and with the help of VR, both the client and consultants could make more informed decisions. This could prevent the implication of unnecessary changes and predict whether rework will occur, which would potentially save much time. However, the process of creating and

updating the virtual model and the use of VR should be taken into consideration because it takes additional time.

Finally, AI (Artificial Intelligence) could also be added to the equation. By giving a list of the changes and implementing them in the simulation, the AI could possibly forecast the potential impact of the change requests on the project with greater accuracy and consuming much less time than the current practices. This would compensate for the additional required time to create the computer-based models, and adjustments could be made easier if further requests come. The last thing to be noted is that the employees must be trained to make use of the AI functionality.

Unclear scope definition, including poor definition of scale, goals, tasks, assumptions, etc.

In principle, as it was mentioned before, in order to have a clear scope definition, there must be as highly detailed WBS as possible given the early phase of the project. This would mean that the project is split into smaller working packages until it reaches a level of detail which cannot or is not required to be split further into smaller packages. To do so, the client and all involved stakeholders need to be considered and brainstorming sessions need to be organized where all questions can be addressed. In this way, the project goals, deliverables, and assumptions can be clearly defined, which is a requirement for completing the WBS.

There are useful brainstorming software such as XMind which help in creating mind maps. It is a good way of visualizing the ideas and sharing them with other project participants.

Another suggestion would be to develop a standardized template for scope definition. The idea is to use previous projects and based on them to determine all of the possible aspects of the project. Then, this template can be used in every future project. The experts need to go through every category and fill it in if they decide it is relevant to the current project. This would minimize the chances of forgetting or overlooking some of the project's aspects and will make sure everything is documented. Additionally, as the construction industry is evolving, any new points that arise from projects need to be added to the standardized template and, in this way, keep it up to date.

This warning indicator can also make use of AI. When the client provides the requirements for the project, the AI could automatically generate the WBS based on a preset template such as the one explained above. This could immediately indicate any gaps, inconsistencies, and potential risks in the scope definition. This would save much time for the consultants, and it could also be used as a validation tool for the WBS they create. For example, the employees can create the WBS on their own and then compare it to the one created using AI. Any major differences could be addressed and acted upon from the earliest stages of the project.

The process from requirements to WBS could go the other way around as well. When there is complete WBS, AI could read it and suggest a contract which would cover all of the requirements set in the WBS. This would ensure the consistency of the documents and common agreements.

Finally, as it was explained in Chapter 5.1. about the measurability, the key stakeholders could be invited to complete a survey in which they can rate the clarity of each aspect on a scale and document the results. Analysing the scores and fixing unclarities early on would reduce the likelihood of having a large number of revisions and other difficulties that would have a negative effect on the project's long-term success.

The project is experiencing a high level of engineering/ design/ specification errors

The main causes of engineering/design errors are unclear scope, which would lead to a mismatch between the expectations of the client and the consultants, or not having the correct people for this project. For instance, the project team does not have the required expertise.

The seniors/the project leaders should be in continuous contact with the client to manage the expectations. When the day comes to submit the design of the final product, it should not come as a surprise to the client; they must have seen it multiple times before that and have a good impression of what is going on. In this way, the expectations can be managed and kept on the same page.

In the current situation, there is an internal quality check, which means that before submitting the design to the client, it must be checked by the senior manager and approved. This is a good practice which minimises mistakes in the final product and Sweco should continue to use it. This process can be improved further once again with the help of AI tools which can analyse design documents and specifications to identify potential errors, conflicts, or areas that do not meet regulatory standards. These tools can provide suggestions for improvements based on historical data and best practices.

The management of Sweco should look at the project and make an estimated judgement of what are the main objectives and the demands, the complexity, the risk profile, etc. Then, ask one of the most important questions: "*Do I have the right people to start the project*?". One issue is that management looks at the available people. In reality, projects are taken over without actually having the right expertise and this causes many issues later. Instead, managers need to look for the right people, the appropriate ones, before the project starts. And in case the best people for the specific project are not available which happens, then the next most suitable people need to be taken.

However, another problem that arises within the Sweco organisation is the lack of coaching between the seniors and the juniors. The connection is loose. The most important recommendation in this case is that the initial best people, with the most relevant experience and knowledge should be coaching the other ones. Usually, this is not the case. There is no vast exchange of knowledge and skills. This is somehow a bit of a disadvantage of the Sweco model – a decentralised model with autonomous teams. The team manager usually looks at, for example, the 10 people around them and tries to start the project with those ones. At the same time, in another team there might be someone else who is more skilled and better suited for the project. Therefore, it would be very beneficial for the organisation if they start exchanging people within different teams and divisions.

Quality of the reports, preliminary plans, and documentation is unsatisfactory

In Chapter 5.1. it was explained that the employees use systems engineering and WBS where the demands of the product/report are put, and in this way, it can be verified whether or not the document meets the requirements, which should be defined before that. The current practice says that someone needs to check/proofread the report and assess whether it meets the demands, if they agree with the information/conclusions presented, whether the right data is used, etc. Then, in case there are any flaws, remarks are made and returned for improvement. In the end, the project leader/manager usually has to check whether the "check" was done and all remarks were addressed sufficiently. It is recommended that Sweco continues employing this practice for their projects.

One suggestion for improvement in the quality of the reports is the implementation of advanced documentation software for technical reports, such as LaTeX, which allows for high-quality layout and complicated formatting. This would make the document look more professional, consistent and easier to follow.

Another suggestion is to develop and implement consistent templates for all reports, plans, and documents. These templates should include all relevant elements defined based on the company's needs and follow a uniform structure to ensure clarity and completeness. In this way, the clients would have similar expectations of the quality of the report and would be easier to comprehend the information.

Finally, similar to the previous indicators, AI could be utilised to improve the documentation quality substantially. Already, AI tools have become quite advanced in reading big documents and giving suggestions for improvement. Furthermore, a special system could be developed for Sweco's needs and requirements where "good" and "bad" examples are given to the AI based on which it can be trained to perform quality checks and even write information on its own. This would save much time and reduce the risk of formatting errors.

Consultants are making continuous attempts to redesign project and alter its scope.

In Chapter 5.1. it was explained that sometimes engineers overdesign something and deliver products that were not requested. This is due to the nature of engineering and everyone involved trying to improve on a product "too much" and deliver better quality than what was requested from the client. In principle, there is nothing wrong with proving product which is of best quality possible. However, this comes with higher costs and longer execution times which the client does not want to cover.

The use of a rather detailed WBS can help with that problem. It shows the working packages and what the client expects, the available budget and working time. When the amount of spent money on the design is compared to the made progress, the issues could be identified and controlled. The project manager needs to communicate this with the involved engineers and find out what is the reason. The earlier the problems are discovered, the easier is for the project manager to overwrite the engineers. They need to understand the importance of delivering the product that the client asked for. For this reason, regular meetings, workshops and trainings should be organised where everyone involved in the project would understand properly what needs to be done.

In the bigger and more complex projects, the project manager does not have the capacity to oversee everything. Therefore, after the WBS is made, the project manager should assign deputy manager, or design managers for separate working packages who need to be responsible of their branch of the "tree" and report back to the manager. Very importantly, these sub-managers need to be trained by the senior manager, because they are their right and left hand and work on behalf of them.

In case the communication, explanation, training and supervision does not deliver the required results and engineers continue to overdesign and deliver products which were not requested, then, incentive/penalty system could be introduced. This system would reward consultants and team members for adhering to the defined project scope and requirements, and minimizing unnecessary changes. Opposed to that, penalties would be introduced for making unapproved and unnecessary changes to the project scope. This could include financial penalties or other consequences, discouraging unnecessary alterations. Nevertheless, there should be a balance between the incentives and the penalties.

Overall, this indicator is closely related to the previous "unclear scope definition" and "high number of change requests". The proposed measures could be applied to all of them because the signals are interconnected.

6.1. Evaluation of the Results

The evaluation of the recommendations serves numerous important functions within the context of improving construction management practices. Primarily, it aims to assess the effectiveness of the proposed strategies for managing Early Warning Signals (EWS). Furthermore, the evaluation aims to confirm the suggestions' application to the unique organizational environment. This approach guarantees that the strategies can be effortlessly incorporated into current workflows, as well as ensuring project teams have access to and use the relevant resources and technology successfully. By doing so, it confirms the practicality and relevance of the recommendations in real-world settings.

Another essential aspect of the evaluation is identifying any obstacles or bottlenecks that could arise during the implementation phase. Recognizing these challenges is essential for understanding potential limitations and areas where additional support or modifications might be required. This understanding is critical for resolving difficulties proactively and facilitating easier implementation procedures.

In order to execute the evaluation, two project controllers from the company which were not involved in the previous exploratory interviews were selected. The participants have been involved in complex projects previously and could provide with valuable insights and feedback on the applicability and potential implementation challenges because of their crucial role as project controllers which seek to steer on any aspect of the projects in terms of performance.

6.2. Expert Feedback

During the session, the recommendations related to the six Early Warning Signals were presented to the experts and as general feedback, they agreed with most of them and the need to implement them in the processes. However, there were some challenges identified and this will be the focus of this chapter. Each indicator will be discussed separately with the specific comments attached to them.

Time for Decision Making/Client Makes Slow Decisions

The experts agreed that establishing clear working agreements specifying decision-making timeframes would be beneficial and the need for a balance between formal and informal communication to avoid excessive bureaucracy. The suggestion to use visual tools like Power BI for better client understanding and decision-making was well-received, though the experts noted that various tools are used, and it might be better not to specify a single tool.

The idea of recording past project data for decision-making processes was deemed theoretically sound but practically challenging due to the lack of a structured system for data recording and monitoring. There should be a system in place which makes sure that the project involved people are indeed taking those measures and recording them somewhere. It needs to be specified how the data should be stored and who has access to it because currently there is no such thing within Sweco.

Large Number of Change Requests/Scope Creep

The experts found all of the recommendations practical and beneficial. Only one note was made about the use of simulation tools and the AI to explain in more detail how AI contributes further in the use of visualisation tools such as BIM and VR and to make clear distinction between them. Also, AI needs to be trained very well specifically for the Sweco projects. The experts also highlighted that capacity constraints could cause delays when implementing changes, suggesting the need for better resource management.

Unclear scope definition, including poor definition of scale, goals, tasks, assumptions, etc.

The experts acknowledged the importance of a detailed Work Breakdown Structure (WBS) and standardized templates for scope definition. However, the templates would not provide with the same set of answers because all projects are different but it could give you a supportive list of questions to be asked. They stressed the significance of capturing all project requirements accurately to ensure clear scope definition. The use of AI for generating and validating WBS was appreciated, but it was noted that practical implementation would require significant investment and training. The idea of conducting surveys with stakeholders to assess the clarity of scope definition was also supported.

The project is experiencing a high level of engineering/ design/ specification errors

The experts appreciated the recommendations for continuous client communication, internal quality checks, and ensuring proper expertise and knowledge exchange. They noted that many errors result from changing assumptions during the project and the need for comprehensive systems to track and manage these changes. They also highlighted the importance of implementing systems engineering to improve the verification and validation of reports. Once again, the experts emphasized that while AI could be beneficial, its implementation would require substantial investment and training that needs to be taken into account.

Quality of Reports, Preliminary Plans, and Documentation is unsatisfactory

The experts agreed on the importance of using advanced documentation software and consistent templates to ensure high-quality reports. However, they pointed out that the primary issue with report quality often lies in the content rather than the layout. Training was identified as a crucial factor to ensure proper use of templates and improve report quality because Sweco has documentation software but people are not using it correctly. Therefore, investing in training the employees to use the software properly would be beneficial. They suggested that the current software for templates is good enough and there is no need for tools such as LaTeX which was proposed. Incorporating AI within the template software would be relatively easy and very beneficial. The experts also suggested that defining what constitutes a "poor quality" report would help tailor the recommendations more effectively.

Consultants Making Continuous Attempts to Redesign Project and Alter Scope

The experts noted that detailed WBS and budget tracking are already practiced within the company which was also mentioned in the recommendations chapter and Sweco should continue to employ these methods. They agreed that assigning multiple design managers for separate working packages for complex projects would help ensure adherence to project scope. However, they raised concerns about the feasibility of implementing an incentive or penalty system, suggesting it could create more problems than it solves and might not fit the company's trust-based model. It is also very difficult to pinpoint whose fault it was in order to penalise someone, therefore, this recommendation would not be fit for Sweco’s model and culture. They emphasized the need for regular communication and training to align engineers' expectations with project requirements.

6.3. Conclusion

This chapter provided strategic recommendations for the effective management of Early Warning Signals (EWS). These EWS, which critically influence project schedules during the design phase, include slow client decision-making, numerous change requests leading to scope creep, unclear scope definition, high levels of engineering/design/specification errors, unsatisfactory quality of reports and documentation, and consultants' continuous attempts to redesign projects.

The analysis finds that, while certain EWS are not currently monitored, they may be made quantifiable by implementing particular methodologies. For example, by tracking decision-making timeframes and carefully documenting modification requests, delays may be identified and their implications assessed. Similarly, using Work Breakdown Structures (WBS) and standardized templates may help to precisely define project scopes and track variances.

The study further recommends leveraging advanced technologies such as Artificial Intelligence (AI), Building Information Modeling (BIM), and Virtual Reality (VR) to enhance the accuracy of measurements and improve decision-making processes. These tools can predict the impacts of changes, identify potential design errors, and ensure consistent documentation quality.

The evaluation section provided an in-depth review of the proposed recommendations for managing Early Warning Signals (EWS) to mitigate schedule delays in the design phase of projects. The feedback from the company experts highlighted both the practical applicability and potential challenges of implementing these recommendations. The evaluation was in line with the expectations and does not impose many changes to the current suggestions as the experts agreed with most of them.

They emphasized the importance of clear communication, proper training, and systematic approaches to managing project changes and scope definitions. While the potential benefits of AI and advanced tools were acknowledged, practical implementation would require significant investment and cultural adjustments within the company. Nevertheless, the potential benefits are expected to outweigh the additional resources that need to be allocated. Overall, the meeting provided valuable insights that helps to refine the recommendations and address potential barriers to their successful implementation. Below, it is presented a summary of the proposed measures for each Early Warning Signal based on data gathered from the interviews and author's own suggestions.

Time for Decision Making/Client Makes Slow Decisions

1. Establish Clear Working Agreements: Specify decision-making timeframes in initial agreements.
2. Balance Formal and Informal Communication: Find a middle ground to avoid excessive focus on the documentation process.
3. Enhance Communication and Collaboration: Use workshops, meetings, and visual tools (e.g., Power BI) to explain the impact of delays.
4. Provide Decision-Making Scenarios: Offer multiple scenarios and preferred options to clients for easier decision-making.
5. Record data of all past projects: Keep log of the measurable data related to the decision-making process and identify the most likely points in time where clients struggle to make on-time decisions.

Large Number of Change Requests/Scope Creep

1. Include Time for Change Process in Contracts: Allocate specific time for assessing requested changes within contracts.
2. Address Rework in Contracts: Include clauses for rework caused by change requests.
3. Utilize Simulation Tools: Implement BIM and VR for visualizing changes and their impacts.
4. Leverage AI for Forecasting: Use AI to predict the impact of change requests and streamline adjustments.
5. Train the personnel: Organise workshops where employees will be trained to make use of visual tools and AI properly.

Unclear Scope Definition

1. Develop a WBS: Create a Work Breakdown Structure with client and stakeholder input.
2. Standardize Scope Definition Templates: Use templates based on previous projects to ensure all aspects are covered.
3. Use AI for WBS Generation and Validation: Employ AI to automatically generate and validate the WBS against a preset template.
4. Use AI for the set of requirements and contracts: Use a completed WBS to create the contract for the project and ensure their consistency and agreement.
5. Conduct a Survey: The key stakeholders could complete a survey in which they can rate the clarity of each aspect on a scale and document the results.

High Level of Engineering/Design/Specification Errors

1. Continuous Client Communication: Keep clients informed and aligned with project progress and expectations.
2. Internal Quality Checks: Continue senior manager approvals before submitting designs to clients.
3. AI Tools for Error Analysis: Use AI to analyze design documents and identify potential errors or areas for improvement.
4. Ensure Appropriate Expertise: Match project requirements with the right expertise and promote knowledge exchange within teams.

Quality of Reports, Preliminary Plans, and Documentation is unsatisfactory

1. AI for Documentation Quality: Train AI systems to perform quality checks and provide improvement suggestions.
2. Conduct a Survey: Monitor client satisfaction by employing a survey and asking them to assign points/scores to different sections or categories of the report.

Consultants Making Continuous Attempts to Redesign Project and Alter Scope

1. Detailed WBS and Budget Tracking: Use WBS to compare spent money against progress to identify overdesign tendencies.
2. Regular Communication and Training: Organize meetings, workshops, and trainings to align engineers with project requirements.
3. Assign Design Managers: Appoint sub-managers to oversee specific work packages and report back to the project manager.

Effective management of these EWS requires the development of explicit working agreements, a balanced approach to formal and informal communication, and continual client involvement. To improve project outcomes, workers must be trained in the use of these sophisticated technologies, as well as develop a culture of information exchange among teams.

Implementing these advice will allow businesses to better manage early warning signals, minimize related risks, and greatly enhance the overall performance and success of their projects. This strategic approach will help to promote more proactive and informed management practices, resulting in improved project delivery and customer satisfaction.

7. Discussion and Limitations of the Research

In this chapter, first, the scientific implications of the research are discussed. Then, the practical value of the thesis is presented and finally, the limitations regarding the research is discussed.

7.1. Scientific Implications

This research contributes to the field of project management in the construction industry by providing a detailed exploration of Early Warning Signals (EWS) within the context of infrastructure projects, specifically during the design phase because current literature has been giving little attention to the front-end stage of projects. By focusing on the identification, measurability and management of EWS, this study adds to the growing body of knowledge that seeks to improve project outcomes through proactive management strategies.

The study explored the signals identified by some of the most influential researchers in the field of Early Warning Signals, including Ansoff (1975), Haji-Kazemi et al. (2013), Nikander and Eloranta (2001), Williams et al. (2012), etc. and refined them further by conducting expert interviews which provided a list of signals relevant in practice. In this way, the gap between theory and practice has been minimised, and strategies for handling those signals in reality have been proposed.

Furthermore, the literature has not explored the topic of the measurability of the signals and their specific importance for management. This study provides an explanation of how to measure the early warning signals and offers a prioritised list indicating the most important and relevant signals based on insight gathered from industry experts. After that, concrete recommendations for acting upon the warning indicators are given, contributing further to the existing information in the literature.

The findings of this research underscore the importance of both formal and informal methods in the identification of EWS. While structured assessments and technical analyses provide a solid foundation for EWS identification, informal methods such as intuition and organizational culture play a crucial role in capturing signals that may be overlooked by formal processes. This dual approach ensures a comprehensive detection mechanism, enhancing the predictive capabilities of project management teams.

Finally, the study emphasizes the potential of advanced technologies such as Artificial Intelligence (AI) and visualization tools in improving the management and handling of EWS. The practical implications of these technologies, as discussed by the experts during evaluation, highlight their relevance in enhancing project management practices.

7.2. Practical Implications

From a practical standpoint, this research provides actionable recommendations for project managers and organizations (consultancy companies) involved in infrastructure projects. The detailed exploration of specific EWS and the strategies for their management offer practical insights that can be directly applied to improve project outcomes. The recommendations include establishing clear working agreements, balancing formal and informal communication, ensuring appropriate expertise, and the use of advanced documentation software and AI tools for quality checks and error analysis.

The study also highlights the importance of regular training and communication to align the expectations of engineers with project requirements. This is particularly relevant in preventing overdesign and unnecessary alterations, which can lead to schedule delays and increased costs. The suggestion to appoint design managers for specific work packages and to develop a supportive list of

questions for scope definition further reinforces the need for structured and systematic project management practices.

The feedback from industry experts provides valuable insights into the practical challenges of implementing the recommended strategies. Issues such as capacity constraints, the feasibility of incentive and penalty systems, and the need for a cultural shift towards proactive management are critical considerations that organizations must address to manage EWS and enhance project performance effectively.

The study found that most participants had heard of EWS and had a general understanding of the concept and its rationale. However, they are not explicitly using or considering EWS in their practices. They lack knowledge on how to apply and recognize these signals effectively. None of the participants had allocated specific time for the identification of EWS and the appropriate responses to them.

An interactive way to represent this reaction is by using the theory of Maslow about the learning cycles. The model illustrates how people learn and the phases they go through in order to achieve a certain competency. Maslow's cycle represents four different stages, namely: Stage 1: Unconscious incompetence, Stage 2: Conscious Incompetence, Stage 3: Conscious Competence and Stage 4: Unconscious Competence. In the beginning, people are ignorant of their lack of knowledge or abilities. To go on to the next step, they must realise that they have a knowledge or skill gap. In the second stage, people become conscious of their own lack of knowledge or abilities, but they have yet to master the desired behaviour or ability. In the third stage, participants have acquired the essential abilities or knowledge, but they must continue to focus on their application. In the last level, the skill or action becomes second nature, and they can execute it without conscious effort or attention (Harianto, 2021; Garcia, 2023).

The cycle is illustrated in Figure 13. Currently, the author believes that most of the interview participants are in the second stage and some of them are in the transition between the second and third phases (learning). They need to consciously start applying the indicators that will be given at the end of this chapter in order to make the transition towards stage 3 of the learning cycle.

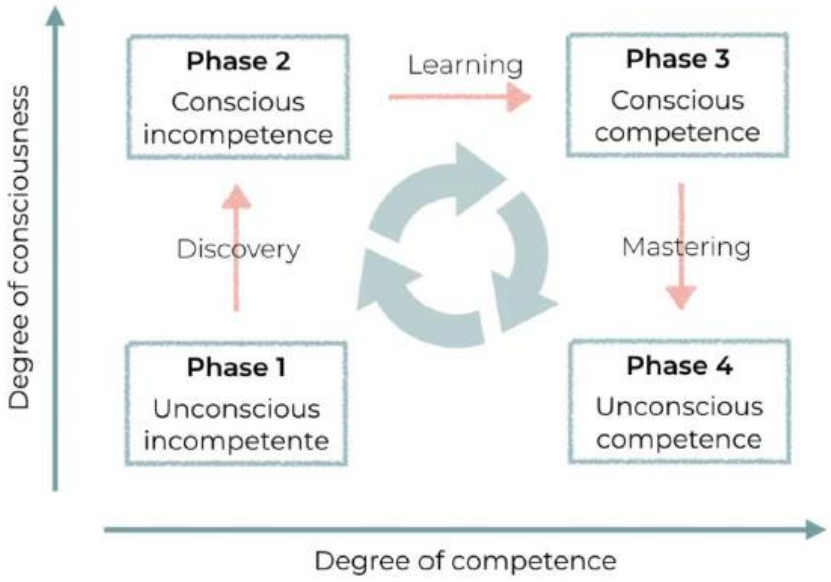

Figure 13. Learning Phases of Maslow (retrieved from De Groot (2021))

This cycle could be linked to the three distinct filters that were identified in Chapter 3, section 4 (Ansoff & McDonnell, 2019). These are surveillance filter, mentality filter and power filter. The surveillance filter processes the data that enters the company, and its properties are decided by the firm's forecasting/analysis procedures. The mentality filter, which is based on managers' mental success models, selects relevant information. The power structure applies a third filter to data. The power filter refers to the decision-making process that determines what information may be used to influence project decisions. If powerful managers lack the right mindset, they may prevent critical signals from affecting choices, resulting in procrastination.

The business model and structure of the consultancy company has numerous levels of acceptance and decision-making which might block the innovations such as the usage and reaction to EWS. The problem with the adoption of this proactive approach lays between the mentality and the power filter. In order to overcome this issue, there must be a change on a very high level where powerful people should understand the need for the adoption of more innovative solutions/methods because the construction industry it lacking that a lot.

As a whole, the research contributes significantly to the practice. In particular, the prioritisation list of all Early Warning Signals identified both from literature and practice, the suggestions given on how to measure the indicators and what data is required, and the final recommendations on how to act upon the Early Warning Signals would help project managers and controllers to make more timely and informed decisions in order to influence the schedule performance of the projects positively.

7.3. Limitations of the Research

Despite the comprehensive approach and significant findings, this research has several limitations. Firstly, the focus on a specific company, Sweco, and its projects may limit the generalizability of the findings to other organizations, departments or cultures. The study is based on data collected from infrastructure projects within the Netherlands; therefore, the cultural and regulatory differences in project management practices across different regions could affect the applicability of the identified leading indicators. While the insights gained are valuable, they are contextual and may require adaptation to fit different organizational environments or project types.

Secondly, the implementation of advanced technologies such as AI and visualization tools, although promising, requires substantial investment and training. The study acknowledges this but does not provide a detailed cost-benefit analysis, which is essential for organizations considering such investments. Moreover, due to the developing and early stage of AI which is starting to be implemented more and more in our lives, there is not enough proof and evidence of the suggested benefits. Future research could explore the application, economic feasibility and long-term benefits of these technologies in more detail because this thesis does not investigate this issue.

Thirdly, it is unknown what the exact impact on schedule performance of the implementation and use of the proposed EWS and recommendations would be. This is mainly due to the impossibility of following a project from the beginning until the end. Also, the rapid evolution of technology and project management practices means that the identified indicators and recommendations may need continuous updates and adjustments to remain relevant. Moreover, the study explores only six (top three from practice and top three from theory) of the 25 identified indicators which leaves the possibility of having another indicator that is more important than the ones examined.

Lastly, the expert opinions and interviews, while providing deep insights, also introduces a degree of subjectivity. The personal experiences and perspectives of the experts may influence the findings, and there is a risk of bias. To avoid this as much as possible, there were minimal requirements related to

the years of experience, department, position, etc. Also, every participant received the same batch of questions in the same order and had the same time to answer them.

In conclusion, this research makes a significant contribution to the understanding and management of EWS in infrastructure projects. The practical recommendations and scientific insights provided are valuable for improving project outcomes. However, the limitations identified highlight the need for further research to validate and extend these findings across different contexts and to explore the economic feasibility of the recommended strategies.

8. Conclusion and Recommendations

This research undertook a comprehensive examination of Early Warning Signals (EWS) and their potential to mitigate schedule delays during the design phase of infrastructure projects. Utilizing a dual approach of literature review and exploratory interviews with experts from Sweco, the study aimed to identify, prioritize, measure and propose actionable strategies for managing EWS.

8.1. Answering the research questions and giving recommendations

The findings reveal that while project managers and controllers at Sweco possess a basic understanding of EWS, their practical application is inconsistent and largely unstructured. Most professionals rely on intuition and experience rather than systematic processes to identify and react to EWS. This reliance on subjective judgment highlights a critical gap in the formal integration of EWS into project management practices. The central research question guiding this study was: ***How are Early Warning Signals (EWS) related to the control and reduction of schedule delays in the delivery of the design phase of Dutch Infrastructural projects?*** To answer this overarching question, five sub-questions were addressed. This section provides an overview of how each sub-question was answered and synthesizes the findings to draw overall conclusions.

> *SQ1: What Early Warning Signals are identified in the literature, what are the identification approaches, and what are the limitations associated with them?*

To answer this question, an extensive literature review was conducted including the most influential and informative papers written on the topic of warning indicators. This includes Ansoff (1975), Haji-Kazemi et al. (2013), Nikander and Eloranta (2001), Williams et al. (2012), Safapour et al. (2019) etc. and three master theses of students, including Stolk (2022), Singh (2023) and Wijtenburg (2018). These studies collectively identified a set of 51 indicators pertinent to the design phase which can be seen in Table 7. Notably, the most frequently recognized indicators are related to unclear scope definition, poor management, ineffective communication, and design errors.

The analysis also highlighted the importance of formal and informal EW identification methods. Formal methods include structured assessments like stakeholder analysis, risk assessment, and technical analysis, supported by documentation and checklists. Informal methods, or "gut-feeling" approaches, rely on intuition, communication, and organizational culture, capturing signals that formal methods might overlook. This dual approach ensures a comprehensive detection of EWs. As a result, a total of 15 identification methods were discovered and presented.

Finally, limitations to effective EW response were discussed, as elaborated by Ansoff and McDonnell (2019), who identified surveillance, mentality, and power filters as potential barriers. In total, this research identified 11 barriers to responding to EWS. The whole list can be seen in Table 10.

To summarise, the literature review identified 51 distinct warning indicators such as delays in the decision making process, high turnover rate of people, scope creep, etc. The identification approaches can be classified as formal which includes assessments such as stakeholder analysis, risk analysis, and technical evaluations and informal which are more subjective and rely on intuition. For instance, a project manager might notice that team members are consistently vague or hesitant during meetings, which could be a signal of deeper issues. Finally, 11 barriers were identified as part of the three filters. Example of some barriers are over-optimism, effects of politics, fragmentation, project complexity, etc.

SQ2: What Early Warning Signals are identified in practice by the managers of Dutch Infrastructure Projects, and how do they act upon them?

This question aims to identify the relevant warning indicators in practice and explore how the current management is acting upon them.

In total, eight industry experts took part in the exploratory interviews with an average experience of 21.1 years. As a result, the participants identified 22 distinct signals. Table 12 presents the whole list of signals with the frequency of identification of each one. For instance, the warning indicator "Scope creep" was identified by all of the experts, whereas the warning indicator "lack of detailed specifications in contracts" was identified by only one expert. Nevertheless, all signals were examined carefully because the lower frequency of identification might indicate the lack of knowledge about certain indicators by most of the interviewed experts.

Managers commonly identified signals such as delayed decision-making by clients, frequent change requests, unclear scope definitions, high turnover rate of people, poor organisation and communication and lack of experience. However, they reported that their awareness of EWS stemmed from gut feeling and vast experience rather than a structured identification process. There was a general consensus that while the concept of EWS was understood, its application was informal and inconsistent.

The main actions taken by the project managers include regular communication with team leaders and project designers, facilitating controlled interactions between employees to resolve differences or reallocating tasks to prevent future conflicts, regular meetings with clients and key stakeholders to discuss the impact of change requests, slow decision making and unclear requirements and finally, monitoring the ratio between spent money and made progress.

SQ3: Which of the Early Warning Signals have the highest influence on schedule delay from an expert's point of view?

To answer this question, first, the final list of warning signals is compiled by combining the results from the literature and practice. As explained above, the literature review resulted in 51 EWS, whereas the exploratory interviews delivered 22 EWS. By combining overlapping signs and integrating new signals discovered during the interviews that had not previously been addressed in the literature, the study produced an exhaustive set of 25 EWS relevant to the design phase of Dutch Infrastructure projects.

From an expert's perspective, certain EWS are more critical than others in terms of their impact on schedule delays. The research identifies the top three indicators identified from practice and the top three indicators identified from theory as having the highest influence. These are as follows:

- *Client Makes Slow Decisions*: This EWS is particularly impactful because delays in decision-making can halt project progress, affecting all subsequent tasks.
- *Scope Creep/High number of changes*: As projects progress, additional requirements or changes to the scope can emerge, often leading to significant delays.
- *Unclear Scope Definition*: An unclear or poorly defined project scope can lead to misunderstandings and rework, which are major contributors to schedule delays.
- *High Level of Engineering/Design Errors*: Errors in the design phase can have a cascading effect, leading to rework and delays in construction.
- *Poor Quality of Reports and Documentation*: Inaccurate or incomplete documentation can lead to confusion and errors during execution. This EWS is important because it often reflects deeper issues in project communication and management.

- *Consultants Making Continuous Attempts to Redesign the Project*: Frequent redesigns can disrupt the project flow and lead to delays.

SQ4: How can the Early Warning Signals be measured?

The six indicators that were selected are the “Client makes slow decisions”, “Scope creep”, “Unclear scope definition”, “High level of engineering/design/ specifications errors”, “Unsatisfactory quality of reports, plans and documentation”, and “Consultants are making continuous attempts to redesign the project”.

The interviews revealed that Sweco employees currently do not measure most of the mentioned warning signals. Below, a brief list with bullet points is provided with suggestions for measuring each indicator.

Time for decision making/ Client makes slow decisions

In order to measure the decision-making process, experts need to:

- Identify and document all significant decision points, also known as milestones, in the project plan.
- Establish baseline timelines: Determine the expected durations for each decision based on the project plan and client agreements. These baseline timings are the criterion against which real decision times will be compared.
- Monitor the process of making decisions: Implementing a system to track the time taken for each decision. There must be a description of the required decision, the date when the decision was formally requested, the date when the client provided their decision, and from there, the number of days/weeks it took the client to make the decision can be calculated.

A large number of change requests or requirements fluctuations within the project/ Scope creep

- As is already the norm at Sweco, the consultants must forecast the number of extra working hours a modification would need as well as its impact on the remaining portions of the project.
- The initial scope and scheduled work must be well documented. This will enable a more precise measurement of the number of extra working hours and a more accurate estimation of the impact of the modifications using the Work Breakdown Structure (WBS).
- Use visualisation tools (e.g. Power Bi) to monitor the change request data, such as the number of submitted changes, additional working hours, percentage of approved and rejected changes, and differences in project schedules before and after the implementation of change requests.

Unclear scope definition, including poor definition of scale, goals, tasks, assumptions, etc.

- Calculate how long it took to finish the WBS and compare it to appropriate time estimates that were previously established based on the budget class and project complexity. In this sense, the measurable unit for "unclear scope definition" may be the time needed to create the WBS.
- It is possible to evaluate if the scope is well defined before work begins by comparing the number of explicitly declared scope items to the total number of scope elements from the predetermined list before the project begins.
- Conduct surveys with key stakeholders and clients to rate the clarity of scope elements. Assessing the results and resolving ambiguities at the beginning could reduce the possibility of a high volume of modifications and other issues that might harm the project's long-term viability.

The project is experiencing a high level of engineering/ design/ specification errors

- Measure the number of errors made in engineering and design. From there, calculate the error rate (e.g., errors per working hours or submitted design pages) and compare it to predefined criteria. For example, it could be acceptable one mistake per 120 working hours.
- Measure the severity of the error by analysing the impact of it on the project in terms of time and required additional resources.
- Monitor the percentage and number of recurring errors internally to create a list of common mistakes.

The quality of the reports, preliminary plans, and documentation is unsatisfactory

- The quantity of remarks and observations made is one variable that can be measured to provide insight into the documentation's quality. But occasionally, the remarks are elementary and relate to anything like the colour that was chosen. It would thus only be fair to categorise the comments and count the number of remarks in each group.
- Define and measure the completion rate of reports and mandatory sections. For example, a report needs to cover 90% of the content before submission.
- Conduct client satisfaction surveys to assign scores to different report sections and identify common issues.

Consultants are making continuous attempts to redesign project and alter its scope.

- At the monthly progress meetings, compare the amount of money spent with the amount of work completed. To find disparities, keep an eye on how the design hours and the allocated hours line up. Large deviations may be a symptom of excessive design.

SQ5: How should the prioritised Early Warning Signals be handled by the management?

Once EWS have been identified and prioritized, management must develop strategies to address them effectively. The research suggests the following strategies presented in the form of bullet points:

Time for Decision Making/Client Makes Slow Decisions

- **Establish Clear Working Agreements**: Set clear decision-making timelines in initial contracts.
- **Balance Communication:** Maintain a balance between formal documentation and informal discussions to streamline processes.
- **Enhance Collaboration:** Use workshops, meetings, and visual tools to illustrate the impact of delays.
- **Record and Analyze Data**: Track decision-making data from past projects to identify patterns and improve future timelines.

Large Number of Change Requests/Scope Creep

- **Allocate Time for Changes:** Include specific timeframes for evaluating change requests in contracts.
- **Incorporate Rework Clauses:** Address rework due to changes in contracts.
- **Utilize Technology:** Implement tools like BIM, VR, and AI to visualize and forecast the impact of changes.
- **Train Personnel:** Ensure employees are proficient in using visual tools and AI through regular training.

Unclear Scope Definition

- **Develop Comprehensive Plans:** Create detailed Work Breakdown Structures (WBS) with stakeholder input and standardize templates.
- **Leverage AI:** Use AI to assist in generating, validating WBS, and ensuring consistency in contracts.
- **Conduct Stakeholder Surveys:** Gather feedback on scope clarity to improve project alignment.

High Level of Engineering/Design/Specification Errors

- **Maintain Client Communication:** Keep clients updated on progress and expectations.
- **Implement Quality Checks:** Continue internal approvals and use AI for design error analysis.
- **Ensure Expertise:** Align project requirements with appropriate expertise and encourage knowledge sharing.

Quality of Reports, Preliminary Plans, and Documentation is unsatisfactory

- **AI for Documentation Quality**: Train AI systems to perform quality checks and provide improvement suggestions. Sweco is currently using the documentation software Templify and it would be very helpful to incorporate AI into it.
- **Monitor Client Satisfaction:** Regularly survey clients to assess and improve report quality.

Consultants Making Continuous Attempts to Redesign Project and Alter Scope

- **Improve Communication and Training:** Hold regular meetings and training sessions to ensure alignment with project requirements.
- **Assign Design Managers**: Appoint sub-managers to oversee specific work packages and report back to the project manager.

Main Question: How are Early Warning Signals (EWS) related to the control and reduction of schedule delays in the delivery of the design phase of Dutch Infrastructural projects?

Early Warning Signals (EWS) are integral to controlling and reducing schedule delays during the design phase of Dutch infrastructural projects. These signals serve as proactive indicators that allow project managers to identify and mitigate potential risks before they escalate into significant problems, thus maintaining the project timeline.

EWS play a critical role in the early identification of potential delays. Signals such as unclear scope definitions, slow decision-making processes, and frequent design changes often indicate areas where delays may occur if not addressed promptly. By identifying these signals early in the project lifecycle, managers can take steps to address the underlying causes before they affect the overall schedule. For instance, if slow decision-making is flagged as an EWS, the project team can implement strategies such as setting clear deadlines and enhancing communication with stakeholders to expedite decisions and prevent delays.

The proactive management of risks is another key aspect of how EWS contribute to schedule control. Instead of reacting to problems as they arise, project managers can use EWS to anticipate issues and take preventive measures in advance. For example, if a high level of engineering errors is identified as a recurring issue, the project team can introduce more rigorous design reviews and quality checks, thereby reducing the likelihood of rework and subsequent delays.

EWS also enhance communication and decision-making processes within the project. By regularly monitoring these signals, such as a client's delay in decision-making or a high volume of change requests, project managers can ensure that critical decisions are made in a timely manner, reducing

the chances of bottlenecks that could disrupt the project timeline. Effective communication, facilitated by the insights gained from EWS, ensures that all stakeholders are aligned and that decisions are made with the project's schedule in mind.

Prioritization of actions based on EWS is another important factor in maintaining schedule control. Not all potential issues have the same impact on the project's timeline, and EWS help project managers determine which issues require immediate attention. By ranking EWS according to their severity and likelihood, resources can be allocated efficiently, focusing on resolving the most critical risks first. For instance, if scope creep is identified as a significant risk, stricter scope management practices can be implemented to prevent schedule overruns.

In conclusion, Early Warning Signals are directly related to the control and reduction of schedule delays in the delivery of the design phase of Dutch infrastructural projects. They provide early insights into potential risks, enable proactive management, enhance communication, prioritize critical actions, and improve the overall quality of project execution. By effectively utilizing EWS, project managers can maintain control over the project timeline, minimize delays, and ensure the successful and timely completion of the design phase.

8.2. Suggestions for future research

In this section, several suggestions for future research are given. Most of them stem from the limitations of this study. The recommendations are as follows:

- **Quantitative Validation of EWS Impact:** Future research should focus on quantitatively validating the impact of the identified EWS on project outcomes. This could involve collecting and analyzing data from multiple projects to assess the effectiveness of EWS management strategies statistically.
- **Implementation of AI and Advanced Tools:** Further studies could explore the practical implementation of AI and advanced visualization tools in project management. This includes evaluating the cost-benefit ratio, required training, and the long-term impact on project efficiency and outcomes.
- **Cross-Industry Comparison of EWS Practices:** Comparing EWS practices across different industries and countries could identify best practices and innovative approaches that could be adapted to infrastructure project management, enhancing the overall efficacy of EWS strategies.
- **Further Measurability Analysis of the Identified EWS:** Due to time constraints, this study could not delve deeper into the topic of measurability and all types of data that could be considered. Additionally, all 25 indicators can be examined.

8.3. Recommendations to Sweco

The successful management of infrastructure projects requires a proactive approach to identifying and mitigating risks, particularly during the critical design phase. Based on the research conducted, several key recommendations can be made to improve project outcomes at Sweco.

1. Strengthen Early Warning Signal (EWS) Implementation

Sweco should formalize the identification and use of Early Warning Signals across all projects. By systematically integrating EWS into the project management framework, Sweco can ensure that potential risks are identified and addressed before they escalate into significant issues.

- Establish EWS Protocols: Develop clear protocols for identifying and responding to EWS. These protocols should be embedded in the project management practices from the outset of each project, with specific guidelines on how to monitor and act on EWS.
- Training and Awareness: Conduct regular training sessions to ensure that all team members are aware of EWS and know how to recognize and report them. This training should emphasize both formal and informal identification methods, ensuring a comprehensive approach.
- Regular Monitoring: Implement a robust monitoring system that regularly tracks EWS throughout the project lifecycle. This system should include both automated tools and manual checks to ensure that no signals are overlooked.

2. Enhance Decision-Making Processes

The speed and quality of decision-making are crucial factors in preventing schedule delays. Sweco should focus on improving the decision-making process, particularly in terms of client interactions and internal approvals.

- Clear Decision-Making Frameworks: Establish clear frameworks that define decision-making roles, responsibilities, and timelines. This should be communicated clearly to all stakeholders at the beginning of the project to avoid delays caused by unclear responsibilities or slow approvals.
- Improve Client Communication: Strengthen communication channels with clients to ensure that decisions are made promptly. This could involve setting up regular decision-making checkpoints and using workshops or visual tools to demonstrate the impact of delays on the overall project timeline.
- Data-Driven Decisions: Use historical data from past projects to inform decision-making processes. By analyzing patterns in decision-making timelines and outcomes, Sweco can identify areas for improvement and implement strategies to expedite future decisions.

3. Refine Scope Management

Scope creep is a significant contributor to project delays. Sweco should implement more rigorous scope management practices to ensure that project scope is clearly defined and adhered to throughout the project.

- Change Management Processes: Strengthen change management processes to control scope changes. This includes allocating specific timeframes for evaluating change requests and incorporating rework clauses into contracts to manage the impact of scope changes.
- Use of Technology: Leverage tools like Building Information Modeling (BIM), Virtual Reality (VR), and Artificial Intelligence (AI) to visualize potential scope changes and their impacts. This

can help stakeholders understand the implications of changes and make more informed decisions.

4. Foster a Culture of Continuous Improvement

Finally, Sweco should foster a culture of continuous improvement by regularly reviewing project outcomes and incorporating lessons learned into future projects. This approach ensures that the company is always evolving and improving its project management practices.

- Post-Project Reviews: Conduct thorough post-project reviews to analyze what worked well and what could be improved. This should include an evaluation of how effectively EWS were used and how well the project adhered to its original schedule.
- Feedback Loops: Establish feedback loops where project teams can share their experiences and insights with others within the company. This can help spread best practices and avoid repeating mistakes across different projects.

By implementing these recommendations, Sweco can enhance its project management practices, reduce the likelihood of schedule delays, and improve overall project outcomes. The integration of EWS, improved decision-making processes, refined scope management, and the strategic use of technology will position Sweco to deliver successful projects that meet client expectations and adhere to timelines. Continuous improvement efforts will ensure that the company remains competitive and capable of handling the increasing complexity of modern infrastructure projects.

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Appendix A – Brainstorming

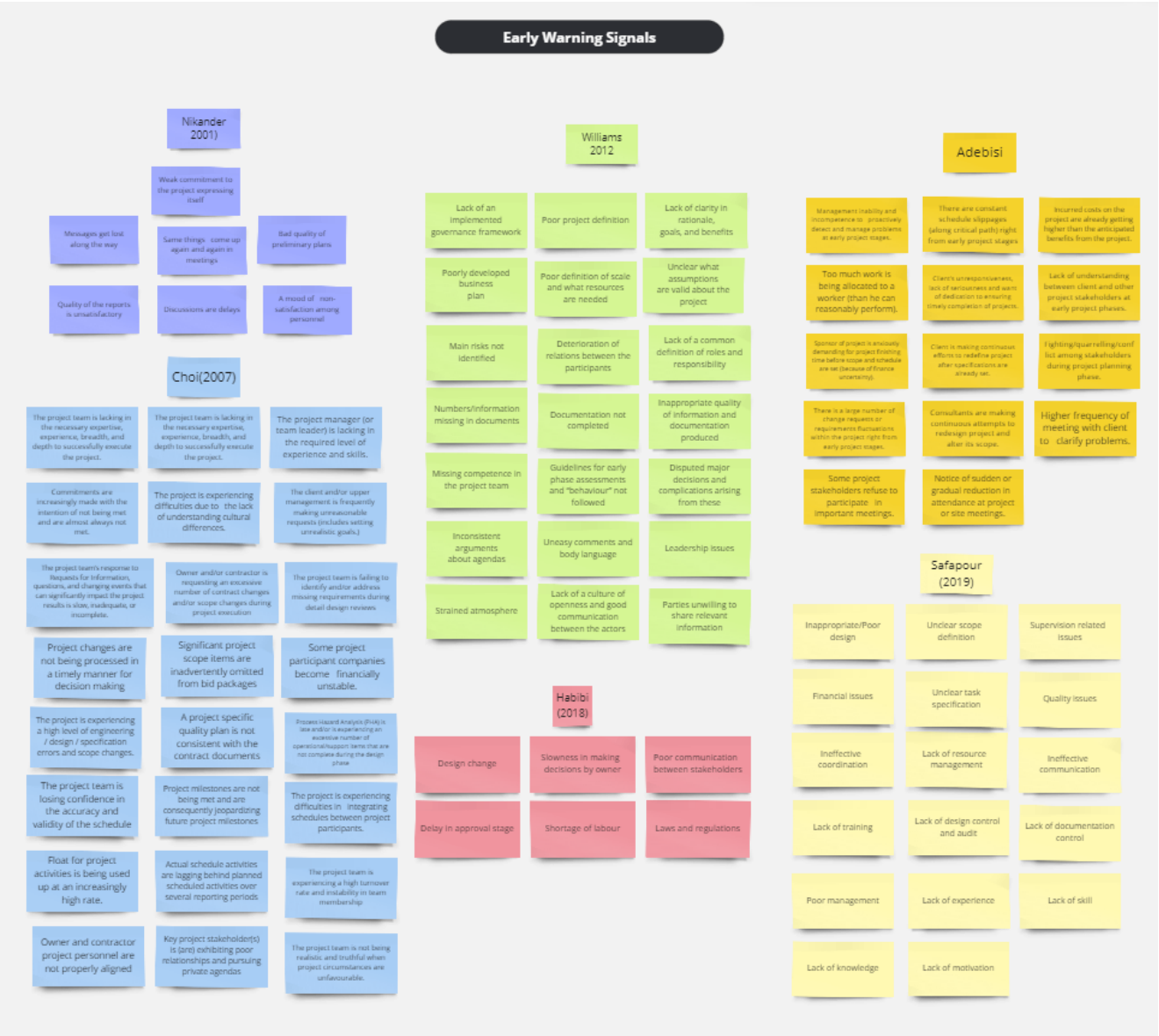

Figure 14. Visualisation of all Early Warning Signals from literature

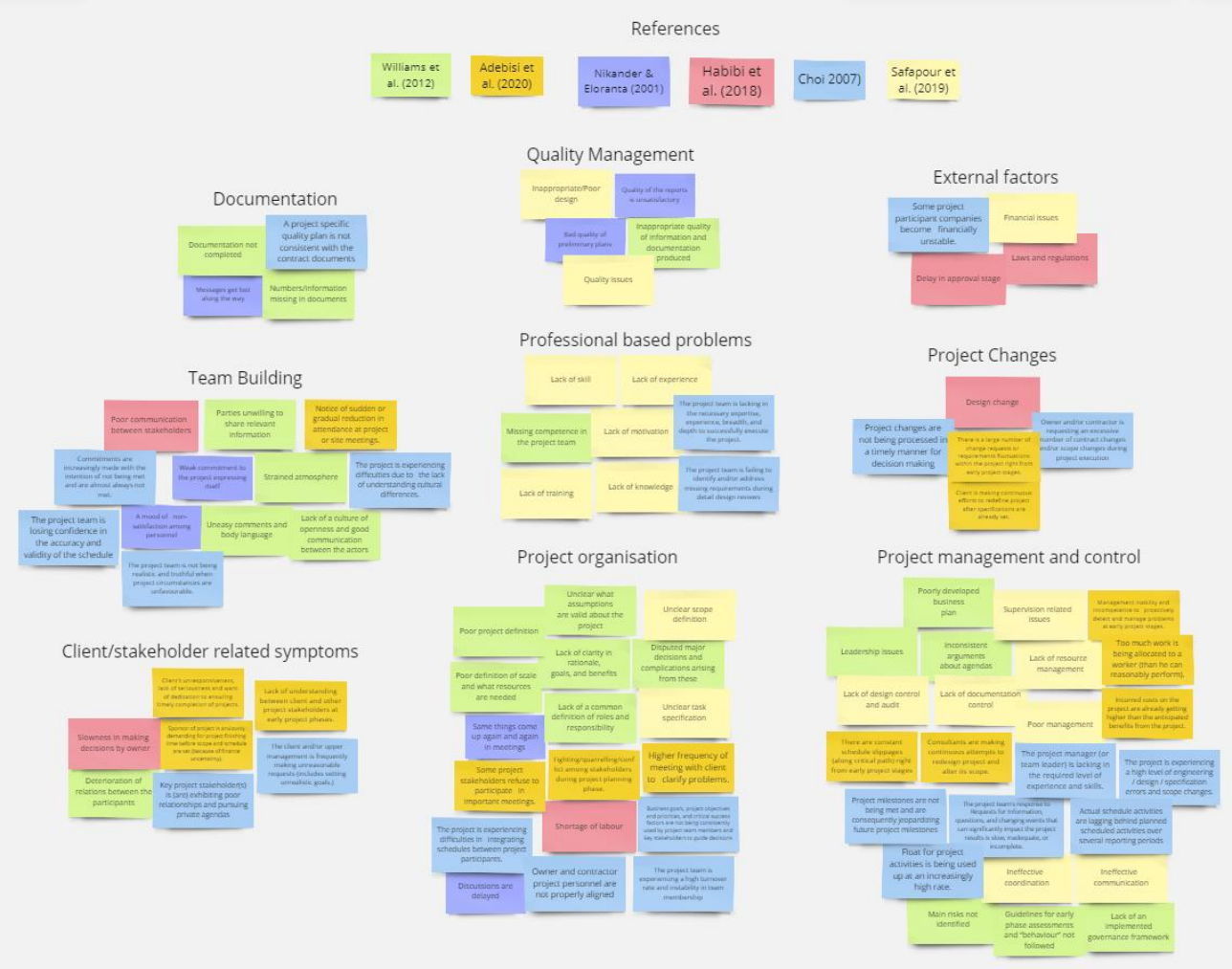

Figure 15. Classification of the Early Warning Signals

Appendix B – Interview Questions

The interview will start with general introduction to the topic and the problem. I will present myself and explain the purpose of the interview and the question that needs to be answered in the end. I will ask if I can record the answers of the respondents and explain how the data will be handled.

Do you understand what EWS are. Explain what is the definition and the purpose. Ask if they understand and if they have questions. Be on the same page.

What Early Warning Signals are identified in practice and how managers act upon them?

General Experience and Understanding of Early Warning Signals

1. Can you tell me about your role within the company and your experience with infrastructure projects?
2. What type of projects have you worked on?
3. Are you familiar with the concept of early warning signals in project management?
4. Have you encountered early warning signals in your projects before? Can you give some examples?
5. Which KPIs were applied to the projects you worked on?
6. Could you describe a situation where you were working on a project and the schedule went overboard?
7. What were the main factors that contributed to the delay?

Identification of Early Warning Signals

1. How do you monitor/measure schedule performance?
2. How does your team identify early warning signals during the design phase of infrastructure projects in terms of schedule performance?
3. What specific methods or tools do you use to detect these signals?
4. Could you provide examples of early warning signals that you have encountered in past projects?
5. How were these signals recognized, and who was involved in the identification process?

Actions Taken in Response to Early Warning Signals

1. What actions are typically taken when early warning signals are identified during the design phase? How did you and your team respond to the schedule overruns?
2. Who is responsible for responding to these signals, and how is accountability assigned?
3. Can you describe the decision-making process that follows the identification of an early warning signal?
4. How do you prioritize and determine the urgency of responding to different signals?

Reflection and Improvement

1. Have there been any notable lessons learned from previous projects in dealing with early warning signals?
2. What are the main challenges your team faces in effectively responding to early warning signals during the design phase?
3. Looking back on the project, is there anything you would have done differently to avoid or lessen the schedule overrun?
4. Do you think Project Managers should pay more attention to Early Warning Signals?

Appendix C – Scoring of the EWS found in literature

Category	№	Early Warning Signal	I1	I2	I3	I4	I5	I6	I7	I8		Score
Project Management and Control	1	Supervision related issues	3	1	3	3	3	1	1	1		16
	2	Lack of resource management	3	3	3	3	3	3	3	3		24
	3	Leadership issues	1	1	1	3	3	1	3	3		16
	4	Inconsistent arguments about agendas	0	3	3	1	0	1	1	3		12
	5	Too much work is being allocated to a worker	1	3	3	3	3	3	3	3		22
	6	Lack of design control and audit	3	1	3	3	3	0	1	0		14
	7	Poor management, inability to proactively detect problems at early stages, management is lacking required level of experience and skills	3	3	3	3	3	3	3	3		24
	8	Incurred costs on the project are already getting higher than the anticipated benefits from the project	3	3	1	3	3	3	3	1		20
	9	There are constant schedule slippages (along critical path) right from early project stages and milestones are not being met	3	3	3	3	1	3	3	3		22
	10	Consultants are making continuous attempts to redesign project and alter its scope.	3	3	3	1	3	3	3	0		19
	11	The project is experiencing a high level of engineering / design / specification errors and scope changes.	3	3	3	3	3	3	3	3		24
	12	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.	3	3	3	3	3	3	3	3		24
	13	Float for project activities is being used up at an increasingly high rate.	3	1	3	3	0	3	3	3		19
	14	Poor communication and coordination	3	3	3	3	3	3	3	3		24
	15	Main risks are not identified	3	0	0	3	3	3	0	0		12
	16	Guidelines for early phase assessments and "behaviour" not followed	0	1	3	3	0	1	1	1		10

	17	Lack of an implemented governance framework	3	1	0	3	0	1	1	1		10
Project Organisation	18	Unclear scope definition including poor definition of scale, required resources, goals, tasks, assumptions, etc.	3	3	3	3	3	3	3	3		24
	19	Lack of a common definition of roles and responsibility	3	3	1	1	3	3	3	3		20
	20	Same things come up again and again in meetings	3	3	3	3	3	3	3	1		22
	21	The project is experiencing difficulties in integrating schedules between project participants.	3	3	1	3	3	3	1	3		20
	22	Higher frequency of meetings with client to clarify problems.	1	0	0	1	0	3	3	0		8
	23	The project team is experiencing a high turnover rate and instability in team membership	1	3	3	3	3	3	1	3		20
	24	Shortage of labour (skilled)	3	3	3	3	3	3	3	3		24
	25	Discussions are delayed/postponed	1	3	3	3	1	3	3	3		20
Client/Stakeholder related symptoms	26	Client's and stakeholders'' unresponsiveness, lack of seriousness and dedication to ensuring timely completion of projects.	1	3	3	3	3	3	3	3		22
	27	Slowness in making decisions by owner	1	3	3	3	3	3	3	3		22
	28	Fighting/quarrelling/conflict among stakeholders and participants during project planning phase.	0	1	1	1	3	1	1	3		11
	29	Poorly developed business plan	0	1	3	1	3	0	1	0		9
	30	Some project stakeholders refuse to participate in important meetings.	0	1	1	3	3	1	1	3		13
Project Changes	31	There is a large number of change requests or requirements fluctuations within the project.	3	3	3	3	3	3	3	1		22
	32	Project changes are not being processed in a timely manner for decision making	3	3	3	3	1	3	3	3		22
Team Building	33	The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project.	3	3	3	3	3	3	3	3		24
	34	Lack of motivation	3	1	3	1	3	3	3	3		20
	35	Lack of training	3	3	3	3	3	3	3	3		24

	36	Poor communication between stakeholders and participants	0	1	3	3	3	1	1	3		15
	37	Parties unwilling to share relevant information	0	3	3	3	1	3	3	3		19
	38	Notice of sudden or gradual reduction in attendance at project meetings.	0	3	1	3	1	3	0	3		14
	39	Commitments are increasingly made with the intention of not being met	0	0	1	1	1	1	1	0		5
	40	A mood of non-satisfaction among personnel, strained atmosphere, uneasy comments, lack of cultural understanding, etc.	3	3	3	1	3	3	3	3		22
	41	The project team is not being realistic and truthful when project circumstances are unfavourable.	0	3	1	3	3	3	1	1		15
	42	The project team is losing confidence in the accuracy and validity of the schedule	0	0	1	1	1	1	1	0		5
	43	Weak commitment to the project expressing itself	0	3	3	3	3	3	1	3		19
Quality Management	44	Inappropriate/Poor design quality	3	3	3	3	3	3	3	3		24
	45	Quality of the reports, preliminary plans, and documentation is unsatisfactory	3	3	3	3	3	3	3	1		22
Documentation	46	Documentation not completed	3	3	3	3	3	3	3	3		24
	47	A project specific quality plan is not consistent with the contract documents	3	0	1	3	3	1	3	1		15
	48	Numbers/information missing, messages get lost along the way, lack of control	0	1	3	3	3	1	0	3		14
External factors	49	Some project participant companies become financially unstable, overall financial issues	0	0	3	1	3	3	1	1		12
	50	Laws and regulations	0	0	1	1	3	1	3	0		9
	51	Delay in approval stage	3	0	3	1	3	3	0	0		13

Appendix D.1 – Prioritization of EWS

№	Early Warning Signal	P1	P2	P3	P4	P5	P6	P7	P8		Score		Ref №	Score
1	High turnover rate of people/ no stability in the team	6	15	15	9	20	16	16	15		14.71429		20	21.00
2	Shortage of skilled labour -> Too many juniors	12	12	8	12	20	15	12	6		12.14286		4	18.29
3	Too much work is being allocated to a worker/ Working on couple of projects at the same time	9	12	12	12	15	16	15	16		13.57143		15	15.00
4	There is a large number of change requests or requirements fluctuations within the project/ Scope creep	20	20	20	15	16	12	16	24		18.28571		1	14.71
5	The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project	12	10	10	12	15	15	10	10		11.71429		16	13.86
6	People not aware what they are doing/ what they are required to do	6	9	9	8	8	8	6	6		7.428571		3	13.57
7	Incurred costs on the project are already getting higher than the anticipated benefits from the project (Earned Value Management)	20	12	12	12	6	12	12	10		12		8	12.43
8	Not following the plan	16	12	15	12	16	8	12	8		12.42857		2	12.14
9	Poor organization and communication/ too many layers of communication	8	8	15	9	9	12	12	6		10		21	12.00
10	Cultural/working differences	6	12	6	6	4	12	8	6		7.714286		7	12.00
11	Consultants are making continuous attempts to redesign project and alter its scope.	12	12	16	9	15	8	10	8		11.57143		13	11.86

12	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	12	12	16	10	12	12	6	6		10.85714		5	11.71
13	The project is experiencing a high level of engineering / design / specification errors	16	9	10	9	15	15	6	12		11.85714		24	11.57
14	A mood of non-satisfaction among personnel, strained atmosphere, negative attitude, uneasy comments/ unpleasant working environment	9	6	8	8	9	12	6	10		8.571429		11	11.57
15	Unclear scope definition including poor definition of scale, goals, tasks, assumptions, etc.	16	20	12	15	12	15	12	18		15		12	10.86
16	Lack of detailed specifications in contracts	12	20	8	12	15	15	9	18		13.85714		9	10.00
17	Same things come up again and again in meetings	8	6	12	6	9	6	6	4		7.285714		18	9.57
18	Discussions/meetings are delayed/postponed (internally and externally)	9	6	12	6	6	12	16	6		9.571429		25	9.14
19	Poor quality of questions coming from people	6	9	12	9	4	6	6	4		6.714286		14	8.57
20	Time for decision making/ client makes slow decisions	30	25	20	20	12	16	20	24		21		22	8.00
21	Project location/ the nature of the project	6	6	15	12	15	15	12	15		12		10	7.71
22	Lack of training	12	12	6	6	6	8	6	6		8		23	7.71
23	Parties unwilling to share relevant information	6	10	8	6	9	8	9	4		7.714286		6	7.43
24	Quality of the reports, preliminary plans, and documentation is unsatisfactory	15	12	12	9	8	12	12	10		11.57143		17	7.29
25	Use of untested tools/software for the project	8	4	15	9	15	10	8	4		9.142857		19	6.71

Appendix D.2 – Layout of the Questionnaire for prioritization

Early warning signal	Probability (1-6)	Impact (1-6)	Total (Prob X Impact)
1. High turnover rate of people/ no stability in the team			
2. Shortage of skilled labour -> Too many juniors			
3. Too much work is being allocated to a worker/ Working on couple of projects at the same time			
4. There is a large number of change requests or requirements fluctuations within the project/ Scope creep			
5. The project team is lacking in the necessary expertise, experience, breadth, and depth to successfully execute the project.			
6. People not aware what they are doing/ what they are required to do			
7. Incurred costs on the project are already getting higher than the anticipated benefits from the project (Earned Value Management)			
8. Not following the plan			
9. Poor organization and communication/ too many layers of communication			
10. Cultural/working differences			
11. Consultants are making continuous attempts to redesign project and alter its scope.			
12. 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			
13. The project is experiencing a high level of engineering / design / specification errors			
14. A mood of non-satisfaction among personnel, strained atmosphere, negative attitude, uneasy comments/ unpleasant working environment			
15. Unclear scope definition including poor definition of scale, goals, tasks, assumptions, etc.			
16. Lack of detailed specifications in contracts			
17. Same things come up again and again in meetings			
18. Discussions/meetings are delayed/postponed (internally and externally)			
19. Poor quality of questions coming from people			
20. Time for decision making/ client makes slow decisions			
21. Project location/ the nature of the project* (see explanation below)			
22. Lack of training			
23. Parties unwilling to share relevant information			
24. Quality of the reports, preliminary plans, and documentation is unsatisfactory			
25. Use of untested tools/software for the project			