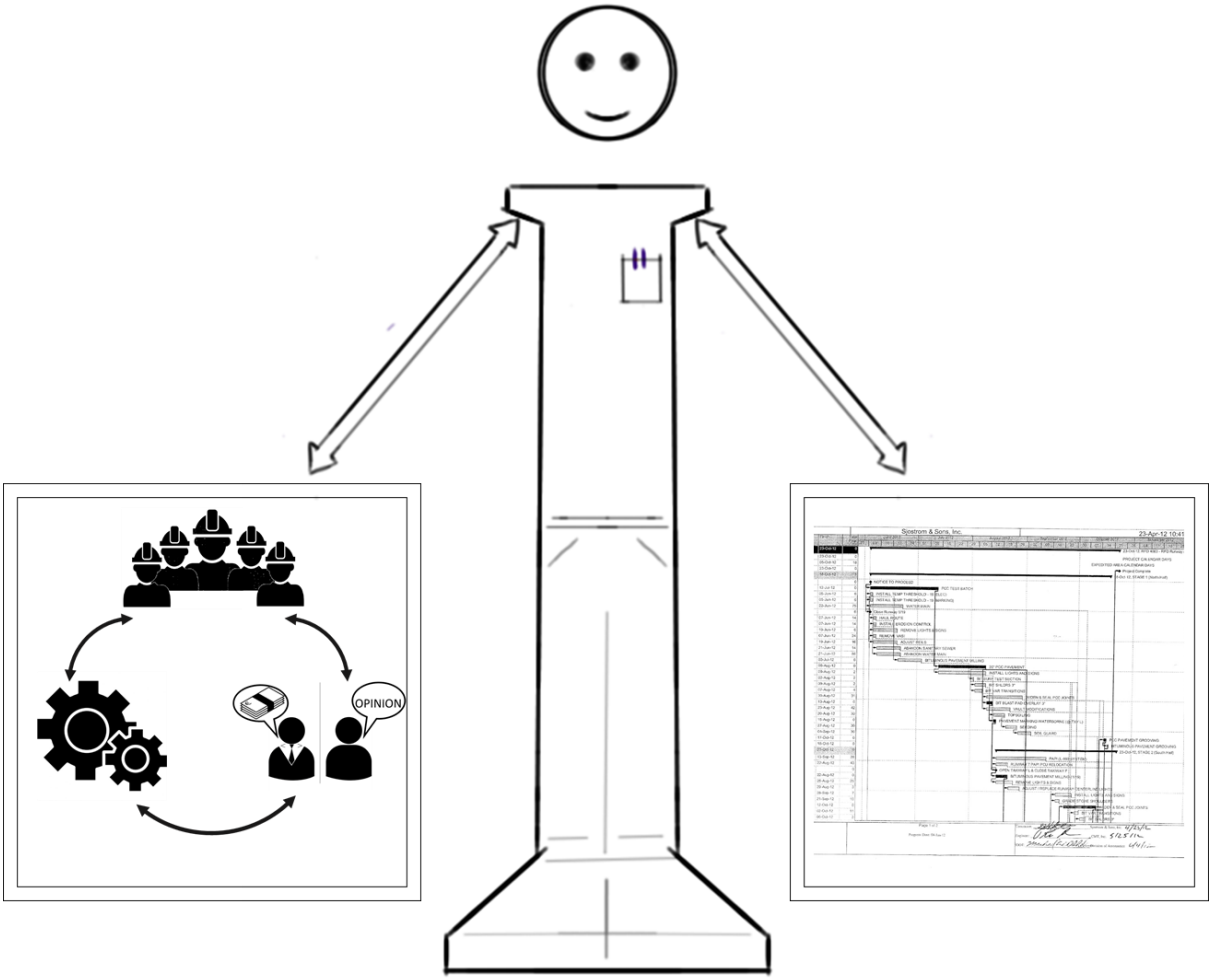

PROJECT COMPLEXITY AND CONSTRUCTION PLANNING:

AN EXPLORATORY RESEARCH INTO THE INFLUENCE OF PROJECT COMPLEXITY ON THE PLANNING PROCESS OF DUTCH INFRASTRUCTURE PROJECTS

Walid Atmar

Master Construction Management and Engineering

Delft University of Technology

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Author

Name	W. (Walid) Atmar
(Mobile phone)	+31(0) 641 22 66 23
Master program	Construction Management and Engineering
University	Delft University of Technology
Faculty	Civil Engineering and Geosciences
E-Mail	w.atmar@outlook.com

Graduation Committee:

Chair graduation committee	Prof.dr. H.L.M. (Hans) Bakker *Faculty of Civil Engineering and Geosciences*
First supervisor	Dr.ir. H.M.J. (Louis) Lousberg *Faculty of Architecture*
Second supervisor	Dr.ir. R.M. (Rob) Stikkelman *Faculty of Technology, Policy and Management*
External supervisor	Ing. F.C.D. (Frans) Viveen MSc *Heijmans N.V.*

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With great pride I present this report as the conclusion to the Master of Science program 'Construction Management and Engineering' (CME) at the Faculty of Civil Engineering and Geosciences of the Delft University of Technology.

In hindsight, this has definitely been a more challenging undertaking that I had anticipated. The CME master program gave me insight in the managerial world of (civil) engineering with a technical twist to it. Managerial studies and collaborating with others is the heart of CME. I chose to conduct this research because of the interest I had developed for the topic of project complexity and because it allowed me to interact with people, something that I have enjoyed since my first day as a bachelor student Architectural Engineering at Hogeschool Rotterdam.

I want to thank my entire graduation committee for the support I have gotten: Hans Bakker, chair of my graduation committee, for keeping me focused on the scope of the research and being critical of the findings (which was really needed). Without his contribution, it could be possible that I would still be conducting this research, but with aerospace projects and interviewees from the animal kingdom included!

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Enjoy reading!

Walid Atmar

Ridderkerk, December 2016

Executive Summary

Researchers have devoted lots of words and pages toward causes of construction project failures and management efforts to achieve project success. The iron triangle, though not without criticism, is the traditional performance measure of projects and consist of time, cost and quality. Despite well documented reasons in literature why projects fail – and the existence of established project management handbooks – cost and time overruns are not uncommon. The nature of projects is changing: projects are becoming increasingly complex and this increasing complexity is another potential reason for failure of projects.

Planning is one of the most important aspects of project management and it considers not only time, but also cost, quality, health, safety, design. Despite the importance of the planning process, the use of sophisticated scheduling software and the increasing interest in project management implementation, projects fail at a substantial rate in planning accuracy and adequate control of planning. The problem is that despite literature mentioning that project complexity influences the planning process and contributes to project failure, there is a lack of research what the influence of project complexity – inclusive of the softer aspects of complexity accepted in more recent publication – is on the planning process of infrastructure projects.
Present literature that examines the influence of project complexity on the planning process focus on the quantitate aspects: the numeric optimization of scheduled activity duration. It is analogous to scheduling project buffers as a result of project complexity. This research is initiated on the belief that in order to adapt planning efforts to project complexity, it must be first understood what the effect of project complexity is on the planning process. The objective of this research is identify what the influence of project complexity is on the planning process of infrastructure projects by answering the main research question:

"What is the influence of project complexity on the planning process of infrastructure construction projects?"

The scope of the research is infrastructure construction project in the construction phase (post tender). First a literature study is conducted, then standing practice explored and the findings synthesized.

Literature study

The is no widely held definition of project complexity. Various definitions are mentioned and used by academics. Baccarini's (1996) definition of complexity as "consisting of many varied interrelated parts that can be operationalized in terms of differentiation and interdependence" is most common. The diversity in project complexity definitions might be explained by its intuitive nature (M. G. C. Bosch-Rekveldt, 2011). These is also a lack of consensus on a project complexity approach, distinguishing two approaches: the first approach assumes that a relatively objective statement can be made from multiple subjective perceptions; second assumed a project to be equivalent to a system and its characteristics, where theory on project complexity is applied to project management. Due to the lack of consensus on a definition and approach, an existing project complexity assessment model was chosen. The TOE-Framework for project complexity was chosen as the project complexity easement model for this research because it was developed with the purpose of assessing project complexity across various project phases, it was developed with the engineering projects in mind and because it has a balance of qualitative and quantitative elements.

The TOE Complexity Framework stands for Technical, Organizational and Environmental Complexity Framework, which are the main categories of the framework. Each category contains specific elements particular to the category.

The second part of the literature study was conducted to find how the planning process is defined in literature. Generally, projects can be divided into three phases: tender phase, pre-construction phase (period between awarding of contract and actual start of construction) and the construction phase. The pre-contract phase and contract phase are within the scope of this research. The main concern of these phases is scheduling and the process of schedule reporting and maintenance (Baldwin & Bordoli, 2014; Cooke & Williams, 2013). A five-level schedule reporting structure is mentioned and advised in literature in context of complex projects. In this structure, a construction schedule is divided into five levels. Each levels has its own schedule density, which is the detail in which activities are scheduled. The closer the scheduled work is to execution, the higher the schedule density on the activities. This five-level structure also assigns roles and responsibilities in schedule reporting. The level 1 schedule is a low density executive summary intended for the project director and project management team. The level 2 schedule is the senior management report. The level 3 schedule is the project manager's report at medium density. In literature, a single scheduler is advised to draft the level 1-3 schedules. The level 4 and 5 schedules are medium to high density schedules drafted by the various disciplines, involving the work per discipline. The level 3 schedule sets the bandwidth in which the level 4 and 5 schedules are drafted. This schedule reporting structure is shown in the table below:

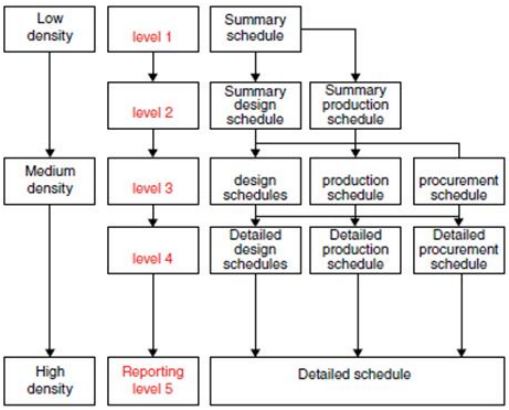

Figure 1: 5-Level schedule reporting structure (Baldwin & Bordoli, 2014)

The final part of the literature review is the overview of what is mentioned in literature about the planning process in relation to project complexity. The following aspects, referred to as 'key concepts' in this report, are mentioned in literature to be important to the planning process.

- Sharing of information (Baldwin & Bordoli, 2014; Cooke & Williams, 2013; Curry, 1977):
- Standard planning and scheduling process design (Baldwin & Bordoli, 2014; CIOB, 2011)
- Role of planner and scheduler (Weaver, 2014)

The first key concept is 'sharing of information'. This is crucial to planning in any context. There other two concepts are 'standard planning process design' and 'role of scheduler' are found in context of complex projects. A 5-level schedule reporting structure is proposed as a standard in literature to facilitate information sharing. The third key concept is the 'role of the scheduler', because it mentioned in literature that scheduling in complex projects requires good interpersonal, managerial skills, which schedulers do not or insufficiently possess from their traditional role.

Standing Practice

Exploratory interviews

Professionals (7 schedulers and 5 managers) involved in the planning process were consulted by means on exploratory interviews to gather the views on the key concepts in relation to complex projects. Table 4* presents the exploratory interview answers and consensus on the literature based key concepts. What is mentioned in this table is related to project complexity. Most of the answers given on the areas of improvement (question 4) and all of the answers given on areas of standardization (question 3) are not related to project complexity.

Literature based key concepts	Exploratory interview consensus
▪ Sharing of information	The information requirement to draft and maintain a construction schedule increases along with the number of information sources. Also, there was a consensus on the notion that key personnel involved in the tender should transition from the tender phase to at least part of the construction phase. This in order to transfer key knowledge from tender to execution.
▪ Role of planner and scheduler	Due to the increased information requirement, (head) schedulers should have a more proactive role in gathering the information needed to monitor, update and integrate the various schedules into the overall schedule.
▪ Standard planning and scheduling process design	**There is a lack of consensus between both managers and schedulers on this topic. The suggestions for standardization are related to schedule presentation and logic, no relation was mentioned to project complexity. **
Additional topics	
View on improvements and bad practices	The vast majority of the suggested improvements are a result of (sub-codes) the proactive approach to scheduling, on which there is consensus. They are also related to the enabling of information and knowledge sharing.

Table 4: Consensus on literature based key concepts from exploratory interviews*

There was consensus in the exploratory interviews that the information requirement to draft and maintain a construction schedule increases along with the number of information sources in complex projects compared to complex that are not considered complex.

Six case studies were conducted to assess what elements of project complexity form the TOE-Framework for project complexity have contributed to budget and/or cost overruns, and what their relation is with the planning process though the key concepts.

Case Studies: Six cases were studied, all from Heijmans' project portfolio. In order to have a greater source of data, project that were not delivered yet, but where the internal prognosis was that they would be delivered at a budget and/ or time overrun, were included in the case studies. The cases study consists of four cases where the project is over budget and over time (three of them were not yet delivered at the time of undertaking the case studies) and two were only over budget (one of them was not yet delivered at the time of undertaking the case studies). The data gathering occurred exclusively through interviews and the analysis was of qualitative nature .The TOE-Framework was used assess the complexity of these projects by assessing during the interviews which elements of the framework were present in the case, what their influence was on project performance and what their relation was to the planning process. Per case, two persons were interviewed to contribute to the validity: person at project manager function level and the scheduler (or the person who scheduler reports to in case scheduler was not available).In total, 22 project complexity elements were identified as having contributed to overruns and being related to the planning process. Table 15 shows the relation of these elements to the key concepts.

Elements from the TOE-Framework	Relation to key concepts
TT3 Dependencies between tasks	**Information sharing:** Higher communication and information requirement to manage dependencies. **Role scheduler**: Proactive scheduler required to facilitate information sharing and monitor dependencies.
TT4 Uncertainty in methods	**Information sharing:** Higher communication and information requirement to cope with uncertainty. **Role scheduler:** Proactive scheduler required to facilitate information sharing
TS2 Uncertainties in scope	**Information sharing:** Higher communication and information requirement to cope with uncertainty. **Role scheduler:** Proactive scheduler required to facilitate information sharing
TR1 Technical Risks	**Information sharing:** Higher information and communication requirement to consider risks in planning process.
TT2 Variety of tasks	**Information sharing:** Higher communication and information requirement to manage variety of tasks **Role scheduler:** Proactive scheduler required to facilitate information sharing and integrate the varied tasks
TS1 Scope largeness	**Information sharing:** Higher communication and information requirement to break down and assess scope. **Role scheduler:** Proactive scheduler required to facilitate information sharing and monitor dependencies.
TS3 Quality requirements	*No relation to the planning process given by interviewees*
TE2 Experience with technology	**Information sharing:** Higher communication and information sharing intensity required.
TE1 Newness of technology	**Information sharing:** Higher communication and information sharing intensity required.
OS5 Size in project team	**Information sharing:** Higher importance of sharing correct information timely. Role scheduler: Proactive scheduler required to manage information required to make sure schedule is actual and integrated.
ORE3 Experience with parties involved	**Information sharing:** Information sharing should be facilitated due to different work ethics.
OS4 Size in engineering hours	**Information sharing**: Lack of effort in facilitating information sharing is caused by a shortage in engineering hours, making people focus on their tasks. Role scheduler: Proactive scheduler required to make sure the most actual schedule is being worked with.
OT2 Trust in contractor	**Information sharing:** A lack of trust in contractor hinders information sharing.
OR1 Organizational risk	**Information sharing:** Higher communication and information sharing intensity required due to minimize effect of organizational risk.
ORE5 Interfaces between disciplines	**Information sharing:** Higher communication and information sharing intensity required to monitor interfaces. **Role scheduler:** Proactive scheduler required to actively monitor interfaces and facilitate in information sharing.
OS1 Project Duration	**Information sharing:** When project duration is too short, information exchange should be facilitated to work as efficient as possible.
OS2 Compatibility of different PM methods and tools	**Standard process design:** A scheduling standard should be set per project to align scheduling methods and diminish inefficiencies.
ORE1 Project Drive	**Information sharing**: Project drive "time" can lead to inefficient working if information sharing is not managed.
OP3 Cooperation JV partner	**Information sharing:** Work ethics have to be aligned to facilitate and streamline information sharing. **Standard process design**: A standard schedule reporting process should be agreed upon. Role scheduler: A scheduler should have the status to mandate following of the standard process.
OT1 Trust in project team	**Information sharing:** Lack of trust in project team hinders information sharing.
ES2 variety in stakeholder perspectives	**Information sharing:** Importance of stakeholder perspectives should be assessed and communicated.
EL1 Interference with existing site	**Information sharing:** Higher information requirement on interferences with existing site.
ES3 Dependencies on other stakeholders	**Information sharing:** Increased information sources and information dependencies.
EM1 Internal Strategic Pressure	**General:** Internal strategic pressure in acquiring a project can influence the care with which a project is prepared, resulting into problems that influence the planning process in general later on the project.

Table 1: Influence of identified complexity elements on key concepts

Overall, three complexity scenarios can be distinguished across the cases:

1. Inherently complex: Project is perceived as inherently complex, with the perception that complexity decreased over time (cases 5 and 6)
2. Inherently complex, partially induced: Project is perceived as inherently complex, with the perception that complexity increased over time (cases 2, 3, 4)
3. Project is not complex, where complexity is fully induced (case 1)

Findings suggest that that the management efforts on induced complexity can influence the effect of an inherent complexity element on project performance. However, regardless of the nature of the complexity element (inherent or induced), its influence on the planning process is the same: the information and communication requirement for adequate planning and scheduling increases.

Conclusion: The key concepts found in literature were explored in light of project complexity by consulting professionals though exploratory interviews. These intuitive views were then assessed in the case studies. Concluding this research, the main research question is answered:

" What is the influence of project complexity on the planning process of infrastructure construction projects?"

The influence of project complexity on the planning process of infrastructure projects is that it increases the information and communication requirement to adequately draft and monitor a schedule. This increased information and communication requirement necessitates the inclusion of proactive scheduler with good interpersonal, managerial skills to fulfil the role of the scheduler as an interface manager.

Recommendations for use in practice:

- Assessment of project complexity: professionals consulted in the case studies mentioned insufficient recognition of project complexity to have contributed to overruns. It was suggested that a complexity assessment would contribute to better project performance.
- Proactive scheduler: a proactive scheduler with good interpersonal, managerial skills and competences is recommended for the position of being responsible for the overall schedule (level 1-3, head-scheduler).
- Information sharing: it is found that the information and communication requirement needed to sufficiently draft and maintain the schedule and making decision increases in complex projects. Aside from the argument that the role of the (head)scheduler needs to evolve, it is recommended that the rest of the project organization should take more responsibility in providing information and better communication.
- Standard process design: It is recommended to make agreements at the start of the project on which planning and scheduling structure to follow and what the roles and responsibilities are in context of the planning process. It's a vessel for communication and provides organizational clarity.
- Organizational continuity: Organizational continuity is recommended to make available knowledge to manage the inherent complexity of the project and/or prevent the inducing of complexity.

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PART I:
INTRODUCTION TO SUBJECT

1. Research introduction

1.1 Introduction

A popular definition of a project is that it is "*a temporary organization and process set up to achieve a specified goal under the constraint of time, budget and resources*" (Shenhar & Dvir, 2007, p. 5). Project Management is the practice of managing projects. The objective of project management is to deliver projects (or: a certain scope) successfully within budget, on time and according to the specified quality. Delivering a project outside of the constraints of time (delayed completion) and cost (cost overrun) is seen as a failure.

Researchers have devoted lots of words and pages toward causes of construction project failures and management efforts to achieve project success. The iron triangle, though not without criticism (Atkinson, 1999), is the traditional performance measure of projects and consist of time, cost and quality. Despite well documented reasons in literature why projects fail – and the existence of established project management handbooks – cost and time overruns are not uncommon (Flyvbjerg, Bruzelius, & Rothengatter, 2003; Morris & Hough, 1987).

Cost overruns occur globally across various construction projects (Flyvbjerg et al., 2003). Time overruns (or: delays) often have direct influence on the cost of a project (Lock, 2008). Overruns are not a recent phenomenon either. Time and cost overruns in infrastructure construction projects (henceforth: infrastructure projects) have been constant for seven decades, measured from 1932 to 2002 (Flyvbjerg, Holm, & Buhl, 2002). Looking at the current available publications on construction project failures, another research into project failures might seem like a dime a dozen. However, the nature of projects is changing: projects are becoming increasingly complex and this increasing complexity is another potential reason for failure of projects (Williams, 2002, 2005), and more specifically, infrastructure projects (Kool, 2013; Neumann, 2010). Generally speaking, construction projects can be divided into building construction projects and infrastructure projects. There is an important distinction in terms of managing these two types of projects: infrastructure projects are politically complex, involve more risk are often larger in scope (De Jong, Annema, & Van Wee, 2013).

The meaning of project complexity and what it entails is ambiguous and there is no clear-cut definition. Different authors have different views on project complexity. Project complexity will be elaborated on in this report. Baccarini defined project complexity as follows (Baccarini, 1996, p. 202): "Project complexity consists of varied interrelated parts and can be operationalized in terms of differentiation and interdependency". Baccarini divided and distinguished the differentiation and interdependency in organization, technical and social complexity. This definition of Baccarini was further built upon by Williams (2002) by grouping Baccarini's definition as structural complexity and adding uncertainty complexity. This definition of complexity is of importance to understand its relation to the planning process, as a key aspect of the planning process is to map interdependencies (Baldwin & Bordoli, 2014). Baccarini's definition of complexity is singled out because leading theoretical concepts of project complexity incorporate or take into account this description (M. G. C. Bosch-Rekveldt, 2011).

The increasing complexity of projects is felt within the construction industry intuitively. Design and build contracts are increasing in popularity (to a point where it is a requirement in Dutch infrastructure projects), projects are executed in multidisciplinary teams (possibly across different locations) and stakeholder involvement is increasing as well. These aspects lead to an increase in uncertainty, which is a departure from the traditional project management approach: "*the traditional, formal approach to project management is based on a predictable, fixed, relatively simple, and certain model*" (Shenhar & Dvir, 2007, p. 9). In stark contrast to this traditional approach, project complexity introduces layers of unpredictability, dynamism and uncertainty to projects (M. G. C. Bosch-Rekveldt, 2011) and their accompanying planning process (Baldwin & Bordoli, 2014; Thomas & Mengel, 2008).

1.2 Problem description

Project planning is one of the most important aspects of project management and it considers not only time, but also cost, quality, health, safety, design and production (Baldwin & Bordoli, 2014; CIOB, 2011). Despite the importance of the planning process, the use of sophisticated scheduling software and the increasing interest in project management implementation, projects fail at a substantial rate in planning accuracy and adequate control of planning (Thomas & Mengel, 2008; Weaver, 2014). The increasing complexity of projects is one of the contributors to time and cost overruns in construction projects (Kool, 2013; Neumann, 2010; Williams, 2002, 2005).

Insufficient attention to crucial interrelationships that are a part of project complexity is believed to contribute to project failure (Neumann, 2010). A project consist of a set of activities divided over various disciplines. Mapping interrelationships and dependencies of activities between the disciplines involved within the project is a very important aspect of the planning process and project scheduling (Baldwin & Bordoli, 2014). Monitoring the planning process, these relations and dependencies is of key importance to the advancement and success of projects (Baldwin & Bordoli, 2014).

However, present publications on project complexity and construction planning are focused on the numeric optimizations of activity durations established in a construction schedule, which is only party of the planning process (Cohenca, Laufer, & Ledbetter, 1989; Gidado, 1996; Laufer & Cohenca, 1990). Also, this quantitative approach does not factor in the soft, qualitative side of complexity. Research into project complexity increasingly recognizes the importance of the softer aspects of complexity and is increasingly proposing project complexity assessment models to have a balance between of qualitative and quantitative aspects (M. Bosch-Rekveldt, Bakker, Hertogh, & Mooi, 2015; M. G. C. Bosch-Rekveldt, 2011; de Bruijn, de Jong, Korsten, & van Zanten, 1996; Obdam, 2016; Thomas & Mengel, 2008; Vidal & Marle, 2008).

The problem is that despite literature mentioning that project complexity influences the planning process and contributes to project failure, there is a lack of research what this influence of project complexity – inclusive of the softer aspects of complexity accepted in more recent publications – is on the planning process of infrastructure projects. As noted before, project planning is key to project success. Present literature only incorporates the quantitative aspects of project complexity in the consideration of its influence on scheduled activity durations by translating project complexity into a correction factor that applies a "complexity buffer" to scheduled activities. The reasoning for this research is thus twofold: 1) the influence of project complexity which is inclusive of the soft, qualitative aspects on the broader planning process, which is crucial to project success, is unexplored; and 2) this influence needs to be understood in order to adapt the associated planning efforts to cope with project complexity. This research is thus of an exploratory nature. Figure 1 shows a schematization of the problem description.

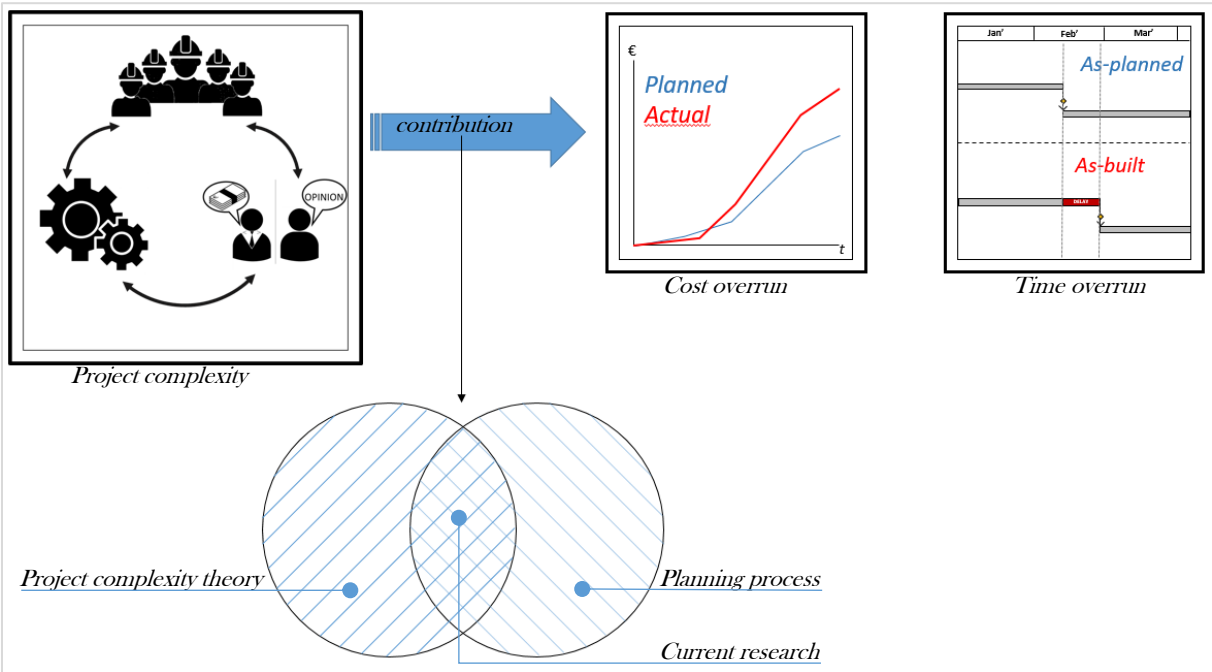


Figure 2: Schematization problem statement

1.2.1 Heijmans N.V.

Heijmans N.V. is one of the largest contractors in the Netherlands. Heijmans is specialized in the construction of residential, non-residential and civil works. This company recognizes that their projects are getting increasingly complex, and the increasing complexity of projects affects the planning efforts and project outcome. Furthermore, Heijmans' interest in the subjects project complexity and project planning initiated the current research. In order to conduct the research, Heijmans' network of employees and partners, as well as their project portfolio will be used to gather data. This knowledge will be gathered through reports, interviews and case studies. Thus, the scope of the current research is the planning process of Dutch infrastructure projects.

2. Research approach

The concepts described in the book 'Designing a Research Project' are used to shape the research approach of the present research (Verschuren & Doorewaard, 2010). The research design contains a (summarized) problem description, research objective, research question and sub-questions. A description of the research scope is drafted in the subsequent section. Finally, the research framework is drafted in order to make the road towards answering the main research question clear and understandable.

2.1 Research Content

2.1.1 Research objective

The objective of the research is to empirically identify the influence of project complexity on the planning process of Dutch infrastructure projects by conducting exploratory case-studies. The goal of this identification is to provide a starting basis and understanding to build further research on.

2.1.2 Research question and sub question

To fulfill the research objective and cater to the problem definition, the following main research question is defined:

"What is the influence of project complexity on the planning process in the construction phase of Dutch infrastructure projects?"

Six sub-questions are defined in order to come to a clear answer to this research question. Since the research is concerned with project complexity and the planning process, literature on both concepts should be consulted to find how they are defined. Subsequently, the views of professionals on the findings in literature should be explored. Finally, the elements of complexity influencing the planning process and project outcome should be identified.

The following sub-questions will be answered in order to answer the main question:

1. *How is project complexity defined in literature*
2. *Which project complexity assessment model can be used to identify project complexity elements?*
3. *How is the planning process described in literature?*
4. *How does Heijmans' planning process compare to literature?*
5. *What is the present literature body of knowledge on the effect of project complexity on the planning process?*
6. *What are the views on the influence of project complexity on the planning process by the professionals involved?*
7. *Which project complexity elements of the chosen complexity model in sub-question 1 can be identified as contributing to project failure and having influence on the planning process?*

Sub-questions one, two and three are answered by means of a literature study. Sub-question four is answered by desk-research. Sub-questions five and six are dependent on empirical data and will be answered by means of exploratory interviews and (six) case studies.

2.2 Research relevance

As stated in the introduction to this research, research into project complexity and project failure is not uncharted territory. The lack of consensus on what the definition of project complexity should be is made apparent by the existence of various project complexity frameworks and models. Interrelationship, dependence and uncertainty – key concepts of project complexity – (Baccarini, 1996) are an important aspect of the planning process. It is also within the scope of the planning process to elaborate on these aspects and define the elements that are affected by them. It's thus important to know how complexity influences planning efforts. So far, literature on complexity and its influence on the planning process has failed to address the soft, qualitative project complexity aspects that influence the planning process.

Thomas and Mengel (2008) recognize the importance of the qualitative aspects of project complexity and have researched how project management education prepares managers to deal with complexity. They found that the vast majority of project management education providers do not prepare managers to deal with complexity (Thomas & Mengel, 2008).

The relevance of this research lies within that qualitative gap in existing literature. The present research will focus **what** the influence of project complexity is on the planning process, rather than the numeric optimization of activity duration in order to cope with possible effects of project complexity. It will use empirical data in order to identify what aspects of project complexity influence the planning process, which is crucial for the successful delivery of projects. This foundation can then be examined and dissected in further research to come up with an improved planning process approach.

2.3 Research Scope

The present research aims to look at projects in the infrastructure construction industry from the view of the contractor and takes into account the project phases after signing the contract (the tender phase is excluded). Since the research is about the infrastructure planning process in light of project complexity, it does not strive to build on or further elaborate theory on the concept of project complexity. Instead, existing concepts of projects complexity and existing models that identify complexity will be used. The recommendation to cope with the identified complexity factors will be based on practices prescribed by literature as well as industry best practices based on experiences of project professionals. The case studies depend on the availability of professionals and their recollection of the events that have occurred during the specific cases. Therefore, projects that are completed and delivered as well as projects currently under construction are part of the scope.

The qualitative aspect of the research led by the fact that the vast majority of the content is empirical in nature, imposes a limitation on the research subject, conclusion and recommendation(s). Added, the professionals consulted and involved in the research are all employed by Heijmans. It's worth to note that while Heijmans is one of the largest construction companies in the Netherlands, it cannot be assumed that the views and opinions of these professionals are representative of the industry as a whole.

2.4 Research design

As mentioned in the problem description, present publications on construction planning in light of project complexity are focused on numeric optimizations of scheduled activity durations by applying a "complexity factor" to calculate activity duration buffers. This research aims to explore the influence of project complexity on the planning process, which scheduling activities is part of. Due to the exploratory nature of this research, a qualitative approach is chosen in order to describe what the influence of project complexity is on the best practice of project planning. This requires consultation of professionals involved in the planning process as well as investigation of the influence of project complexity in failed projects.

2.4.1 Research methodology

Six sub-questions are formulated to answer the main research question of this master thesis: "*What is the influence of project complexity on the planning process of infrastructure construction projects?*". The research questions serve as building blocks of answering the main research question. The research methodology used to answer the sub-questions are elaborated below.

- *How is project complexity defined in literature?*
  Through a literature research, leading theoretical concepts of project complexity will be researched in order to gain an understanding for project complexity.

- *Which project complexity assessment model can be used to identify project complexity elements?*
  The aim of this question is to find an applicable complexity model for the context of the present research. It is not within the scope of this research to expand upon project complexity theory. Rather, present literature on the leading theoretical concepts will be consulted by means of an *exploratory literature researc*h to gather the relevant information, and to select a complexity model that fits the context of the research. The selected model will be used in sub-question 6.

- *How is the planning process described in literature?*
  The aim of this question is to gain an understanding of the key concepts and context of the planning process. By means of a literature research, a description/ outline of the planning process will be given in order to facilitate this understanding.

- *What is the present literature body of knowledge on the effect of project complexity on the planning process?*
  The aim of this question is to gather existing views and theories on the influence of project complexity on the planning process by means of an exploratory literature research. The outcome of this literature study will serve as the basis for the exploratory interviews in sub-question 3.

- *How does Heijmans' planning process compare to literature?*
  The aim of this question is to compare Heijmans' standing practice to what is described in literature by means of a desk research.

- *What are the views on the influence of project complexity on the planning process by the professionals involved?*
  The aim of this question is explore the thoughts of professionals involved with the planning process on the quality of said process by means of semi-structured exploratory interviews, and to find parallels between the views from literature. Semi-structured interviewing is well suited for gathering data and is the most used interviewing technique (DiCicco-Bloom & Crabtree, 2006). The interview protocol can be found in chapter 5.2.

- *Which project complexity elements of the chosen complexity model in sub-question 1 can be identified as contributing to project failure and having influence on the planning process?*
  The aim of this question is to identify which elements of project complexity from the chosen project complexity model contributed to project failure across multiple projects and what their influence was on the planning process. This is done by means of six case-studies. The required case data will be gathered though semi-structured interviews. The case study method is chosen because the interest of this research is a contemporary phenomenon (project complexity) within a real-life context and the investigator has little control over the events (Yin, 2009). The case-study protocol can be found in Section 8.1.3.

2.4.2 Framework

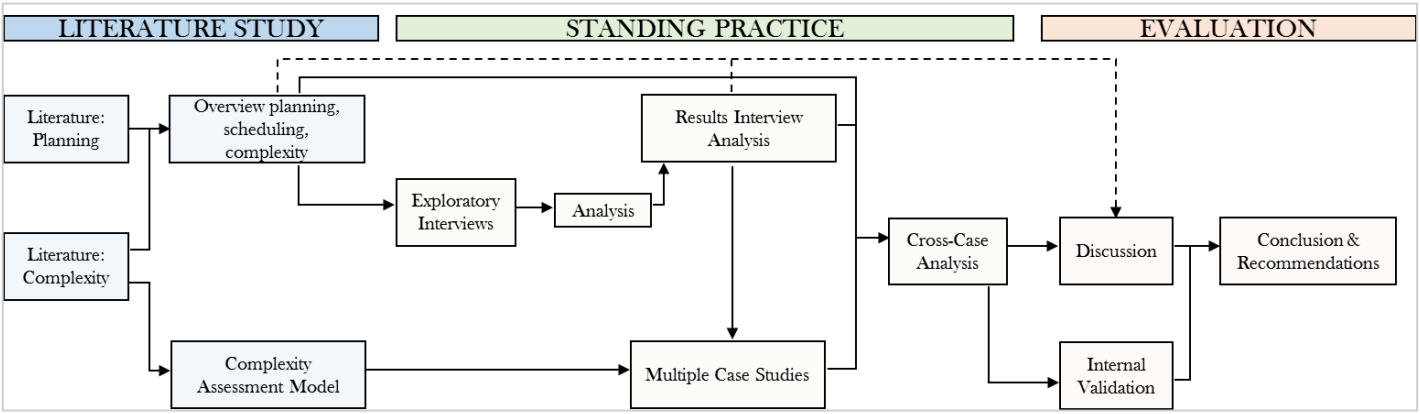


Figure 3: Research Framework

The research framework is shown in Figure 2. The goal of the research is to explore the influence of project complexity on the planning process. The framework is set-up in a way to accompany this goal. The starting point of the research is a literature study, which is conducted in order to gain an understanding of the underlying theoretical concepts this research is based on – project planning and project complexity – and to find and select a suitable project complexity assessment model. The final part of the literature review is an overview of what is found in literature on the relation between planning, scheduling and complexity.
Subsequently, standing practice is analyzed. In order to assess the validity of the literature review to compare it with standing practice, the views of professionals involved in the planning process are consulted by means of exploratory interviews. Chapter 5 serves as the basis of the interview questions to be asked. The exploratory interviews are conducted in order to gain a better understanding of the issues facing the planning process in complex projects by consulting professionals involved in the planning process. These views are analyzed by means of qualitative data analysis and the results are used together with the literature review in drafting interview questions for the case studies. The aim of the case studies is to identify which elements of the chosen project complexity assessment model contributed to budget and time overruns in the six

selected projects, and what their interface is with the planning process. Additionally, a cross-case analysis is performed to gain a better understanding of the governing project complexity elements that contributed to budget and time overruns across all the cases. The cross-case analysis in chapter X, the theoretical overview in chapter Y and the results of the exploratory interview analysis in chapter X are synthesized and discussed in chapter Z. This synthesis is validated internally within Heijmans by management level personnel (see chapter X). Finally, the conclusion(s) and recommendation(s) are provided.

2.4.3 Thesis Outline

Four main parts can be distinguished in this master thesis. The introduction to the research and the research approach are contained in the first part. The second part contains the literature review on project complexity (models) and project planning. In the third part, the findings of the second part are transformed into interview questions to explore what the view of professionals involved in the planning process is on the influence of project complexity in the planning process. This analysis and literature review are used to conduct six case studies. In the fourth and final part, the findings of the research are evaluated and synthesized, concluding the research and providing recommendations.

	Chapters
PART I: Introduction to subject	1. Research introduction 2. Research approach
PART II: Literature Review	3. Project complexity 4. Planning and scheduling 5. Overview planning, schedulign and complexity
PART III: Standing Practice	6. Exploratory interviews 7. Case Studies
PART IV: Evaluation	8. Discussion 9. Conclusion 10. Recommendations 11. Reflection

Table 2: Thesis outline

PART II: LITERATURE STUDY

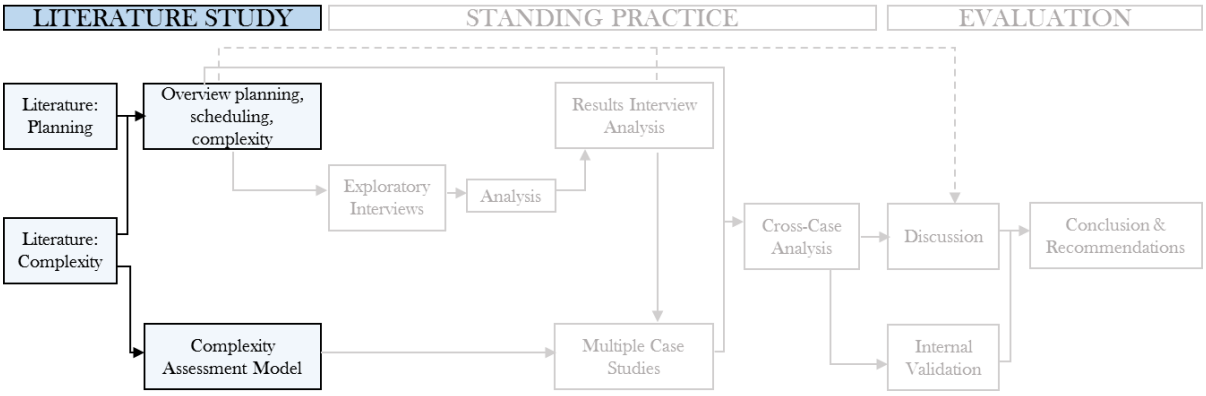


Figure 4: Research framework - Literature study

3. Project Complexity

The goal of this chapter is answer the following research questions:

1. How is project complexity defined in literature?
2. Which project complexity assessment model can be used to identify project complexity elements?

3.1 Project complexity theory

The increasing complexity of projects is seen as one of the reasons of project failure. Understanding project complexity and adapting managerial efforts to cope with it can lead to better project performance failure (M. G. C. Bosch-Rekveldt, 2011; Kool, 2013; Neumann, 2010; Williams, 2002, 2005). Project complexity theory focusses the aspects that make a project complex. It should be distinguished from 'complex project', which is project classification, namely complex (M. G. C. Bosch-Rekveldt, 2011).

However, there is no single, widely held definition of project complexity. Project complexity is often defined based on experience and intuition (M. G. C. Bosch-Rekveldt, 2011). Structural, dynamic and interaction elements should be included in a description of complexity (Whitty & Maylor, 2009). Project complexity seems best described as a concept rather than a singular definition, seeing the various descriptions that exist.

Turner and Cochrane have classified projects according to the degree of uncertainty in their goal definition and the degree of uncertainty in achieving the goals. This classification is called the goals and method concept (Turner & Cochrane, 1993).

Baccarini (1996) published a concept of project complexity in the construction industry, which later was used as the foundation of other definitions. The definition proposed is: "Project complexity consists of many varied interrelated parts and can be operationalized in terms of differentiation and interdependence" (Baccarini, 1996, p. 202).

He further elaborated on the definition describing it in context or organizational and technical complexity. Organizational complexity is split in: vertical differentiation referring to the depth of the organizational hierarchical structure and horizontal differentiation referring to the number of formal units and task structure. Organizational complexity by interdependence refers to the "degree of operational interdependencies and interaction between the project organizational elements" (Baccarini, 1996, p. 202). Technical complexity by differentiation refers to the diversity or variety of tasks (number of specialties, inputs/outputs etc.). Technical complexity by interdependence refers to the interdependencies between different technologies, inputs, network of tasks or between teams.

Turner (1993) and Baccarini's (1996) concepts are further expanded by Williams (1993). Williams distinguishes pooled, sequential and reciprocal interdependence and argues project complexity is influenced differently by them . He also added the uncertainty dimension to his model of complexity. These additions to Tuner (1993) and Baccarini's (1996) concepts form the following model:

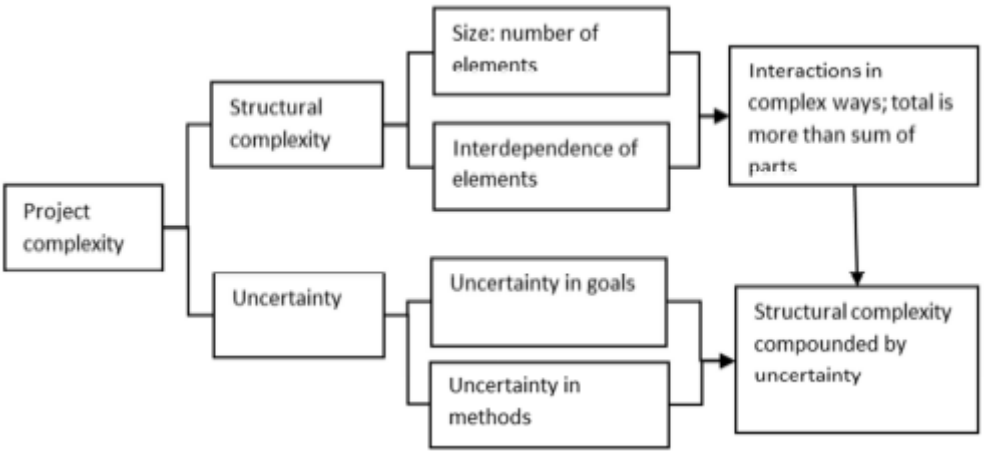


Figure 5: Project complexity as operationalized by Williams (2002)

This model, incorporating Baccarini's (1996) definition, is often used as the template to expand upon or modify by various authors in the field of project management research(M. Bosch-Rekveldt et al., 2015; M. G. C. Bosch-Rekveldt, 2011; de Bruijn et al., 1996) This model lacks softer aspects that are assumed to have influence on project complexity as well (M. G. C. Bosch-Rekveldt, 2011; de Bruijn et al., 1996). Various authors have developed concepts of project complexity that include softer aspects.
J.G. Geraldi and Adlbrecht (2007) used Williams' (2002) model and developed into a model consisting of complexity of fact, faith and interaction. The latter describing describes the softer aspects that are believed to contribute to project complexity: interaction between organizations and people. The softer aspects of complexity also garnished attention by de Bruijn et. al. (1996), who broke down project complexity into technical (related to uniqueness, dynamics and uncertainty of projects), organizational (organizational structure, involved actors and project team) and social complexity (actors and stakeholders involved) (de Bruijn et al., 1996).

It is clear that there are different views on what project complexity entails. Vidal and Marle (2008) defined project complexity by focusing on the drivers of complexity, as they acknowledged the lack of consensus concerning the definition of project complexity. The definition is as follows: *"Project complexity is the property of a project which makes it difficult to understand, foresee and keep under control its overall behavior, even when given reasonably complete information about the project system. Its drivers are factors related to project size, project variety, project interdependence and project context"* (Vidal & Marle, 2008). Other definitions of project complexity encountered in literature can be found in Appendix A1.
Vidal and Marle (2015) mention that there are two different scientific approaches regarding project complexity. The first is in the area of perceived complexity, seeing complexity as subjective. The second sees complexity as a descriptive property of system, making it measurable (Vidal & Marle, 2015). The first approach assumes that a relatively objective statement can be made from multiple subjective perceptions. The second assumed a project to be equivalent to a system and its characteristics, where theory on project complexity is applied to project management. Despite projects having characteristics of a complex system, there is no support or justification in literature that a project is equivalent to a complex system (J. Geraldi, Maylor, & Williams, 2011).

Summarizing, there is a lack of consensus on a project complexity definition and on a project complexity approach. Therefore, in the next sections a literature review is done to find a suitable project complexity assessment model for the present research.

3.2 Project complexity models

The present research will use an existing project complexity assessment model to assess the influence of project complexity, as described by the model, on the planning process in construction. Various authors from various sectors have researched complexity and published models containing aspects contributing to project complexity.

The majority of project complexity models were published after 2007 (Obdam, 2016). Obdam (2016) sought to develop an objective complexity model by means of a quantitative research incorporating various project complexity models. In total, twenty-seven project complexity models/frameworks were consulted an analyzed. In his report, he mentions numerous times that project complexity aspects are context related and in his conclusion, he mentions that a single quantifiable model might never be developed because of this contextual dependency. In assessing a complexity model, Obdam (2016) recommends:

> "Because of the contextual dependency of project complexity a model should only be developed for a specific context and purpose" (Obdam, 2016, p. 83)
> "It is believed that a project complexity model that rather includes quantitative aspects will most probably only cover a part of project complexity. The research supports the importance of qualitative and subjective aspects to be included in a model (Obdam, 2016, p. 83)

Other aspects that classify a model as 'good', according to Obdam (2016), are: the inclusion of significant complexity aspects (number of information systems, man months, departments, disciplines and project- duration and size in terms of capital), comprising of a reasonable ratio of quantifiable and non-quantifiable aspects. The models that were classified as 'good' are:

- List of complexity aspects proposed by Vidal & Marle (2008)
- PMCAT Tool (Damasiotis & Fitsilis, 2015)
- TOE-Framework for project complexity (M. Bosch-Rekveldt, Jongkind, Mooi, Bakker, & Verbraeck, 2011)

Due to Obdam's (2016) contextual dependency criterion, the TOE-Framework for project complexity is chosen for further review because it is developed with engineering projects in mind.

3.2.1 Gidado's model

Gidado's (1996) model is mentioned because it builds its own definition and model of project complexity rather than building upon popular foundations of project complexity. It also aims to specifically apply the model to construction time and cost planning. Gidado defines project complexity as "the measure of the difficulty of implementing a planned production work flow in relation to any one or a number of quantifiable managerial objectives" (Gidado, 1996, p. 218). The model uses this definition to numerically assess the effect its project complexity definition on scheduled project activity durations. This model is elaborated in Appendix A2.

3.3.2 TOE-Framework for Project Complexity

Bosch-Rekveldt et. al. (2011) conducted research into managing project complexity. Part of that research was answering how project complexity can be characterized in large engineering projects. In answering this question, Bosch-Rekveldt et. al. (2011) analyzed what elements of projects contribute to project complexity according to literature and according to professionals. This inductive approach aimed to synthesize existing theory and empirical work in order to establish

a detailed description of project complexity. The result of the theoretical and empirical research is the TOE (Technical, Organizational and Environmental) framework (figure 5).

The intended application of the framework coincides with the objective of the present research. The framework is intended as a tool to assess the complexity of the project. The framework gives a footprint of the expected complexity of the project. While the framework is initially intended as a footprint assessment in the Front-End Engineering and Design phase of projects, its use as an assessment tool in subsequent phases is recommended as well. This is due to the changing complexity of projects during the project life cycle (M. G. C. Bosch-Rekveldt, 2011).

The TOE division is based on literature review and case studies. Based on the literature review, the concepts of structural complexity, uncertainty, softer aspects and environment were incorporated in the model. Structural complexity and uncertainty is the operationalization of Baccarini's (2006) definition by Williams (2002). The main themes are differentiation, interdependence and uncertainty in goals and methods. Apart from these aspects, the model also assumes the softer aspects and environmental aspects as having influence on project complexity. Williams' (2002) concept was built upon by Geraldi (2007). She added soft aspect he deemed important for project complexity to Williams' (2002) concept: complexity of interaction (J.G. Geraldi & Adlbrecht, 2007). This is aimed at the interaction interface between organizations and people. The earlier mentioned work of de Bruijn et. al. (1996) in identifying the softer aspects of complexity reinforced the adoption of the soft aspects into the model. De Bruijn et. al (1996) divided project complexity into technical, organizational and social complexity. This distinction is largely adopted in the TOE framework. The model relates technical complexity to technological uncertainty, uniqueness of a project and technological dynamics. Organizational complexity is linked to the organizational structure, involved actors and their interests and the project team. Environmental complexity includes environmental influences such as stakeholders and weather.

The model does not consider risk as an uncertainty. Instead, it adopts the view of Perminova, Gustafsson, and Wikström (2008) who think of risk as one of the implications of uncertainty. Figure 5 shows the TOE-Framework for grasping project complexity.

TOE	Sub-ordering	ID	Source L/E/B[1]	Elements defined	Explanation
T	Goals	TG1	L	Number of goals	What is the number of strategic project goals?
T	Goals	TG2	B	Goal alignment	Are the project goals aligned?
T	Goals	TG3	B	Clarity of goals	Are the project goals clear amongst the project team?
T	Scope	TS1	B	Scope largeness	What is the largeness of the scope, e.g. the number of official deliverables involved in the project?
T	Scope	TS2	B	Uncertainties in scope	Are there uncertainties in the scope?
T	Scope	TS3	E	Quality requirements	Are there strict quality requirements regarding the project deliverables?
T	Tasks	TT1	B	Number of tasks	What is the number of tasks involved?
T	Tasks	TT2	B	Variety of tasks	Does the project have a variety of tasks (e.g. different types of tasks)?
T	Tasks	TT3	B	Dependencies between tasks	What is the number and nature of dependencies between the tasks?
T	Tasks	TT4	B	Uncertainty in methods	Are there uncertainties in the technical methods to be applied?
T	Tasks	TT5	B	Interrelations between technical Processes	To what extent do technical processes in this project have interrelations with existing processes?
T	Tasks	TT6	B	Conflicting norms and standards	Are there conflicting design standards and country specific norms involved in the project?
T	Experience	TE1	B	Newness of technology (world-wide)	Did the project make use of new technology, e.g. non-proven technology (technology which is new in the world, not only new to the company!)?
T	Experience	TE2	B	Experience with technology	Do the involved parties have experience with the technology involved?
T	Risk	TR1	B	Technical risks	Do you consider the project being high risk (number, probability and/or impact of) in terms of technical risks?
O	Size	OS1	L	Project duration	What is the planned duration of the project?
O	Size	OS2	B	Compatibility of different project management methods and tools	Do you expect compatibility issues regarding project management methodology or project management tools?
O	Size	OS3	B	Size in CAPEX	What is the estimated CAPEX of the project?
O	Size	OS4	B	Size in Engineering hours	What is the (expected) amount of engineering hours in the project?
O	Size	OS5	B	Size of project team	How many persons are within the project team?
O	Size	OS6	E	Size of site area	What is the size of the site area in square meters?
O	Size	OS7	B	Number of locations	How many site locations are involved in the project, including contractor sites?
O	Resources	ORE1		B	Project drive Is there strong project drive (cost, quality, schedule)?
O	Resources	ORE2	B	Resource and skills availability	Are the resources (materials, personnel) and skills required in the project, available?
O	Resources	ORE3	B	Experience with parties involved	Do you have experience with the parties involved in the project (JV partner, contractor, supplier, etc.)?
O	Resources	ORE4	E	HSSE awareness	Are involved parties aware of health, safety, security and environment (HSSE) importance?
O	Resources	ORE5	B	Interfaces between different disciplines	Are there interfaces between different disciplines involved in the project (mechanical, electrical, chemical, civil, finance, legal, communication, accounting, etc.) that could lead to interface problems?
O	Resources	ORE6	B	Number of financial resources	How many financial resources does the project have (e.g. own investment, bank investment, JV-parties, subsidies, etc.)?
O	Resources	ORE7	B	Contract types	Are there different main contract types involved?
O	Project team	OP1	B	Number of different nationalities	What is the number of different nationalities involved in the project team?
O	Project team	OP2	B	Number of different languages	How many different languages were used in the project for work or work related communication?
O	Project team	OP3	B	Cooperation JV partner	Do you cooperate with a JV partner in the project?
O	Project team	OP4	B	Overlapping office hours	How many overlapping office hours does the project have because of different time zones involved?
O	Trust	OT1	B	Trust in project team	Do you trust the project team members (incl JV partner if applicable)
O	Trust	OT2	B	Trust in contractor	Do you trust the contractor(s)?
O	Risk	OR1	B	Organizational risks	Do you consider the project being high risk (number, probability a nd/or impact of) in terms of organizational risks?
E	Stakeholders	ES1	B	Number of stakeholders	What is the number of stakeholders (all parties (internal and external) around the table, pm=1, project team=1, NGOs, suppliers, contractors, governments)?
E	Stakeholders	ES2	B	Variety of stakeholders' perspectives	Do different stakeholders have different perspectives?
E	Stakeholders	ES3	B	Dependencies on other stakeholders	What is the number and nature of dependencies on other stakeholders?
E	Stakeholders	ES4	B	Political influence	Does the political situation influence the project?
E	Stakeholders	ES5	B	Company internal support	Is there internal support (management support) for the project?
E	Stakeholders	ES6	B	Required local content	What is the required local content?
E	Location	EL1	E	Interference with existing site	Do you expect interference with the current site or the current use of the (foreseen) project location?
E	Location	EL2	E	Weather conditions	Do you expect unstable and/or extreme weather conditions; could they potentially influence the project progress?
E	Location	EL3	E	Remoteness of location	How remote is the location?
E	Location	EL4	E	Experience in the country	Do the involved parties have experience in that country?
E	Market conditions	EM1	E	Internal strategic pressure	Is there internal strategic pressure from the business?
E	Market conditions	EM2	B	Stability project environment	Is the project environment stable (e.g. exchange rates, raw material pricing)?
E	Market conditions	EM3	B	Level of competition	What is the level of competition (e.g. related to market conditions)?
E	Risk	ER1	B	Risks from environment	Do you consider the project being high risk (number, probability and/or impact of) in terms of risk from the environment?

[1]L = based on literature data, E = based on empirical data, B = based on both literature and empirical data.

Figure 6: TOE-Framework for assessing project complexity(M. Bosch-Rekveldt et al., 2011)

3.3 Choosing the model

Gidado (1996) bases his views on project complexity on mathematician von Neumann's principles: Complexity could be numerically measured, like any other system observable, if it was to be related to such things as the dimension of a state space, the length of a programme (schedule) or the magnitude of a "cost" in money or time. There is a threshold of complexity, below which systems behave in some simple sense (Gidado, 1996; Rosen, 1987).

Gidado's (1996) model on the numeric influence of project complexity on project cost and planning is based on these principles and is heavily focused on technical complexity. This chapter's introductory paragraph on project complexity mentioned the softer aspects of project complexity and does not support this notion that project complexity is of a purely technical character. The interest of the present research lies not in the quantitative optimization of scheduled activities as a result of project complexity. Instead, the qualitative influence of project complexity on the planning process as a whole is explored, as it is a people process (Weaver, 2010, 2014) and requires sharing of information (Currie, 1977).

Taking Obdam's (2016) recommendations into account, the TOE-Framework of grasping project complexity is well suited to be used with present research as it meets the requirements set by Obdam and is developed in the context of construction engineering projects. The TOE-Framework is also a more comprehensive and elaborated project complexity model, as it is intended to be used as a complexity assessment model across the process industry. The framework is used in the case studies to identify which elements of the framework have influenced the outcome of the project, and what its interface with the planning process is. This is in line with the intended application by the authors of the framework as a complexity assessment tool .The case-study protocol further described the use of the framework.

3.4 Using the model

The TOE-Framework for project complexity consists of 46 complexity elements, categorized in technical complexity elements (15 elements), organizational complexity elements (21 elements) and environmental complexity elements (10 elements). The framework comes is used in the case studies. Per case, interviewees are asked to identify the project complexity elements from this framework that have contributed to cost and/or time overruns. After the identification, the interviewees are asked how the elements contributed to the cost/and or time overruns. Figure 6 shows a snippet of the research framework where the complexity assessment framework comes into play.

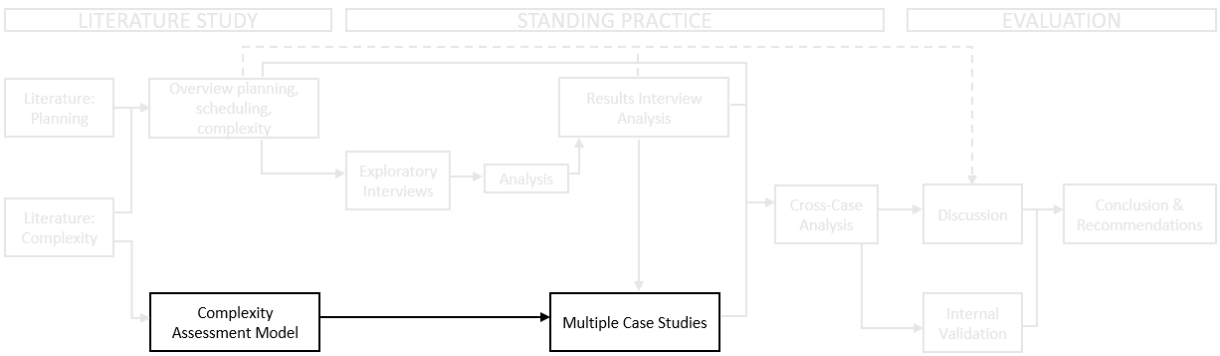


Figure 7: Research framework - using complexity assessment model

3.5 Answering sub-question(s)

Sub-question 1 : *How is project complexity defined in literature?*
The is no widely held definition of project complexity. Various definitions are mentioned and used by academics. Baccarini's definition of complexity as "consisting of many varied interrelated parts that can be operationalized in terms of differentiation and interdependence" (Baccarini, 1996, p. 202) is most common. The diversity in project complexity definitions might be explained by its intuitive nature (M. G. C. Bosch-Rekveldt, 2011). These is also a lack of consensus on a project complexity approach, distinguishing two approaches: the first approach assumes that a relatively objective statement can be made from multiple subjective perceptions; second assumed a project to be equivalent to a system and its characteristics, where theory on project complexity is applied to project management. Based on these findings, in the subsequent sections, research is conducted to find a suitable model to assess project complexity in context of the present research (infrastructure projects). The model is used in assessing project complexity in the case studies and finding its interface with the planning process.

Sub-question 2: W*hich project complexity assessment model(s) can be used to identify complexity factors?*
The TOE-Framework for project complexity can be used because it was developed with engineering projects in mind, and by having a balance of qualitative and quantitative elements. The intended application the framework is to prepare the project team for what complexities might arise, and it is proposed that it could be used to assess and evaluate the project complexity in different project phases.

4. Planning and scheduling

The goal of this chapter is to answer the following research questions:

3. How is the planning process described in literature?
4. How does Heijmans' planning process compare to literature?

4.1 Difference planning and scheduling

A brief history of planning and scheduling development can be found in Appendix B. Project planning is more than the creation of time schedules as time is only one aspect of planning. Cost, safety, quality, production and design are also aspects to be considered in planning (CIOB, 2011). A few definitions are singled out in order to understand the importance and broader context of planning:

- Planning is the determination and communication of an intended course of action incorporating detailed methods showing time, place and the resources required (CIOB, 2011).
- Planning is the production of budgets, schedules, and other detailed specifications of the steps to be followed and the constraints to be obeyed in project realization (Ballard & Howell, 1998a)
- Faniran et. al describe the planning process as "*the process of determining appropriate strategies for the achievement of predefined project objectives. In construction projects, the objective of planning is the completion of a prescribed amount of work within a fixed time, at a previously estimated cost, and to specified standards of quality*" (Faniran, Oluwoye, & Lenard, 1998, p. 245).
- Planning is 'the creative and demanding mental activity of working out what has to be done, how, and when, by whom, and with what, i.e. doing the job in the mind' (Neale & Neale, 1989).

Project planning and scheduling, although they are allied disciplines, are not the same. Project planning is a team operation involving the management team, cost control team, design team, construction team and maintenance team. Planners create the project development strategy. Whereas scheduling is a mixture of art and science, involving the interpretation of the results of project planning by using appropriate software tools and techniques to ascertain, amongst other things, the start and finish dates of activities and their sequence. Though planning and scheduling are described as an iterative process, scheduling is the result of planning and should thus precede scheduling. Planning is obligatory, regardless of the type of construction project. Similarly, regardless of the type of project a schedule needs to be produced, varying from the simplest of form to the most complex.

4.2 The planning process

There are various depictions of the construction project life-cycle, from inception to (post)completion. What all of the models have in common is the general phases of construction (Cooke & Williams, 2013): tender phase, pre-contract phase and the construction phase.

In the tender phase, a price for executing the construction work as specified by the client is submitted by the contractor based on their cost estimates and willingness to accept the risk/reward tradeoff of the project. Planning and scheduling in this phase is key. The chosen construction method and the resulting schedule heavily influence these estimates, determining (Cooke & Williams, 2013):

- Duration and sequences of (key) activities
- Use and timing of sub-contractors
- Workflow (material delivery)
- Duration of on-costs (material transport, supervision etc.)

The pre-contract phase is the period between the rewarding of contract to the contractor and the commencement of work. The focus of this phase is to facilitate the efforts to start on-site work, where planners and scheduler have a role in alignment of key aspects of the work from tender to realization. Due to the abundance of information in this phase, communication is of utmost importance in order to work with the most recent and updated information. The contract phase is the period commencing the start of work on-site until completion. Contract planning is mostly concerned with construction progress.

The planning relation efforts per phase are shown in Table 1. It is very important that project knowledge is transferred between these main project phases (Baldwin & Bordoli, 2014). Preferably, key management positions involved in planning should transition from tender to realization, and the plans made in the tender phase should not be deviated from (Baldwin & Bordoli, 2014; Cooke & Williams, 2013).

	TENDER PHASE	PRE-CONTRACT PHASE	CONSTRUCTION PHASE
PLANNING EFFORTS	▪ Decision to tender ▪ Pre-tender arrangements ▪ Site visit report ▪ Enquiries to subcontractors and suppliers ▪ Tender Method Statement ▪ Build-up estimate ▪ Pre-tender programme ▪ Build up preliminaries ▪ Response to pre-construction Health and Safety ▪ information ▪ Tender risk assessment ▪ Management adjudication ▪ Analysis of tender performance	▪ Pre-contract meeting and arrangements for commencing work ▪ Place subcontractor orders ▪ Site layout planning ▪ Construction method statement ▪ Drafting master schedule ▪ Requirement schedules ▪ Contract budget forecasts ▪ Risk Assessment ▪ Preparation and approval of the construction ▪ health and safety plan	▪ Monthly scheduling (long term) ▪ Weekly scheduling (short term) ▪ Progress Reporting ▪ Cost and Value Reconciliation ▪ Report to management ▪ Review/update the health and safety plan

Table 3: Project phase and planning relation actions, adapted from (Cooke & Williams, 2013)

The pre-contract phase and contract phase are within the scope of this research. The main concern of these phases is scheduling and the process of schedule reporting and schedule maintenance (Baldwin & Bordoli, 2014; Cooke & Williams, 2013). It is thus of importance to focus on the scheduling part of the planning process. Due to the fragmented nature of the construction industry, the different parties involved have their own requirements that will be reflected within their own specific schedules. Looking at the contractor's organization, a project manager, site engineer, site agent and work-gang leader (Dutch: ploegleider) will have different schedules. The importance lies in enabling the organization to integrate the schedules to benefit the planning process (Baldwin & Bordoli, 2014). The next section will discuss schedule monitoring and reporting in complex project as prescribed in literature.

4.2.2 Schedule reporting levels

Over the years, the demand for standardization in schedule design grew in light of increasing complexity of projects, and more structure and integration was required in the levels of information provided by the schedules (Baldwin & Bordoli, 2014). The Project Management Institute (PMI, 2007) recommends five schedule reporting levels. These reporting levels are also recommended by the CIOB in their "Guide to Good Practice in the Management of Time in Complex Projects" (CIOB, 2011). This five-levels model of schedule reporting for a single project is commonly accepted (Baldwin & Bordoli, 2014; CIOB, 2011).

The key is to integrate the schedules from the different reporting levels. Schedule density comes into play here (CIOB, 2011):

- Low Density: Appropriate for work intended to take place 9 month or more after the schedule date
- Medium density: Appropriate for work intended to take place between 3 and 9 months
- High density: Appropriate for work that is intended to take place within 3 months after the schedule date

In essence, the closer the scheduled work is, the more information is available for detailed scheduling. Higher density schedulers are breakdowns of the work into more detailed segments. The concept of schedule density is portrayed in Figure 3 below.

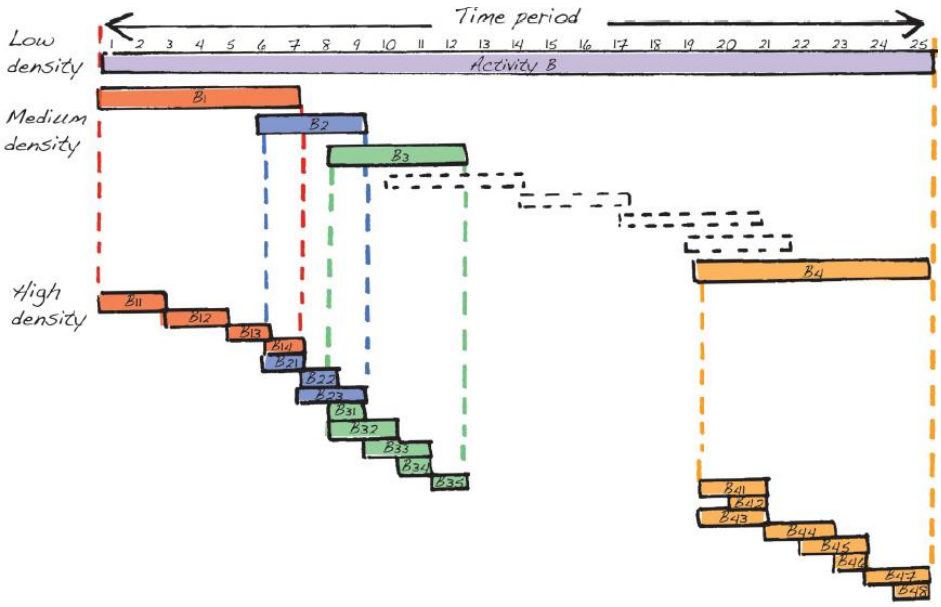


Figure 8: Illustration of schedule density (CIOB, 2011)

The schedule reporting levels and the accompanying schedule densities also aid in efficiently monitoring and reporting scheduled activities. Project personnel on various levels are in that way concerned with the information they are responsible for. Senior project management personnel are concerned with the general project milestones, i.e. the low density schedule at the lowest level. The detail-schedulers and sub-contractors are concerned with timing and duration of the project activities and are thus concerned with the high density schedule.

The reporting levels, the accompanying densities, tasks and responsibilities are described below (Baldwin & Bordoli, 2014; CIOB, 2011).

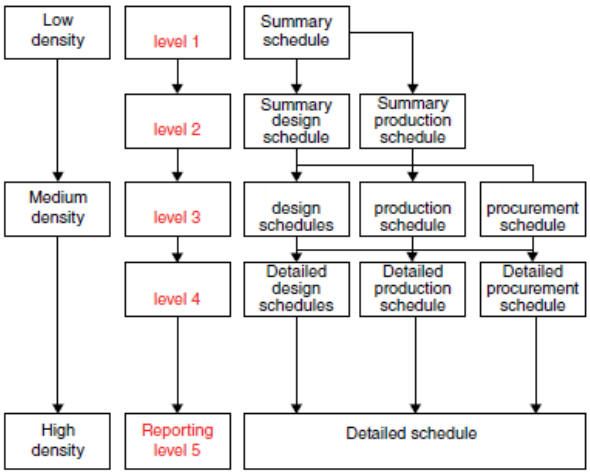


Figure 9: 5-Level schedule reporting structure (Baldwin & Bordoli, 2014)

<u>**Level 1:** Executive summary schedule report- low density</u>
The Level 1 schedule is the highest possible reporting level on the project. It gives an overview of the contractual milestones. It is also known as the master schedule, or executive summary report, because it's a summary of all the lower level reports (Level 2-5). The critical path through this schedule should be clear. The senior project management team and project director are mostly concerned with the progress of the Level 1 schedule. Milestones set in this schedule are tied to payments and delay of these milestones tied to fines

<u>**Level 2**: Senior management report – low/med density</u>
The Level 2 report is for senior management. It is a summary of the Level 3 schedule. The report should be divided into major components on the basis of areas or elements within the project. The report may be a single schedule that combines details from different schedules or a suite of individual schedules. Ideally, one person should produce the schedule. The schedule should enable all concerned within each element of the project to fully understand what needs to be done and how their work interfaces with other elements. The report should enable progress on each element to be monitored. On smaller projects, Level 2 reports may not be required.

<u>**Level 3**: Project manager's report – med density</u>
The Level 3 schedule, also known as project manager's schedule, shows in detail the timing of project activities and the critical path that goes through these activities. All the elements of the work must be considered. The distinction between on-site and off-site activities must be clear within the Level 3 schedule. Sub-contracts are also involved as the Level 3 schedule incorporated their activities, which must be agreed upon by the said sub-contractors.

<u>**Level 4**: Section manager's report – med/high density</u>
The Level 4 schedule is a more detailed schedule, stemming from the Level 3 schedule. Level 4 information is multidisciplinary as the information presented relates to specific aspects or areas of the project. The Level 4 schedule is concerned with work to be undertaken in short-term (weeks) and medium-term (months). Modern project management software tools provide options for activity coding. This makes it possible to directly derive the Level 4 schedule form the Level 3 schedule, but also integrate the Level 4 schedule with the Level 3 schedule.

Level 5: (Sub)contractor's schedule report – high density
The Level 5 report is a more detailed Level 4 report and specifies, in high detail, all the activities and their timing, undertaken by sub-contractors and different trades. The different trades and sub-contractors have their own specific Level 5 schedules containing detailed activities on how the work will be executed. However, all the activities are aligned with the Level 3 (and thus) Level 4 schedule. This schedule is used as guideline for the realization of works by work-gang leaders. Level 5 schedules are short term. The critical path should be incorporated in the Level 5 schedule.

Level 1-3 schedules should ideally be produced by a single scheduler. The Level 4 and 5 schedules are produces by different people depending on the trade/discipline (Baldwin & Bordoli, 2014; CIOB, 2011). To operate efficiently, the five levels of schedule described above must form a set of coordinated schedules where activities are integrated and where, importantly, the timing of the activities (and sub-activities) is clearly evident and consistent. Ideally, the schedules should be produced in a 'top-down' way whereby the Level 1 schedule is produced, agreed with all parties and then used to form the basis of Level 2, then Level 3 schedules and so on. Given the time available, the number of parties concerned and often their different locations, this may not always be possible. More often, schedules are created and maintained as standalone programmes and then combined to produce schedules at a higher level. This 'real-world' situation demands clear rules for both the timing of schedule production and the content required. Schedule production needs to be planned, agreed and actively managed (Baldwin & Bordoli, 2014; CIOB, 2011).

4.3 Heijmans' planning process

The planning process and schedule reporting levels described in sections 4.1-4.2 are mentioned in literature in context of complex projects. The five-level schedule reporting process is prescribed in various publications and specifically mentioned in the context of complexity in "Guide to Good Practice in the Management of Time in Complex Projects" (CIOB, 2011). It is thus important to analyze how Heijmans' internal planning process compares to what is found in literature to see if Heijmans applies the state of the art.
Heijmans' "Planningsmanagement Handboek" (Heijmans, 2015), the planning and scheduling policy documents, shows strong resemblance to the integrated and structured approach prescribed in literature and outlined above. This approach is intended to address the need for a certain degree of standardization that became apparent due to the increasing complexity of projects (Baldwin & Bordoli, 2014; CIOB, 2011). In literature, drafting and reporting the Level 1-3 schedule (overall-schedule) is advised to be done by a single person through multidisciplinary input. In practice, this is also done by a single head-scheduler, overseeing the schedules of the different disciplines.
The integration between Level 3 and Level 4 schedules (overall and detail schedules) is crucial. An integrated approach, and integration in general, is also heavily dependent on sharing of information and knowledge (Baldwin & Bordoli, 2014; CIOB, 2011; Weaver, 2010, 2014). The schedulers in the planning process as described in literature and in the HPM are dependent on the information they receive from planning sessions. Also, within the described planning process, it must be monitored that the bandwidth allowed by the overall-schedule (level 1-3) is not exceeded by the detail-schedules (level 3-4). The followed planning process is thus a standard process design as described in literatures that focuses on structuring and integrating a schedule reporting breakdown. Heijmans' planning process shows strong resemblance to what was found in literature because it's modeled after the recommended process by The Project Management Institute (PMI, 2007), whose recommendations are used in other areas by Heijmans as well.

4.4 Answering sub-question(s)

Sub-question 4: *How is the planning process described in literature?*
There are various depictions of the construction project life-cycle, from inception to (post)completion. What all of the models have in common is the general phases of construction (Cooke & Williams, 2013): tender phase, pre-contract phase and the contract phase. The planning related efforts per project phase are shown in Table 1 (p. 19).
The pre-contract phase and contract phase are within the scope of this research. The main concern of these phases is scheduling and the process of schedule reporting and maintenance (Baldwin & Bordoli, 2014; Cooke & Williams, 2013), which will be the focus of the subsequent chapters. A five-level schedule reporting structure is mentioned and advised in literature in context of complex projects. In this structure, a construction schedule is divided into five levels. Each levels has its own schedule density, which is the detail in which activities are scheduled. The closer the scheduled work is to execution, the higher the schedule density on the activities. This five-level structure also assigns roles and responsibilities in schedule reporting. The level 1 schedule is a low density executive summary intended for the project director and project management team. The level 2 schedule is the senior management report. The level 3 schedule is the project manager's report at medium density. In literature, a single scheduler is advised to draft the level 1-3 schedules. The level 4 and 5 schedules are medium to high density schedules drafted by the various disciplines, involving the work per discipline. The level 3 schedule sets the bandwidth in which the level 4 and 5 schedules are drafted. It is key to integrate the level 4 schedule with the level 3 schedule. A figure of this breakdown is shown in Figures 8 and 9.

Sub-question 5: *How does Heijmans' planning process compare to literature?*
Heijmans' "Planningsmanagement Handboek" (Heijmans, 2015) shows strong resemblance to the integrated and structured approach prescribed in literature and outlined in section 4.2. In literature, drafting and reporting the Level 1-3 schedule (overall-schedule) is advised to be done by a single person through multidisciplinary input. In practice, this is also done by a single head-scheduler, overseeing the schedules of the different disciplines.

5. Overview planning, scheduling and complexity

5.1 Answering sub-question(s)

The whole section below is the answer to research question 5: *"What is the present literature body of knowledge on the effect of project complexity on the planning process?"*

Planning is scheduling is part of a construction project. The important thing is to take into consideration what characterizes construction projects and how the process of planning and scheduling is affected by these characteristics. Winch (2002) argues that construction projects are characterized by uncertainty and that it is central to the management of projects:
"*The management of construction projects is a problem in information, or rather, a problem in the lack of information required for decision making. In order to keep the project rolling, decisions have to be made before all the information required for the decision is available*" (Winch, 2002, p. 32). The planning process needs to be seen in this context of information flow and uncertainty (Baldwin & Bordoli, 2014; Winch, 2002). Curry (1977) argues that planning requires active sharing of information. The information flow needs to be relevant to the roles of planners and schedulers. This is not always the case, as they typically spend a large amount of time on searching through information provided to them (Baldwin & Bordoli, 2014). This is one of the arguments why detailed scheduling must be done by and decentralized to the parties responsible for the realization of the works, in a way that is compatible with integrated schedule management (Ballard & Howell, 1998b; Barber, Tomkins, & Graves, 1999; Faniran, Love, & Li, 1999). The issues regarding information flow and uncertainty lead to the adoption of an integrated approach to planning and scheduling, where sharing of information though a standard process design is key (CIOB, 2011; Cooke & Williams, 2013; Curry, 1977; Weaver, 2014; Winch & Kelsey, 2005).

Weaver (2010) states that the scheduler has three roles:
1. Commitment planning : the scheduler gains consensus from the project bit team in working out time aspects and delivery strategies.
2. Realization scheduling : the scheduler assembles and integrates information needed from the project team in order to develop the project implementation schedule.
3. Performance control : the scheduler has a supporting role during the realization of a project by maintaining the schedule.

Weaver (2014) argues that the understanding of these roles is insufficiently present in complex projects because after having learned to operate scheduling software by trial and error, schedulers are too focused on the tool rather than the process of planning and scheduling. Weaver (2014) argues that this tool centric focus is not sufficient in complex projects as planning and scheduling are social activities requiring good interpersonal, managerial skills, which schedulers do not or insufficiently possess. These managerial skills and attributes have not been part of the traditional role of a scheduler (Baldwin & Bordoli, 2014; CIOB, 2011; Weaver, 2010). It is thus interesting to explore how manager see the role of the scheduler in complex projects.
Summarizing the findings in this chapter, the followings points are found to be of importance to the planning process (and are seen as part of the planning process) and are referred to from this point on as 'key concepts':

- Sharing of information (Baldwin & Bordoli, 2014; Cooke & Williams, 2013; Curry, 1977)
- Standard planning and scheduling process design (Baldwin & Bordoli, 2014; CIOB, 2011)
- Role of planner and scheduler (Weaver, 2014)

PART III:
STANDING PRACTICE

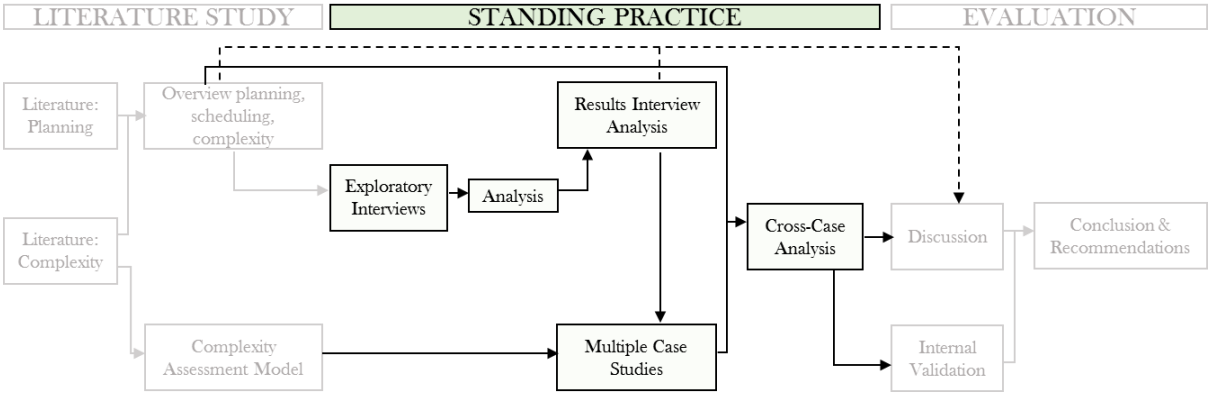


Figure 10: Research framework - standing practice

6. Exploratory interviews

The goal of this chapter is answer the following research questions:

6. What are the views on the influence of project complexity on the planning process by the professionals involved?

6.1 Approach

The concepts and guidelines described in the book 'Interviewen: theorie, techniek en training' (Emans, 2002) are used to determine the interview methodology and choose an approach. In Chapter 5, the following three key concepts were found to be of importance to the planning process (p. 24).

- Sharing of information (Baldwin & Bordoli, 2014; Cooke & Williams, 2013; Curry, 1977)
- Standard planning and scheduling process design (Baldwin & Bordoli, 2014; CIOB, 2011)
- Role of planner and scheduler (Weaver, 2014)

No explicit mentions could be found in literature on the effect of project complexity on the planning process. Therefore professionals involved in the planning process are consulted to see what their view is on the influence of project complexity on the three aspects of project planning above, by means of exploratory interviews. Due to this exploratory nature, a semi-structured approach is chosen, structured around six main questions. All participants will be asked these same questions. A semi-structured approach allows for additional unscripted questions when in need of additional information.

6.1.1 Interview Protocol

- Participants are invited to an exploratory interview, participation is voluntary
- All participants work for Heijmans' infrastructure process management department (Heijmans Infra).
- Participants were informed on the research topic when asked about their views on the current planning process.
- Participants were informed on the research topic when asked about their views on the planning process when project complexity increases.
- Participants were asked the same main questions, which differ for planners/project managers and for schedulers
- All interviews were recorded with permission
- All interviews were transcribed to facilitate qualitative data analysis
- In order to ensure an open interview, the recordings, transcripts and participants' names are not included in this report. Summarized interpretation of the interviews were confirmed prior to data analysis.
- Participants were unaware of the answers from other participants
- Participants had the possibility to share their opinion, give feedback and give suggestions for further improvement of the research and interviews.

A list of planners/ project managers to approach was suggested by Heijmans. All the in-house schedulers have been approached and all of them participated. In total, seven schedulers (head-schedulers and detail-schedulers) and five managers (process manager, realization manager, two project managers and head of the 'process and environment management' department participated. All the manager and five schedulers have experience with complex projects.

6.2 Interview questions

Key Concept	Question	Code: schedulers	Code: planners/managers
Role related: Scheduler	1. How do you fulfill your role in the planning process? *In case the role fulfillment differs from traditional scheduling (table x)* 1a. How is the support for this approach from planners? 1b. How is the appreciation for this approach from the rest of the team?	1 S: Role fulfillment 1a. S: Role support 1b. S: Role appreciation	
Role related: Planner/project manager	1. How should the role of the scheduler be fulfilled and why? *In case the role fulfillment differs from traditional scheduling (table x)* 1a. Is there support for this approach?		2 PM: Role fulfillment 1a. PM: Role support
Information related	2. How is the required information for adequate planning and scheduling shared and transferred?	2 S: Information/ knowledge transfer	2 PM: Information/ knowledge transfer
Standard process design related	3. What is your view on standardization in the planning process?	3 S: View on standardization	3 PM: View on standardization
View on improvements and bad practice	4. What aspects related to planning and scheduling should be improved in your view and why?	4 S: Areas of improvement	4 PM: Areas of improvement

Table 4: Exploratory interview questions and their code

The first column of the table presents the topic of the questions, taken from the key concepts. One topic is added: the view of professionals on improvements and bad practice in the planning process. This is to gather additional information that might not be covered the three key concepts. The second column presents the transformation of the key concept into interview questions. The third and fourth columns present the transformation of interview questions into codes. These codes are used to facilitate data analysis (see section 6.3).

6.3 Analysis methodology

Table 2 on the next page shows the outline of the exploratory interview analysis process.

1. Collecting data : In the first step, data is gathered though semi-structured exploratory interviews (see previous sections for the interview protocol and main questions to be asked).
2. Organizing data : The data is organized to facilitate a qualitative data analysis. The interview transcripts were imported into ATLAS.ti. This is a software tool that organizes data and facilitates in qualitative data analysis. It is used as the interview and case-study analysis tool. The software works with codes and quotations. It defines a code as a conceptual construct through which data is accessed. It intends to capture meaning in the data. The codes are linked to quotations. Quotations are defined as a segment from a document that is interesting or important to the users.

3. Coding data : After importing the data in the software, the transcripts are coded. The main interview questions serve as primary codes. The full answers to the interview questions are designated as quotations. Open coding is applied in order to identify, name, categorize and describe phenomena found in the interview answers. The codes that are assigned to the main questions are found in the third and fourth columns of Table 2 (27). The main questions for schedulers and for managers are assigned different codes in order to sort the answers given. It's worth to mention that open coding is an approach in which the researcher assigns codes to the documents at hand. The networked view is a result of the researchers understanding of the interview data. The key codes (main interview questions) and the relations are described.
4. Code sorting : After coding the transcripts, the codes were sorted and grouped based on common properties. This is to prevent multiple codes describing the same phenomenon.
5. Code networking : The second to last step is the visualization of the relation between codes. A visualization in the form of a code network gives direct insights into the code relations.
6. Interpreting : Finally, the relations between codes are interpreted and analyzed.

Further elaboration and an example of this data analysis methodology is given in Appendix C1.

Process Step	Actions
1: Collecting data	▪ Semi-structured interviews
2: Organizing data	▪ Transcribing interviews ▪ Importing transcript into ATLAS.ti
3: Coding data	▪ Coding transcripts
4: Code sorting and grouping	▪ Grouping codes based on common properties
5: Code networking	▪ Visualizing relations between codes
6: Analysis	▪ Interpreting the relations between codes

Table 5: Data analysis process exploratory interviews

6.4 Interview Analysis

6.4.1 Interview analysis: consensus managers and schedulers

This section provides the combined analysis of the interviews with the schedulers and the managers. Figure 11 shows the joint network diagram of managers and schedulers. Three code groups are separated in this diagram: codes assigned to answers by managers only, codes assigned to responses by schedulers only, and codes assigned to answers by planners and managers where they are in agreement. The separate analyses of the interviews with the schedulers and managers can be found in Appendix C3. The list of codes and what they describe can be found in Appendix C2.. In total, 21 codes were assigned to the answers given. 13 codes overlap, 5 codes are exclusive to schedulers and three codes are exclusive to schedulers.

All the interviewees that had experience in (in their view) complex projects mentioned that in complex projects, the information requirements but also the information sources increase. Both managers and schedulers mentioned that maintaining a schedule so that it is the actual representation of the work to be done is heavily dependent on information and knowledge sharing. According to managers, this increasing information requirement should urge head-schedulers to work in a more proactive way by proactively gathering information. Especially because head-schedulers are responsible for integrating various schedule in a single project schedule (level 1-3). Traditionally, schedulers are seen as experts in scheduling tools and software. They are provided information by various disciplines within a project. The traditional role of the scheduler is to update the schedule, set the new progress line and calculate the effect on the critical path.

Five out of seven schedulers mentioned that in complex projects, this traditional approach does not suffice for the head-scheduler position. They take initiative in a pro-active way in order to acquire the required information to draft and maintain the construction schedule. One of the two schedulers that did not support this notion was a junior scheduler without experience in complex projects. The other is a senior scheduler that admitted to have worked for most of his career in a more traditional way, passively maintaining the construction schedule by the information he is provided. All the schedulers agreed that when it comes to knowledge/information sharing, key personnel involved in the tender phase of the project should transition to at least part of the execution phase.

The schedulers and manager (with experience in complex projects) also agreed that in complex multidisciplinary projects, the head-scheduler is essentially an interface manager and needs to have the managerial competences to carry out that task. Being an expert in scheduling software does not suffice if you're a head-scheduler. Project complexity introduces more interdependences according to the interviewees and head-schedulers should monitor more the progress of the activities that are interdependent. This way, the information and actualities are integrated by the head-scheduler into the main project schedule. In the joint network diagram (figure 11), what was said about the active management approach by managers and schedulers overlaps each other. Schedulers and managers are in agreement in that regard. The network diagram also shows overlap in what was said about standardization, information sharing and areas of improvement.

The statements given by the schedulers and managers on the proactive scheduling requirement in complex projects is aimed at the position of head-scheduler. The head-scheduler is responsible

for integrating the level 4 schedules (scheduler per discipline) into the overall project schedule (level 3 schedule).

There are differences in answers given on the topic of standardization and areas of improvement, which can be explained by the roles of the interviewees: managers have suggested improvements from a managerial point of view (assessing project complexity and linking schedules) and schedulers suggested improvements from a scheduling point of view (scheduling design requirements, standard schedule activity database and availability planning logic).

When it comes to standardization, certain suggested practices that can be standardized were mentioned, also as areas of improvement. However, no relation could be made by the interviewees that standardization practices are the result of increasing complexity of projects. Instead, the suggested standardization aspects are practices to improve the scheduling process in general and are related to standardizing schedule presentation and schedule setup logic. An overview of the codes and what they entail is given in Appendix C2.

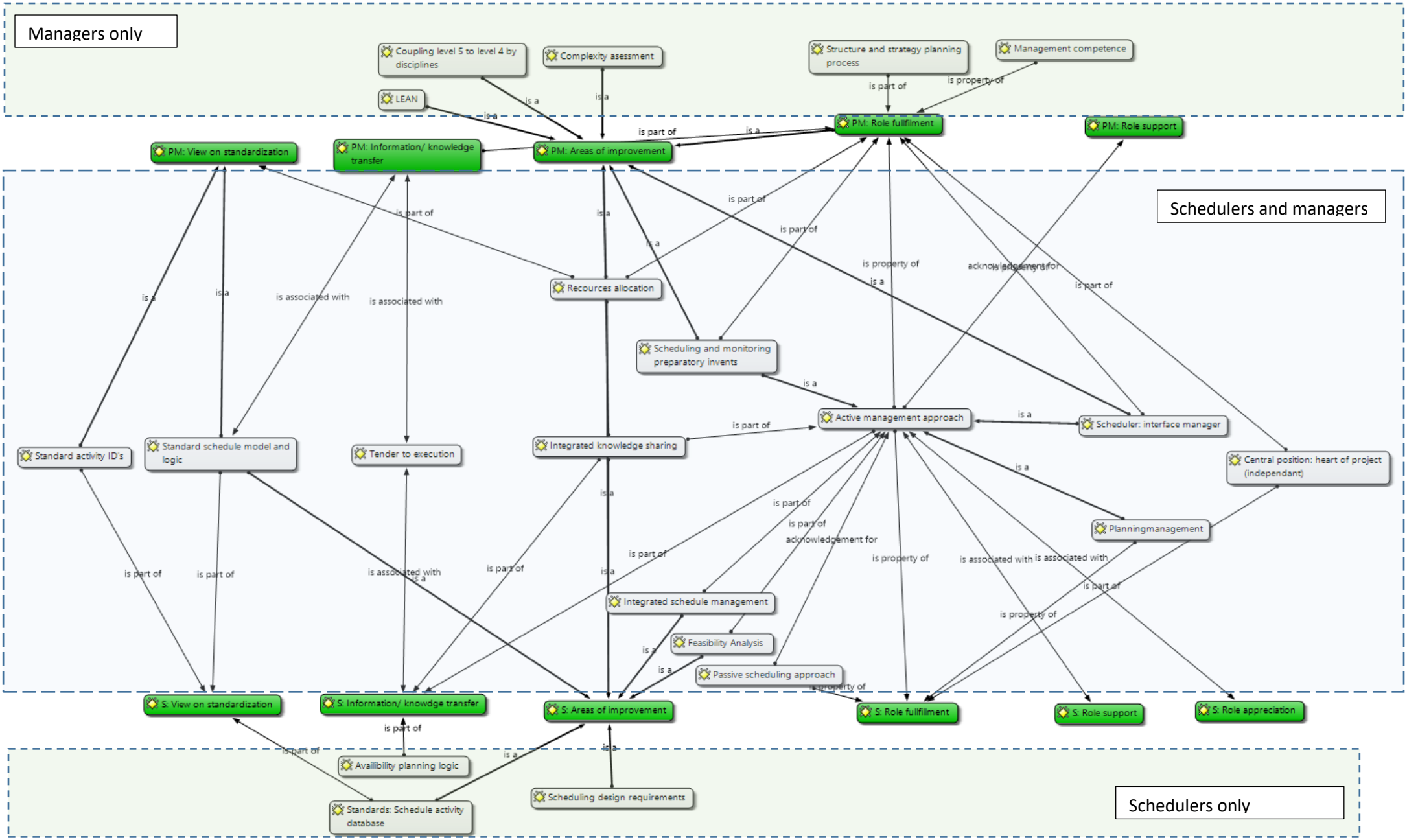


Figure 11: Joint code network of managers and schedulers

6.5 Answering sub-question(s)

Sub-question 6: *What are the views on the influence of project complexity on the planning process by the professionals involved?*

Table 4 below presents the exploratory interview answers and consensus on the literature based key concepts. What is mentioned in this table is related to project complexity. Most of the answers given on the areas of improvement (question 4) and all of the answers given on areas of standardization (question 3) are not related to project complexity.

Literature based key concepts (Ch. 5)	Schedulers	Managers	Exploratory interview consensus
▪ Sharing of information		LEAN scheduling is seen as an information sharing enabler by the managers. In complex projects, this aids in bringing people together to share knowledge.	The information requirement to draft and maintain a construction schedule increases along with the number of information sources. Also, there was a consensus on the notion that key personnel involved in the tender should transition from the tender phase to at least part of the construction phase. This in order to transfer key knowledge from tender to execution.
▪ Role of planner and scheduler			Due to the increased information requirement, (head) schedulers should have a more proactive role in gathering the information needed to monitor, update and integrate the various schedules into the overall schedule.
▪ Standard planning and scheduling process design	**There is a lack of consensus between both managers and schedulers on this topic. The suggestions for standardization are related to schedule presentation and logic, no relation was mentioned to project complexity. **		
Additional topics			
View on improvements and bad practices		A complexity assessment should be done according to the managers in order to assess what areas to focus the managerial efforts on.	The vast majority of the suggested improvements are a result of (sub-codes) the proactive approach to scheduling, on which there is consensus. They are also related to the enabling of information and knowledge sharing.

Table 6: Exploratory interview consensus managers and schedulers

The takeaways from the interviews largely overlap the key concepts form the literature study. In the next chapter, six case studies are conducted into project that are over budget and/or time (failure). The goal of the case studies is to identify the influence of project complexity on the failure of these projects, what their relation is to the planning process and the key concepts in Table 4.

7. Case studies

This chapter presents the structure and setup for the case studies. The introduction and problem analysis of this research states that the increasing complexity of projects contributes to cost and time overrun (Ch. 1.2). The unit of analysis in this research is on the level of a an infrastructure project, either delivered or still in execution, with cost and/or time overrun.

In chapter 5, based on a literature study, three key concepts that are of importance to the planning process were. These concepts are then explored by consulting professionals involved in the planning process though exploratory interviews. The goal of the case studies is to find what the influence of project complexity is/has been in the cost and/or time overrun of the selected cases and what its relation is to the planning process.

The goal of this chapter is answer the following research questions:
"Which project complexity elements of the chosen complexity model in sub-question 1 can be identified as contributing to project failure and having influence on the planning process?"

A multiple case study embedded approach, in which six cases are analyzed, is chosen in order to have sufficient basis for scientific generalization (Yin, 2009). The choice for three cases is based on time constraints for the present research and the availability of information sources.

7.1 Methods

7.1.1 Case-study design

Yin (2009) defines the case study design as "a plan that guides the investigator in the process of collecting, analyzing, and interpreting observations. It is a logical model of proof that allows the researchers to drawing inferences concerning causal relations among the variables under investigation" (Yin, 2009, p. 26). The case study design thus serves as the bridge between the collected data, conclusions and initial research questions.

A multiple-case study embedded design is followed due to the different aspects studied: general project information (including the planning process), complexity, project outcome and vision. Six cases are included in this research, which is what the multiplicity of the case study design refers to.

In total, six case studies are conducted. While two cases is seen as the bare minimum, three (or more) cases presents a better possibility of direct replication. Other benefits of three or more cases are that the analytic conclusions are more powerful and that contrast between cases can be shown better (Yin, 2009). The six projects that are selected as cases are part of Heijmans' project portfolio.

7.1.2 Sources of information and method selection

There are various ways to collect data to facilitate a case-study. In the context of the planning process, there are various ways to approach this. Yin (2009) describes six main sources of evidence: documentation, archival records, interviews, direct observations, participant observation and physical artifacts.

Interviews are best suited in context of present research due to its direct focus on case study topics and its possibilities in offering insight in perceived cause interferences and expiations. The limitations in physical retrievability of information (documentation, archival records) also points toward the selection of interviewing as a method. Thus, the case study design knows a single phase: in-depth case study through semi-structured interviews. A semi-structured approach allows for additional exploration of answers given, which can offer more insight into the course of a project and its outcome. The TOE-Framework or project complexity is used to find out which elements of the framework for assessing project complexity (section 3.3.2) have influenced project performance.

Per case, two professionals are interviewed:

1. Project manager of person at project manager function level
2. Scheduler or person who scheduler directly reports to (process manager).

7.1.3 Case study protocol

Interviewing, as a data gathering methodology, can lead to bias due to poorly articulated or formulated questions, response bias, inaccuracies due to poor recall and reflexivity (interviewee gives what interviewer wants to hear) (Yin, 2009). The following protocol is followed in order maximize the outcome and validity of the study:

- Prior to the start of the interview, interviewees are informed about the research topic
- Participants are asked the same main questions, which differ for project managers and for schedulers/process managers
- The questions asked are grouped into four themes:
  1. general project information (planning process included)
  2. complexity;
  3. project complexity and;
  4. vision.
- The questions are asked in numeric order of themes, starting with the general project information, closing with vision. The approach per group in table 5. The list of questions can be found in Appendix E.
- All interviews were recorded with permission
- All interviews were transcribed for purpose of data analysis
- Participants were unaware of the answers from other participants
- Participants had the possibility to share opinion, feedback and suggestions for further improvement of the case-study design
- Due to the sensitive nature of project failure as a result of time and budget overruns, the projects are anonymized. To facilitate an open interview, the interviewees were ensured that names of interviewees, transcripts, names of the projects and project details (budget, client etc.) are not included in publication of this research.

	GENERAL PROJECT INFORMATION	COMPLEXITY	PROJECT OUTCOME	VISION
GOAL	The goal of this part is to gain an understanding on the context of the project and gain general project information. Also, the setup of the planning process is explored in this part.	The goal of this part of the interview is to introduce the interviewee to project complexity and allow for a preliminary assessment of complexity on a high aggregation level (project is technically/organizationally, environmentally complex).	The goal of this part of the interview is to find which elements of complexity from the TOE-Framework for project complexity have influenced the project outcome or the state of the project at the time of the interview, what their influence was on the planning process and how they were coped with (if at all).	The final part of the interview allows the interviewee to give his/her vision on the role of the scheduler in complex projects.
APPROACH	▪ Interview questions	▪ Interview questions ▪ Brief interviewee on project complexity theory used in this research	▪ Interview questions ▪ Use TOE-Framework	▪ Interview questions

Table 7: Goal and approach interview segment

7.1.4 Case selection

In the introduction chapter and the problem statement of this research, it is mentioned that the increasing complexity of project is contributing to budget and time overrun. Studies into the definition of project success have been done where good project performance was defined as "delivering the project with sufficient quality, with less than 10% budget overrun and with less than 10% schedule overrun (with respect to the budget and schedule agreed at the final investment decision)" (M. G. C. Bosch-Rekveldt, 2011; Shenhar, Dvir, Levy, & Maltz, 2001). Overruns up to 10% are deemed acceptable by this definition. Not enough cases could be provided by Heijmans that have exceeded this 10% threshold, thus the selection criteria were broadened. Wamelink, Geraedts, Hobma, Lousberg, and de Jong (2010) link building projects to 5 control aspects: budget, time, organization, information and quality. The following selection criteria are defined:

1. Budget : Was the project delivered over budget?
2. Time : Was the project delayed?
3. Organization : Is the organizational structure of the project clear?
4. Information : Is information about the project accessible?
5. Quality : Did the project meet the specified quality?

Little amount of delivered infrastructure projects could be found within Heijmans that complied with all of these criteria, mainly because of the information criterion. Managers and schedulers involved in most completed, delivered projects had no sufficient recollection of the project to signify a meaningful analysis. Therefore, project that are still in execution where it is expected that it will be delivered with cost and or time overrun are also considered as a potential case. For this reason, the final selection criteria are:

1. Budget : Is the project delivered over budget; or is the project over budget at the point of the interview with the expectation that it will be delivered over budget?
2. Time : Is the project delivered over time; or is the project over time at the point of the interview with the expectation that it will be delivered over time?
3. Organization : Is the organizational structure of the project clear?
4. Information : Is information about the project available?

The criteria above can be combined in three ways in order for a project to be considered for case study:

Criteria:	1 Over budget?	2 Over time?	3 Organizational structure clear?	4 Information about the project available?
Answer	Yes	Yes	Yes	Yes
	Yes	No	Yes	Yes

Table 8: Case selection scenarios

Table 6 implies that a project needs to have budget and time overrun or just budget overrun to be considered a case. The reason for this is that an over budget project does not necessarily mean there were no planning related issues. Additional resources might have been spent to cope with the planning related issues. Therefore, project that are only over budget are not excluded from case study consideration. Similarly, a project that is delivered over time but not over budget is not considered for case study because in that case the exceedance of time had no direct ramifications. Six projects in realization or closing phase are selected that comply with these criteria and are thus the subject of the case studies. Due to the fact that some project were not yet delivered at the

time of writing this report, full anonymity of cases is promised and applied: no project name, no participant names, no project budget and overrun estimates. The interview questions can be found in Appendix E.

7.1.5 Data Analysis

A delay and disruption analysis is conducted in practice to explore what influenced project delays and overruns in over budget/time projects (Baldwin & Bordoli, 2014). A brief description of this analysis is given in Appendix D. Due to the scope of the project, time constraint and lack of knowledge about these analysis, a delay and disruption analysis was not feasible for this research. Like the analysis of the exploratory interviews, a qualitative analysis was done per case and across the different cases. The interview results per case were all transcribed and kept separate. Also, the interviews per case were summarized to get a general idea of the case.

Table 5 shows the themes that were explored per case. A broad picture about the project was sketched based on the answers given in the general project information theme. Information about the setup of the planning process per case is assessed as well. After the broad picture was sketched, project complexity in relation to the case was explored by used the TOE-Framework for project complexity.

The analysis was conducted by assessing the perceived influence of the project complexity elements defined in the TOE-Framework that contributed to budget and/or time overrun, on to the planning process. The analysis is of qualitative nature. The interviewees were not made aware of the answers given by other interviewees that were part of the same case. The interviewees were asked on their perspective on why the project went over budget, if they considered their project complex and why, and how project complexity influenced the project performance.

After studying single cases in-depth, a cross-case analysis was performed in order to deepen the understanding of the results (Yin, 2009). The focus of the cross case analysis was on an overall comparison between the elements of complexity that contributed to budget and/or time overrun and have affected the planning process. This is done in order to find trends across the results of the single case analyses. Table 7 shows an overview of the interviewees, their roles in the project and in which project phase they got involved in the project.

Case A	Overrun	Phase	Interviewees	Involvement
1	Budget Time	Delivered	Project manager (PM) Process manager (PCM)	Involved when project was already in realization Involved when project was already in realization
2	Budget Time	Closing	Project manager (PM) Process manager (PCM)	Involved from the start of realization Involved when project was already in realization
3	Budget Time	Closing	Project manager (PM) Process manager (PCM)	Involved from the start of realization Involved from the start of realization
4	Budget Time	Delivered	Project manager (PM) Process manager (PCM)	Involved when project was already in realization Involved when project was already in realization
5	Budget Time	Realization	Realization manager (RM) Head-scheduler (HS)	Involved from tender till realization Involved when project was already in realization
6	Budget	Realization	Integral Realization Manager (IRM) Head-scheduler (HS)	Involved from tender till realization Involved when project was already in realization

Table 9: Role and involvement interviewees

The case analyses are structures as follows:

- A basic case description and information on project performance is given;
- A table is presented that summarizes the views of the interviewees on the project complexity elements selected from the TOE-framework that contributed to budget and/or time overrun, which is the answer to sub-question 7: Which project complexity elements of the chosen complexity model in sub-question 1 can be identified as contributing to project failure and having influence on the planning process?
- The first column shows the elements. In case a complexity element in mentioned by both interviewees and the elaborations are aligned, these views are combined in a single summary. In case the elaborations are not aligned, or in case an element is mentioned by only one of the interviewees, then the summary of the element will be listed in the column of the interviewee. The final column of the table shows the relation of the element to the key concepts.

  The format of the table is:

	Interviewee 1	Interviewee 2	Conclusion
	Technical Complexity elements (T)		
Element as listed in the TOE-Framework*			
	Organizational Complexity elements (O)		
Element as listed in the TOE-Framework*			
	Environmental Complexity elements (E)		
Element as listed in the TOE-Framework*			

** the elements listed in this column are identical to how they are listed in the TOE-framework in order to make it easier to find them in the TOE-framework.*

- A summary is given on the view of the interviewees on project performance
- A summary is given on the view of the interviewees on project complexity
- A summary is given on the view of the interviewees on the planning process of said case
- A case conclusion and summary is given
- The relation of the project complexity elements to the key concepts is given

The tender integration question is asked because in the exploratory interviews, the vast majority of the interviewees mentioned a weak tender transition to be a contributor to loss of information and ultimately budget and/or time overrun.

7.2 Single-case results

Case 1 : Local road construction
Client : Municipality
Exceedance : Budget, time
Tender : The realization team and tender team were completely different.
Contract : Design and Construct
Description : The goal of the project was to design and construct a 5km road around a city in order to reduce traffic intensity in the heart of the city.

CASE 1	Project Manager	Process Manager	Conclusion
ELEMENT	TECHNICAL COMPLEXITY		
TT3: Dependencies between tasks	Design and cables and piping were heavily dependent on each other. These are the two major project components.	The activities within the project relied heavily on each other. The moving of cables and piping depended on the design. If the coordinates of the cables and piping were wrong, then the design had to be changed	Dependencies between tasks were underestimated.
ELEMENT	ORGANIZATIONAL COMPLEXITY		
OS1 Project duration	The duration of the project was underestimated. This led to understaffing and overworking. Also, according to the PD, the time available for the tender given the months in which the tender had to be done added to the organizational complexity. The two months available for the tender were already short according to the PD, but these two months coincided with holidays, leading to unavailability of certain client side and contract side staff. Certain knowledge was unavailable.	The project was too short to do proper engineering given the size of the project team.	Project duration was too short given the team composition and experience.
OS3 Size in CAPEX		The estimated CAPEX lead to organizational complexity. In early project phased, when certain problems were identified, no extra staffing could be attracted to the project budget.	CAPEX underestimated.
OS4 Size in Engineering hours	The size in engineering hours added to organizational complexity because it was severely underestimated and the project depended on the engineering effort.		
OS5 Size in Project Team	The size of the project team added to organizational complexity because the project was understaffed and inexperienced.	According to the PSM, the project was understaffed. This and the fact that the available staff was not qualified led to organizational complexity.	Milestones could not be met due to understaffing.
OT1 Trust in Project team	The lack of trust in the project team added to organizational complexity. The initial management team of the project consisted of part-time people or external people, this decreases the sense of responsibility in the eyes of the PD. Also, the PD lacked trust in the project team due to key personnel being externally hired and part-time, they have a weaker bond with Heijmans and according to the PD, a weaker sense of responsibility.		Certain questions need to be asked twice due to lack of trust in the capabilities of the project team. This require time investment and slows the process. This also questions the certainty of schedules activities
OT2 Trust in Contractor	A lack of trust in the contractor developed once the problems got exposed, adding to organizational complexity because the lack of trust influenced the communication between client and contractor.		The communication with the client was slow due to the lack of trust in the contractor as a result of the delays. This lead to inefficient communication process.

ELEMENT	ENVIRONMENTAL COMPLEXITY		
EM1: Internal Strategic Pressure	According to the PD, the internal strategic pressure due to economically rough times to acquire a project might have influenced certain decisions in the tender phase that ultimately turned out to be bad decisions.		The scheduled duration of the project was too optimistic. This requires tight control of the schedule and interfaces.

Table 10: Influence project complexity on project performance and planning process - Case 1

Project performance : The project is considered as a failure by the project manager and process manager due to time and budget overrun. According to the project director, the crux of the problems lie at the tender phase and starting execution phase, where Heijmans underestimated the project. The project organization was not suited to manage the project: the project team was understaffed and not experienced enough to successfully cope with the issues that had arisen.

Project complexity : Complexity of the project was perceived to increase over time. The project manager did not consider the project to be complex from the outset, but did acknowledge that the project was made organizationally complex due to inadequacy of the project team and underestimation of the project. The PCM did consider the project to be complex due to the crucial interrelations between design and cables and piping. The elements of complexity and their influence on project mentioned is shown in table 8. The project was mainly perceived as made organizationally complex due to the understaffing and underestimation of the project. For example, the element 'OS3 Size in CAPEX', is listed as an element contributing to project failure because the CAPEX was underestimated. This underestimation could have been prevented according to the PD with more effort in the tender phase. Another example: element 'OS5 Size in Project Team' is mentioned as a complexity element due to understaffing of the project team.

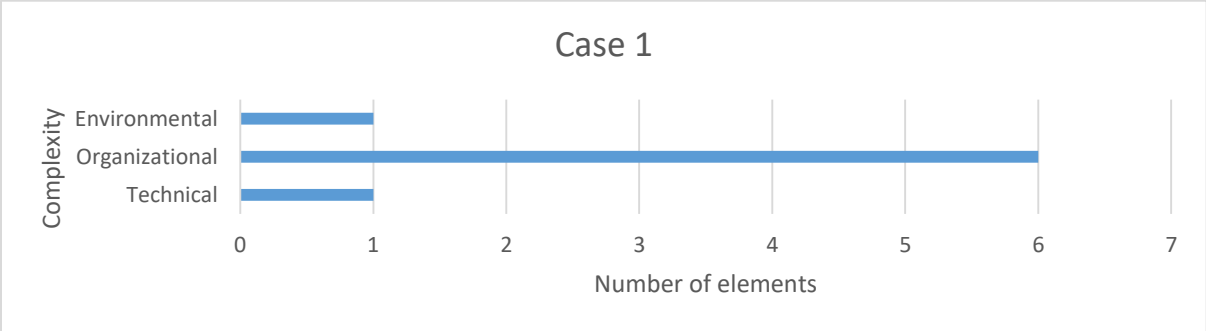


Figure 12: Number of complexity elements per category - Case 1

Case Conclusion : Both the Project Director and Process-Manager agree that the project was severely underestimated. The tender process was not carried out with enough care. Worthy to note according to the PD is that the client also had a certain responsibility in not scheduling the tender phase in a holiday period because it results into unavailability of information, also on the client side. The majority of the complexity elements are from the Organizational category. According to the PD and PCM, the organizational complexity influenced the technical complexity, implying they are not mutually exclusive. The scope of the project was mismanaged and underestimated by project team because, in the words of the PD, they were not the right people for the job. The elements of complexity seem to be interrelated.

The project needed to be acquired due to internal strategic pressure from Heijmans, which led to too optimistic estimations in the tender phase, leading to an insufficient budget and insufficient time allocated to the project. Added, the project team composition was insufficient. According to the PD, the contractor needs to put the right people with the right competences on the job. The project team was imbalanced: part-time management personnel and key positions that were filled by inexperienced people, mainly the scheduler. The project buffers were all used up because the relatively easy parts of the project were executed before the complex parts. Even then, the easy parts got delayed and were delivered over budget.

Looking at case 1, organizational complexity is the foremost contributor to budget and time overrun. The elements of complexity from the TOE-framework identified by interviewees as contributing to these overruns are listed in column 1 of table 8. A summary this influence is presented in columns 2 and 3 and the relation to the key concepts is presented in column 4.

Key Concepts : When asked about the relation of the project complexity elements identified (table 8, column 1), both the PD and PCM agreed that the project should have had a dedicated, experienced scheduler who understand a schedule logic and project sequencing. Additionally the PD agreed that knowledge sharing should be standard practice from tender to realization. It needs to be transparent what the reasoning is behind a construction schedule drafted in the tender phase and why certain choices were made. The design team and the cables and piping team did not communicate properly, which help back working integrally. Once the project got complex, this was needed to sort the problems out. The PCM and PD think that once there is information uncertainty within the process, the scheduler should proactively ask what information is lacking and provide that information, also in order to maintain the schedule. Lastly, the PD thinks that a project team should not only be based on checking off boxes of which project roles are present in the project team, but also the right competences to create a balanced project team. The PD and PCM did not have experience in working with the 5-level schedule reporting structure, but did comment that the form of the structure is not as important as what it needs to achieve: an integrated way of working.

Case 2 : Modification sewage treatment plant

Client : Waterboard
Exceedance : Budget, time
Tender : The Tender-manager was part of the design team in the realization phase for a certain period. This facilitated a certain level of knowledge sharing between the tender phase and realization phase.
Contract : Design and Construct plus Maintenance
Description : The goal of the project is to produce a Sewage Treatment Plant that uses an innovative process to extract energy in the form of gas out of silt. An existing plant was modified and expanded.

Complexity	Project manager	Process Manager	Conclusion
ELEMENT	TECHNICAL COMPLEXITY		
TS2: Uncertainties in scope		The contractual scope added to the project complexity because the contract specified that the process technology should meet a certain performance requirement, but the design Heijmans submitted in the tender documents, read: promised, could not meet the scope requirements. Heijmans was under the impression that scope definitions was open due to the nature of the contract.	Scope unclear due to contract and performance requirement
TT2: Variety in tasks	The project did not only construct a plant, but also disassemble. The existing plant was operationalized and the new plant was started up. The PM compared it to restructuring a shop while it's still open for business. Added, certain environmental regulations needed to be met in this restructuring, adding to the variety in tasks to be undertaken.		Project consisted of a variety in tasks, mainly due to the fact that the project was part new construction, part modification existing facility
TT3: Dependencies between tasks	The form of contract in combination with innovation is not a fit. Innovation is met with relatively high risks, both in time and budget. It's bad practice to wrap that around performance penalties.	The present plant was required to be operational throughout the project, which added complexity. Also, the plant is heavily dependent on the engineering process. The construction of the modified plant was heavily dependent on the engineering. For instance, while the project was under construction, the engineering team listed the need for additional pumps. On the planning process, this adds for a delay, become other processes are again dependent on this pump.	High task dependency.
TT4: Uncertainty in methods	The elements of the project were not new, it's proven technology. However, the combination of the proven technology creates a new process, which is the innovation in this project. Traditionally the contractor pours concrete and does some post measurements. When it comes to installations, the challenge is after it's installed, because certain performance requirements need to be met. Building the process is only half the job.		Innovation and lack of knowledge adds to uncertainty.
TE1: Newness of technology	The parts used in the treatment process were not new, but how the parts were used was an innovation.		Innovation.
TE2: Experience with technology	The client was knowledgeable on the process, but didn't know the new installation. Both parties did not have experience with the tech. The way this influences the planning process is that we don't have clear expectations to build a schedule on. We're not certain what the technology will do.	Heijmans had no experience with the technology and the client had no experience with the combination of the technology.	No experience with the technology in-house.
TR1: Technical Risks	The form of contract in combination with innovation is not a fit. Innovation is met with relatively high risks, both in time and budget. It's bad practice to wrap that around performance penalties.		Lack of knowledge combined with innovation adds to technical risk
ELEMENT	ORGANIZATIONAL COMPLEXITY		
OS4: Size in engineering hours		The lack of engineering hours available led to commencing realization before designs/engineering was fully completed. As engineering went on, the designs needed to be changed, which in turn influenced realization. Engineering and realization should have been sequential, but due to lack of engineering hours available, it was done partially in parallel, which led to a trial and error situation.	

ORE1: Project Drive	The project drives changed during the course of the project. However, due to the time being a strong project drive at a certain in the project, a lot of pressure was induced on the project team. As time passes and the financial result of the project gets worse, the project drive changes to what will cost less: delaying the project or applying correction measures.		Time driven project drive added pressure to the project.
ORE3: Experience with parties involved	Culture differences. One of the subcontractors is certainty focused. They won't move a muscle unless there is absolute certainty. In the design process, it was indicated that the subcontractor could commence work at a certain point, but they wanted to have more information before starting, information that was unreasonable to have at that point. That's a part of the construction industry, there is always an element of uncertainty. The way it influenced the planning process is directly. Work couldn't commence and got delayed.	In general, a lot of the problems in relations with parties were created by Heijmans according to the PSM. A lack of experience with the parties led to Heijmans not knowing the way the subcontractor responsible for process engineering worked: certainty based. Heijmans wanted to commence construction when engineering and design was not fully complete, the subcontractor didn't. This led to conflicts.	Lack of experience led to misunderstanding of work philosophy.
ORE5: Interfaces between different disciplines	The core of the project is the process technology. When something gets changed there, it influences mechanical engineering and the instruments, which influences civil, which influences permits. It's a relatively standard dependency, but there is a different deciding factor in every project. In this project, it was the process technology. Without knowing and understanding the process technology, Heijmans already started designed the installations. Characteristic for the project is that the Functional Design should have been completed before the Realization design could have started. The Function Design was delivered 2.5 years later than what was required in the contract. The functional design details how the installations work. It's the heart of the project, it should have been done before realization.	The biological aspect of the process plant introduced another level of uncertainty. Getting that component right involves trial and error, disturbing the traditional interfaces between disciplines. Realization is dependent on design, design is deponent on what the process technology does, which can only be seen after it's constructed. It had direct influence on the planning process because nothing could be scheduling with certainty.	Crucial interfaces between disciplines which were underestimated due to technical complexity.
OT2 Trust in Contractor	A lack of trust in the contractor developed once the problems got exposed, adding to organizational complexity because the lack of trust influenced the communication between client and contractor.	The lack of trust in contractor created by the situation added to the complexity because the client did not bulge for anything. The communication by the contractor was not takes as the truth and needed more effort to be takes as truth by the client. This inefficiency takes time, which is its relation with the planning process.	Lack of trust in the contractor due to project performance.
OR1 Organizational risk	The organizational risk of the project according to the PM was that knowledge was not available in-house. This worked two-fold, the knowledge hired externally needed to adapt to the work culture and the knowledge needed extra verification.	Organizationally, it was a risky project because knowledge had to be hired externally. Whenever external parties join the project team, in takes time to adapt to the working culture. Time to adapt isn't a given in a project where time is a strong project drive. Another layer of organizational risk is that the project have limited number of project members that are knowledgeable on the material. If for some reason those project members exit the project, it will be in more trouble.	Due to lack of on-house knowledge on the process technology, the project is considered organizationally risky.

Table 11: Influence project complexity on project performance and planning process - Case 2

Project performance : The project is considered to be a failure because of budget and time overruns which lead to a net loss. There was insufficient insight in what was required and there was no oversight in what was promised. According to the PM, the main reason of project failure is that Heijmans was unconsciously incompetent to develop this project.

Project complexity : The project is considered as inherently complex and its complexity was perceived to increase. The project is considered to be technically very complex and organizationally complex. The technical complexity lies in the fact that the project features innovation in a field that isn't Heijmans' expertise. The organizational complexity is related to the technical complexity. Due to the fact that process technology is not Heijmans' bread and butter, there was the need to cooperate with external partiers that are knowledgeable on the process technology. This was perceived as contributing to organizational complexity because of different work cultures involved in the project. Another way how the technical complexity affected the organizational complexity was in negotiations with suppliers. Due to a lack of technical knowledge on the process technology part, discussions with suppliers (that did have a knowledge on the technology to a certain extent) were lengthy because it needed extra verification.

Planning process : The planning process did not follow a certain standard. The common practice was to have periodic meetings to update the schedule. The scheduler reported on the actualities based on the information at that moment, and decisions were made based on that information. The PM's vision is that schedule is a product of the knowledge available. The knowledge available was insufficient due to the great focus on process technology, which isn't Heijmans' bread and butter and was underestimated. Because of this, the schedule was surrounded by uncertainty. The scheduler on the project was a software oriented scheduler and the project manager is of the opinion that only a software expertise is not sufficient in complex projects. The scheduler needs to have the communicative competences to ask questions and be critical of information provided to him or her.

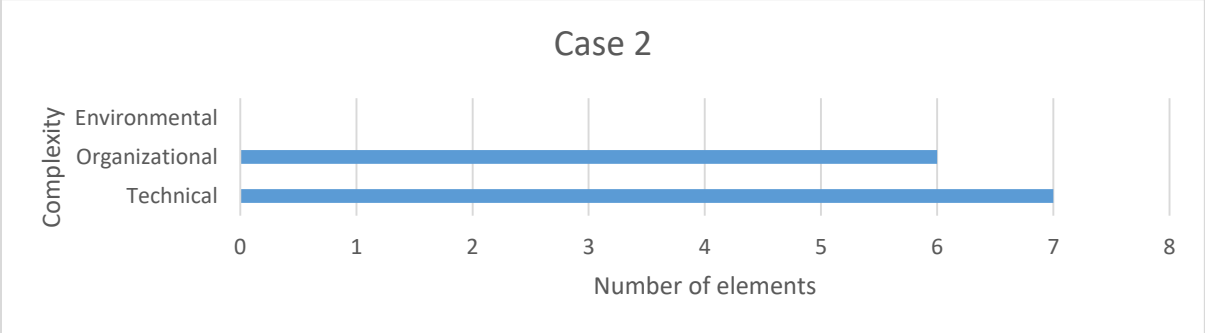


Figure 13: Number of complexity elements per category - Case 2

Case Conclusion : The project was experienced as technically very complex. The perception of the technical complexity increased the organizational complexity according to the interviewees. In the perception of the PM and PCM, it is the combination of designing an innovative process together with Heijmans having a lack of experience in process technology that makes the project highly complex technically. According to the PM, not enough attention to the contract was spent in the tender phase, something that should have been done more thoroughly, especially since it's an innovative project that Heijmans has no experience with, and according to the PM, is also out of the scope of Heijmans. The process technology dominates the infrastructure construction parts of the work, the project should have been managed around that.

The project is also seen as organizationally complex. The knowledge required to understand the treatment process was not available in-house. The technical complexity influenced this organization complexity because external advisors were hired. At a certain point, the amount of advisors grew to an amount that needed a manager to govern it. This adds more opinion to the project and different work cultures, adding to organizational complexity. The partners working

on the project had a different working philosophy leading to a conflict. The project problems led to a lack of trust toward the contractor, making communication difficult. There was no real grip on the planning process due to these areas of complexity. Scheduling certainty was moderate to low due to the uncertainty surrounding the process technology.

Key concepts : The PCM and PM did not have experience with the 5-level schedule reporting structure. The PCM moved to a project where they worked with that structure and could immediately list the benefits compared to what went wrong in this case: integration led to facilitation of information sharing and the sense of working in one project team. Emphasis on team integration was described when talking about how the external advisors led to organizational complexity. One key area of improvement noted by the PM is the role of the scheduler. The scheduler on this project was too software focused, missing the ability to ask the right questions and challenge the information provided.

Looking at case 2, there is balance between technical and organizational complexity that contributed to budget and time overrun. The elements of complexity from the TOE-framework identified by interviewees as contributing to these overruns are listed in column 1 of table 9. A summary this influence is presented in columns 2 and 3 and the relation to the key concepts is presented in column 4.

Case 3 : Construction underground parking facility
Client : Municipality
Exceedance : Budget
Tender : The tender-manager and coordinating calculator transferred from tender to realization and transferred as much knowledge as possible within a timeframe through knowledge-transfer sessions.
Contract : Design and Construct
Description : The goal of the project was the urban restructuring of an area to create more open space and constructing an underground parking garage.

Complexity	Project Manager	Process Manager	Conclusion
ELEMENT	TECHNICAL COMPLEXIY		
TS3: Quality requirements	This element is twofold. First, the architect was instructed an evaluative role by the client, a municipality. The architect had a stake in the project being constructed at the best quality possible because the architect's name was attached to it. Thus, the wishes of the architect were dominant. Another quality aspect was the fact that the concrete was supposed to be CUR-100 class in order to waterproof certain constructions. The contracted stated that CUR-100 should be used and the construction should be waterproof. This waterproofing could not be met by applying concrete of this class alone, additional costs needed to be made.	One of the contract requirements was the waterproofing level of the concrete to be used. These requirements were unreasonable seeing the product to be worked with: concrete is porous by nature and cracks by nature (or else reinforcement wouldn't be needed). This requirements should have been addressed in the tender phase according to the PSM, didn't happen.	Unreasonable quality requirements led to additional effort in meeting them, exceeding the design budget.
TT2: Variety in tasks	This aspect has to do with the variety of tasks the project is built up from. Traffic flow needed to be sustained, archeological research was part of the project, groundwater levels needed to stay neutral during construction, stress on surrounding structures as a result of construction needed to be minimized etc.		Variety of tasks present on the project.
TT3: Dependencies between tasks	This aspect has to do with the variety of tasks the project is built up from. Traffic flow needed to be sustained, archeological research was part of the project, groundwater levels needed to stay neutral during construction, stress on surrounding structures as a result of construction needed to be minimized etc. So the variety in tasks was also dependent on each other.		High level of dependency between tasks.

TT4: Uncertainty in methods		Uncertainty in methods played a role for a while because the waterproofing requirement needed to be met, which took time to engineer.	Linked to the quality requirements.
Organizational ORE3: Experience with parties involved		There was no experience with the client side personnel, which influenced communication behavior negatively and led to inefficiencies.	Communication inefficiencies.
Environmental			
ES 2: Variety in stakeholder perspectives	The external stakeholders who wanted to have a say in the project ranged from archeological organization, to inhabitants to nature organizations. Also, the inclusion of the architect in the design validation added to environmental complexity		Multiple points of view to take into account.
ES4: Political influence		The municipality, client, lost arbitration cases in other projects which cost the municipality a lot of money. The municipal budget was therefore of importance as it was felt in the project that the client was on edge with regard to spending money, they were extremely cautious which made collaboration difficult at times. The political situation, the municipal finance, influenced the project also in additional work.. The PSM was of the opinion that the rightfulness of compensation for extra work was determine by the price of the extra work..	Municipal budget influencing client-contractor relation.
EL1: Interfaces with existing site	The project also interfaces to local surroundings.		

Table 12: Influence project complexity on project performance and planning process - Case 3

Project performance : The project is considered a success by both the project manager and the process manager. The reason for this consideration is that by the project manager is that the project got delivered in a financially difficult period. Also, Heijmans built something they're proud of. The client is also satisfied with the project. The budget overrun mostly due to underestimation of the effort required to execute the design.

Project complexity : The PM and PCM have a different opinion on the complexity of the project. The PM considers the project to be technically complex, mainly due to the interfaces of the project with the environment, the variety and dependency in tasks. The PCM does not, he stated that Heijmans' managerial actions increased the complexity of the project. He thinks that the project would have performed better if more effort would have been spent in estimating the project in the tender phase. As it stands, the PCM thinks the project was underestimated and this underestimation influenced the project performance. A single complexity elements has been listed by the PCM, namely 'experience with parties involved', which led to communication inefficiencies according to the PCM. No other organizational elements were mentioned, this might be because the organization of the project was subject to the trouble that was caused by an underestimation of the project in the tender phase, and had little to do with the organization of the realization team in general. The environmental complexity had to with the fact that the project is not only the construction of an underground parking facility, but also the restructuring of an urban area on top of the facility. Urban restructuring goes hand in hand with external stakeholder involvement according to the managers.

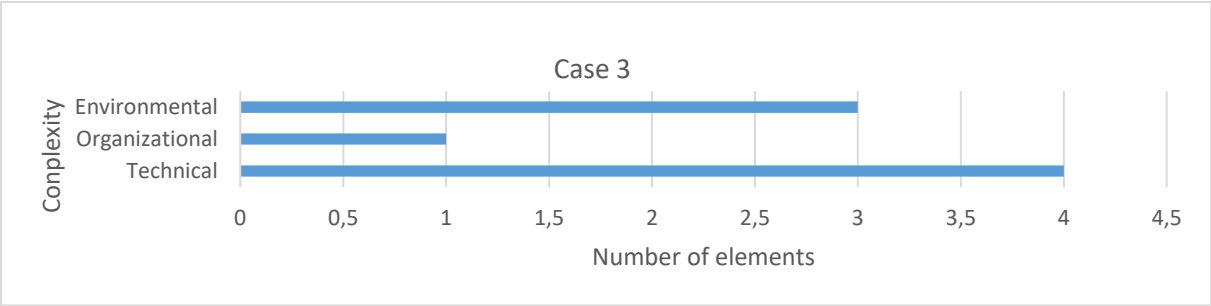


Figure 14: Number of complexity elements per category - Case 3

Planning process : No standard planning process was followed in this project. The main method of scheduling on the project was transferring the collaboratively drafted LEAN schedule into a linked bar-chart. This process was inefficient according to the PCM, because it caused a loss of overview in activity dependencies. A LEAN schedule is not capable of automatically updating, because the activities aren't linked. The PCM is also of the opinion that there should have been a dedicated scheduler on the project from the start, and a schedule reporting process should have been agreed upon at the start of the project.

Case conclusion : Project complexity cannot be stated as a contributing factor to budget overrun in this case. The project does not appear to be complex in general, but having experienced certain project complexity elements. In essence, the most important reason for budget exceedance is that the project is underestimated, in terms of risks and in terms of budget: the bid was too low. The damage has been reduced as much as possible, so the PCM thinks the team did a good job seeing the circumstances. The cooperation within the management team of the project was one of the reasons why the project went the way it did. The PCM pledges for the right people on the job in terms of competences. While the project is not considered as complex in general, the listed elements of project complexity that contributed to overrun are included in the cross-case analysis.

The elements of complexity from the TOE-framework identified by interviewees as contributing to budget overrun are listed in column 1 of table 10. A summary this influence is presented in column 2 and 3 and the relation to the key concepts is presented in column 4.

Key concepts : The budget exceedance would have been less if there was a dedicated scheduler on the job form the start, according to the PCM. Not only a scheduler, but a scheduler who drafts the process: the schedule deviation procedures, reporting responsibilities, maintaining schedule responsibilities etc. This relates to the key concepts as it creates a platform though which information can be shared in an integrated way. The PCM is of the opinion that the scheduler should not always be someone from within Heijmans by definition, as long as there is a dedicated schedule and the roles are responsibilities are clear. It should be clear who are responsible for that process. Using LEAN, Primavera or other should be agreed and someone should feel responsible for it. Also, the procedure should be described on what to do when schedule adjustments are needed. There were no agreements made on a planning process. More structure though a standard schedule reporting procedure on the project would have been beneficial according to the interviewees.

Case 4 : Broadening sluices to facilitate shipping traffic and replacing bridges
Client : Province
Exceedance : Budget, time
Tender : The (first) project manager and contract manager transferred from tender to the starting months of the realization to facilitation knowledge transfer.
Contract : Design and Construct
Description : The goal of the project was to broaden existing sluices to allow better shipping throughput and to replace bride infrastructure that was at the end of life.

Complexity	Project Manager	Process/Contract Manager	Summary
ELEMENT	TECHNICAL COMPLEXITY		
TS2: Uncertainties in scope		Uncertainty in scope influenced the project result due to lack of information of the state of the surrounding and thus scope of works: what can be done and what can't be	Scope uncertainty
TT2: Variety in tasks	The project site involves a water body, ground works and a densely built environment. A variety in tasks had to be done in order to ensure integrity of all those elements.		Variety of structures to take into account
TT3: Dependencies between tasks	This aspect has to do with the variety of tasks the project is built up from. Traffic flow needed to be sustained, archeological research was part of the project, groundwater levels needed to stay neutral during construction, stress on surrounding structures as a result of construction needed to be minimized etc. So the variety in tasks was also dependent on each other.	The project site involves a water body, ground works and a densely built environment. A variety in tasks had to be done in order to ensure integrity of all those elements. A high level of variety in tasks coupled with uncertainty caused loss of overview in interfaces between them	High task dependency
TT4: Uncertainty in methods	Uncertainty in methods affect project result because it was not certain what the predefined methods would cause. Lack of information on the surrounding environment lead to this uncertainty.	Uncertainty in methods affect project result because it was not certain what the predefined methods would cause. Lack of information on the surrounding environment lead to this uncertainty.	Geotechnical uncertainty influences uncertainty in methods
TR1: Technical Risks	Technical risks influenced the project result due to uncertainty in methods and the unknown structures within the ground.	Technical risks influenced the project result due to uncertainty in methods and the unknown structures within the ground.	
ELEMENT	ORGANIZATIONAL COMPLEXITY		
ES 2: Variety in stakeholder perspectives	Variety of stakeholders' perspectives delay and work against relatively easy solutions to the problems the project faces by, not allowing the solutions to be applied	Variety of stakeholders' perspectives delay and work against relatively easy solutions to the problems the project faces by, not allowing the solutions to be applied.	Varied stakeholder views that need to be considered.
ES3: Dependencies on other stakeholder	The project crosses various structural bodies that belong to different parties. Due to scope change, the impact of redesigns have to be re-assessed with these parties and construction can only commence once all parties agree. The information requirement to map the ground structures is also hiding in the archives of various other stakeholders.	The project crosses various structural bodies that belong to different parties. Due to scope change, the impact of redesigns have to be re-assessed with these parties and construction can only commence once all parties agree.	High environmental dependency on other stakeholders.
EL1: Interfaces with existing site	The project activities have influence on the neighboring water body and structures, erect as well as in the ground.	The construction work interferes with the existing site in the form of vibrations and noise nuisance. The effect of the vibrations is unknown because the subsurface structures are not clear.	Project interferes with existing environment.

Table 13: Influence project complexity on project performance and planning process - Case 4

Project Performance : The project is considered to be a failure by both the PM and PCM. The construction works involved in the projects heavily depend on the geotechnical situation of the construction site. The problem this project faces is that the construction site is close to the built environment consisting of historic structures, and the structure in the ground is unknown. It is unknown how the environment will react to geotechnical works. What was assumed in the tender phase turned out to be inconsistent with reality.

Project complexity : The interviewees stated that the project is seen as inherently complex, and the complexity increased. The case is considered to be technically and environmentally complex by both the PM and PCM. The technical complexity lies in the fact that there is a high level of uncertainty on what structures are hiding in the soil. The environmental complexity impacts coping with the technical complexity. The project crosses various structural bodies that belong to different parties. Due to scope change, the impact of redesigns have to be re-assessed with these parties and construction can only commence once all parties agree. What's interesting to note is that no organizational complexity elements have been mentioned. This might be explained by the fact that the PM and PCM were not part of the project team that started the construction phase, but they replaced their role equivalents on the project for the purpose of reorganizing. There organizational complexity might have been mitigated by this reorganization/ change in project team. The project is considered to be environmentally complex because of the dependencies on the environment in commencing construction and clarifying the soil structure.

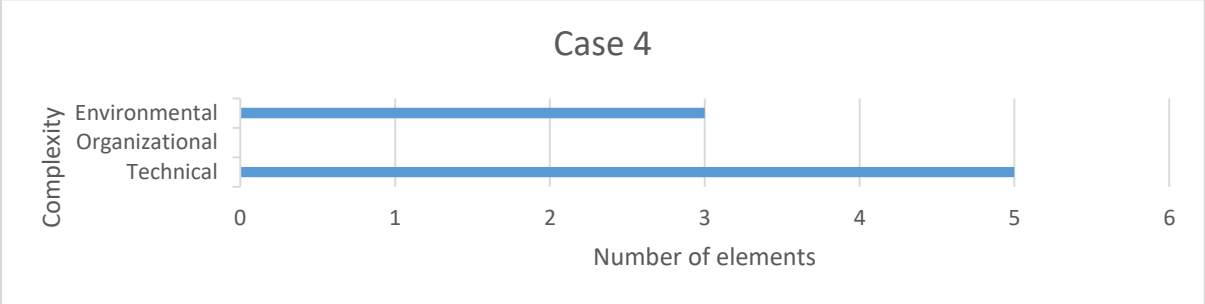


Figure 15: Number of complexity elements per category - Case 4

Planning process : No standard planning process was followed on the project. The main scheduling method was LEAN. The LEAN output was transferred to a linked bar-chart. There was a dedicated scheduler on the project who monitored the schedule.

Case Conclusion : The case is considered to be technically and environmentally complex by both the PM and PCM. The technical complexity lies in the fact that there is a high level of uncertainty on what structures are hiding in the soil. The environmental complexity impacts coping with the technical complexity. The project crosses various structural bodies that belong to different parties. Due to scope change, the impact of redesigns have to be re-assessed with these parties and construction can only commence once all parties agree.

The complexity of this project was technical and environmental. No organizational complexity elements were identified. The elements of complexity from the TOE-framework identified by interviewees as contributing to budget overrun are listed in column 1 of table 11. A summary this influence is presented in column 2 and 3 and the relation to the key concepts is presented in column 4.

Key concepts : According to the PM the key concepts would not have positively influenced the project result because the problems of the project were outside the scope of the planning process and the scheduler. According to the PCM, a different kind of scheduler, one that knows the importance of gathering information, asking questions, reporting back etc. could have positively influences the outcome of the project. One of the delaying events of the project was late application for certain permits, something that delayed the successor activity. The PCM is of the opinion that a proactive approach to monitoring and communicating would have prevented this. According to the PCM, the scheduler should proactively approach the trades dependent on permits for commencement of work to see if everything is set and done. This pro-active, managerial style of scheduling, which according to the PCM is a necessity for these kind of works.

Case 5 : Provincial road construction
Client : Province
Exceedance : Budget, time
Tender : Management team transferred from tender to realization.
Contract : Design and Construct plus maintenance
Description : Goal is to realize and upgrade the provincial road connection between two cities in order to improve traffic flow, livability and traffic safety in the region.

Complexity	Realization Manager	Head-Scheduler	Summary
ELEMENT	TECHNICAL COMPLEXITY		
TS2: Uncertainties in scope	There was uncertainty in settling time and pre-loading of the ground, crucial for the development of the project. Also, the coordinates of the cables and piping as assumed was not the same as what was found in practice.	The dependency on geoparameters is the key theme of the project. This is crucial information in proceeding with the project.	Project dependent on geotechnical parameters, which were uncertain.
TT3: Dependencies between tasks	The project activities, mainly design, had a sequential relation and dependency. Due to time constraints introduced by erroneous geotechnical parameters, this had to be in parallel.	The longer the time available for pre-loading, the lesser need for settlement acceleration measures. However, settlement acceleration measures are practically impossible, thus there was a high dependency between the tasks	The project tasks are highly dependent on the geotechnical parameters and design.
TT4: Uncertainty in methods	Uncertainty in methods affect project result because it was not certain what the predefined methods would cause. Lack of information on the surrounding environment lead to this uncertainty.	This is a natural consequence of the uncertainty in scope. The settlement behavior of the ground is a prognosis, but what how it actually will turn out in uncertain. The settlement behaviors will largely dictate the methods, as there are scheduled milestones that need to be reached.	It's uncertain which methods van be applied due to uncertain geotechnical parameters.
ELEMENT	ORGANIZATIONAL COMPLEXITY		
OS5 Size in Project Team	The project team was large but consisted also for a significant part of people form outside Heijmans. This lead to organizational complexity as such a group consist of people with different work ethics and work culture, which needed to be molded in a single team with a single work culture, that of Heijmans.	Due to the size of the project team, it's crucial to keep communicated and informing each other in order to make sure that everyone is working with the right information in mind. The project team is multidisciplinary as well, reflected in the work culture. However, the project team is integrated. Close collaboration and information sharing between the disciplines is required for the progress of the project. This information sharing needs to be facilitated and needs to be front and center.	
ORE5: Interfaces between different disciplines		Problems occurred at the project, mostly related to cables and piping that have been drilled through or sheet piling though cables and piping. This is the interface between the geotechnical and realization team. This interface needs to be managed properly.	

Table 14: Influence project complexity on project performance and planning process - Case 5

Project performance : The project was executed as an integrated project: all Heijmans infra disciplines were involved and the team was multidisciplinary. The project is over budget and delayed. The main reason for exceedance of budget according to the PM is the difference between geotechnical parameters listed by the client in the tender phase and the actual geotechnical situation found in the construction area. These geotechnical parameters include the soil structure and the coordinates of cables and piping. The RM also mentioned wrong doing on Heijmans' part that negatively influenced project performance: the design team did not manage to act timely and accordingly to the uncertainties the altered scope introduced. The RM criticized the design team because they didn't communicate properly what their information requirement was in order to meet design deadlines.

Project complexity : The project is considered to be complex. The complexity induced by the mismatch of geotechnical parameters from tender to realization increased the technical complexity of the project as it added uncertainty is scope. This leads to uncertainty in methods as the actual geotechnical parameters require a different approach in soil settling and pre-loading. Other project activities are heavily dependent on these parameters as settling and pre-loading times influence the construction schedule. The project is considered to be organizationally complex due the size of the project team, the fact that it's multidisciplinary with interfaces between the disciplines and the coordination requirement to manage such an organization. While the number of elements doesn't seem high, their implication is significant.

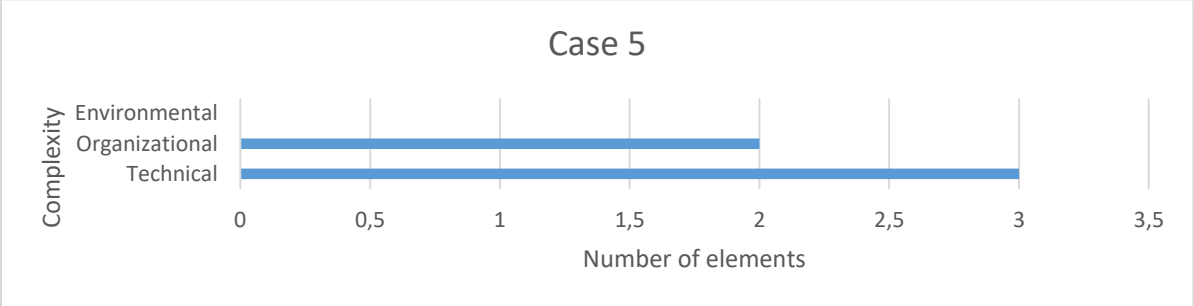


Figure 16: Number of complexity elements per category - Case 5

Planning process : The 5-level schedule reporting structure was applied in this project. According to the HS and the PM, this reporting structure worked really well. The HS officially reported to the RM. The HS was assisted by a detail-scheduler (level 4). The HS integrated the detail-schedules and monitored those. According to the HS and RM, the role fulfillment of the HS in the planning process of this project is uncharacteristic for a traditional scheduler: the HS served as an interface manager and gather information pro-actively. This worked well according to the RM because this serves the information requirement positively.

Case Conclusion : The size of the organization along with the multidiscipline nature of it requires strict coordination to manage it properly, which is the reason why the project is seen as organizationally complex. The scope changes and the uncertainty it caused introduced technical complexity by introducing a lot of unknowns to the project, which construction methods and the construction schedule depend on. Part of complexity was contributed to, according to the RM, by the contractor itself by the design and cables and piping disciplines not communicating properly and owning up to their responsibilities.

The complexity of this project was technical and organizational. No environmental complexity elements were identified. The elements of complexity from the TOE-framework identified by

interviewees as contributing to budget overrun are listed in column 1 of table 12. A summary this influence is presented in column 2 and 3 and the relation to the key concepts is presented in column 4.

Key concepts : Both the RM and HS think that the key concepts are crucial in managing the complexity of a project. A lack of information sharing proved to be critical in de design process, as other processes depend on design. Working in integrated teams helped to manage the organizational complexity because it was a solid foundation for structure. However, working in an integrated teams need to be managed or else it can add to complexity according to the RM instead of decrease it. This is where the HS's competences came into play. His pro-active approach to scheduling is seen as interface management. Having these management competences helped in structuring information flows in order to make sure that the schedule was the most actual representation of the work to be done.

Case 6 : Large infrastructure project
Client : Rijkswaterstaat
Exceedance : Budget.
Tender : Management team transferred from tender to realization.
Contract : Design, Build, Finance, Maintain, And Operate.
Description : Improving throughput and accessibility of urban agglomeration.

Complexity	Integral Realization Manager	Head-Scheduler	Summary
ELEMENT	TECHNICAL COMPLEXITY		
TS1: Scope largeness	The vast scope of the project added to the complexity of the project due to the smaller elements of the project having a potential large influence on the outcome. Time being the major project drive, these smaller elements can be lost out of sight until critical.	The vast scope of the project added to the complexity of the project due to the smaller elements of the project having a potential large influence on the outcome.	Very large scope
TS2: Uncertainties in scope	This influenced the design process. Realization was not the same as what was thought of in the tender, resulting into larger construction requiring stronger machines to build. This added to the overrun. Also, assisting constructions were insufficiently accounted for in the tender phase. In order to construct certain design drafted in the tender, the assisting constructions needed to be adapted. Some of these constructions ended up being twice as expensive as planned. The changes in design also led to more foundation piles, deeper piles and different pile types, this added to the overrun.		Scope uncertainties influenced design process.
TT3: Dependencies between tasks		A large part of the project is repetition work, once that part start it is expect to move at a steady pace. However, to get to that part of the project, certain interdependent tasks needed to be done. Task dependency is emphasized by the time project drive.	Task dependency critical to schedule due to project drive 'time'.
TR1: Technical risks		Due to the fact that the smaller project elements can cause large problems. Also, the main project drive is time, the project duration given the scope is unheard of in Dutch infrastructure construction. Time sensitivity of the project adds to it being technically risky because smaller elements can have a big influence on the outcome.	Project drive 'time' together with the large scope makes the project technically risky.

ELEMENT	ORGANIZATIONAL COMPLEXITY		
OS2: Compatibility of different project management methods and tools	The design team worked in different scheduling software than the software to manage the integral project schedule. This led to inefficiencies and unnecessary discussions.	The design team worked in MS Project at a certain point in time, the milestones were manages in Primavera (main scheduling software agreed). Integration of various schedules is of utmost importance to the 5-Level system and with the different software used, this was not efficient and sometimes led to communication problems. Due to this interface, the effects of certain delays couldn't optimally be presented. Later in the project, the design team agreed in working in Primavera after long periods of discussions.	Integration inefficiencies between MS Project and Primavera.
OS4: Size in engineering hours		Engineering hours: The amount of engineering hours available was tight. In order to increase production of engineering documents and designs, the quality had to suffer because less people had to do the same amount of work. This influenced the time available for the engineering process and contributed to the budget overrun, as slight as it might be.	Project drive 'time' pressures amount of engineering hours.
OS5 Size in Project Team	The project team is multidisciplinary and large is size. This adds to complexity because the information that is spread around must be up to date at all times. Information can also get lost in a large organization. Constant communication was encouraged. Not only was the team large in size, but also multidisciplinary with people from different companies. Once work culture needed to be created	The project team is multidisciplinary and large is size. This adds to complexity because the information that is spread around must be up to date at all times. The larger the project team, the more people that needed to be steered, the more important it is that the right information is available to the right person.	Very large, multidisciplinary project team.
OP3: Cooperation JV partner	Working in a JV, you can't choose who you\re going to work with. Project management methods are different, work culture is different and communication process is different.		Different work cultures cause inefficiencies.
ORE3: Experience with parties involved		A lack of experience with the involved parties led to discussion on how to approach certain processes. These discussions were centered around how to approach a certain problem instead of how to solve the problem. Added, one of the project partners is used to outsourcing works, Heijmans is used to doing as much as they can themselves. This led to a lot of paper work and administration not foreseen, which took time.	Inefficiencies due to lack of experience with partners.
OR1: Organizational risks		Due to the size of the organization and the organization consisting of people from multiple companies, there was a certain communicational risk. This has to do with work culture. Also, certain departments got added to the project's organization that were new to Heijmans: informationmanagement and configurationmanagement. More departments equal more opinions.	Organizationally risky due to large multidisciplinary project team and two new organizational departments, which increase the coordination efforts required.

Table 15: Influence project complexity on project performance and planning process - Case 6

Project performance : The project is still in realization at the time of publishing this report and is at a budget overrun. The main reason for this according to the IRM and HS is the project drive, which is time. The project is time sensitive. The construction works in the given amount of time will set a precedent for Dutch infrastructure projects. It occurred too often to increase production to meet schedule. The organizational inefficiencies also added to the budget overrun, as these led to unnecessary discussions, which cost time.

Project complexity : The project is considered to be technically and organizationally complex. The technical complexity has to do with the high task dependency which can potentially become critical due to the construction time of the project, which is unprecedented in Dutch infrastructure projects. The large scope couples with a strong dependency between tasks, emphasized by the project drive 'time' makes it technically risky and adds to technical complexity. The organizational complexity is mainly due to the large, integrated multidisciplinary project team. It's interesting to note that no environmental complexity elements were mentioned as contributing to budget overrun. This might be due to the view that environment management is done adequately and thus it's not noticed by the interviewees what the environmental complexity entails on an element level.

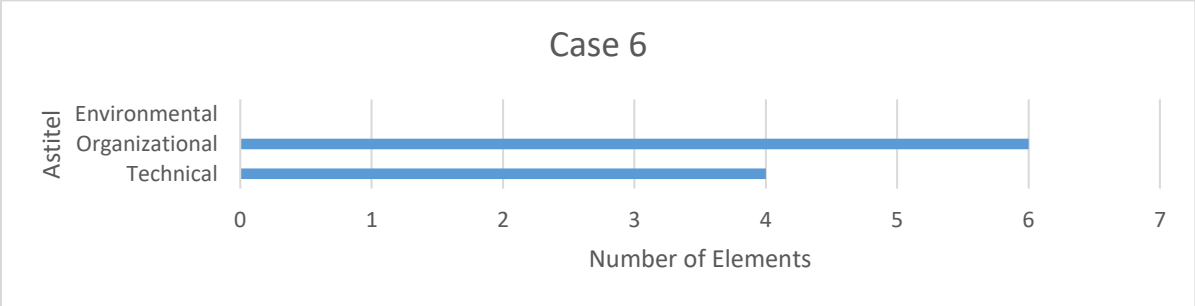


Figure 17: Number of complexity elements per category - Case 6

Planning process : The 5-level schedule reporting model was implemented in this project. The HS integrates the schedules of the disciplines into a single overall schedule, and reports this to the management team. The planning process in this project is considered to be good by the IRM and HS. However, the IRM emphasized that in order to successfully integrate schedules in an organization like the one in this project, there needs to be HS that has managerial competencies. The information flow in a large organization can get convoluted according to the IRM. The HS should thus serve as an interface manager: what disciplines are dependent on each other and what information do they need. The HS according to the IRM should pro-actively facilitate in this information requirement. This approach is confirmed by the HS as necessary.

Case Conclusion : The project is considered as technically, organizationally and environmentally complex by the HS and the RM. The technical complexity of the project lies is the fact that the dependencies of various activities on the projects can become relatively easily critical to the schedule if not managed properly. Given the scope, managing such activities is important. In organization needs to communicated and inform each other what is going on in relation to project progress: the schedule. An integral HS is important to glue the pieces of the project together and make sure the right information gets to the right people at the right time. The HS who had a pro-active way of working contributed to the project substantially by doing this in a pro-active way. It triggered people to be alert whenever the HS would schedule meetings to assess the progress.

The integral project team is something both the HS and RM are proud of. It's set up and managed in an impressive way according to IRM, this is where the HS plays a role as an interface manager. This works well. However, having structure in the organization is not enough, the organization needs the right competences. The budget overruns, or differently, the reason that certain aspects

lead to budget overrun could be attributed to the competences of certain key players in the project team according to the HS and IRM.

The complexity of this project was technical and organizational. No environmental complexity elements were identified. The elements of complexity from the TOE-framework identified by interviewees as contributing to budget overrun are listed in column 1 of table 13. A summary this influence is presented in column 2 and 3 and the relation to the key concepts is presented in column 4.

Key concepts : the project's schedule reporting was done though the 5-Level structure, which required an integrated project team to work. This went well. However, this did emphasize the need to share information to make it work. Information sharing in a large organization is very difficult according to the IRM because it's hard to assess if the right information landed within the organization. According to the IRM, a HS that serves as an interface manager is a necessity due to the pro-active approach in gathering and spreading information to make sure the project schedule is the actual representation of the state of the project and the work to be done.

7.3 Cross-case analysis

In total, 12 interviews were conducted with managers and schedulers: four with project managers, one with a realization manager, one with an integral realization manager, four with process managers and two with head-schedulers. The perspectives provided by these interviewees will be analyzed in this section. Figure 17 shows the total amount of unique elements per case. It does not represent a summation of elements. If the interviewees both mentioned the same element, it is interpreted as one unique element instead adding it together. The amount of times an element is mentioned across the cases is a summation and displayed in figures 18 and 19.

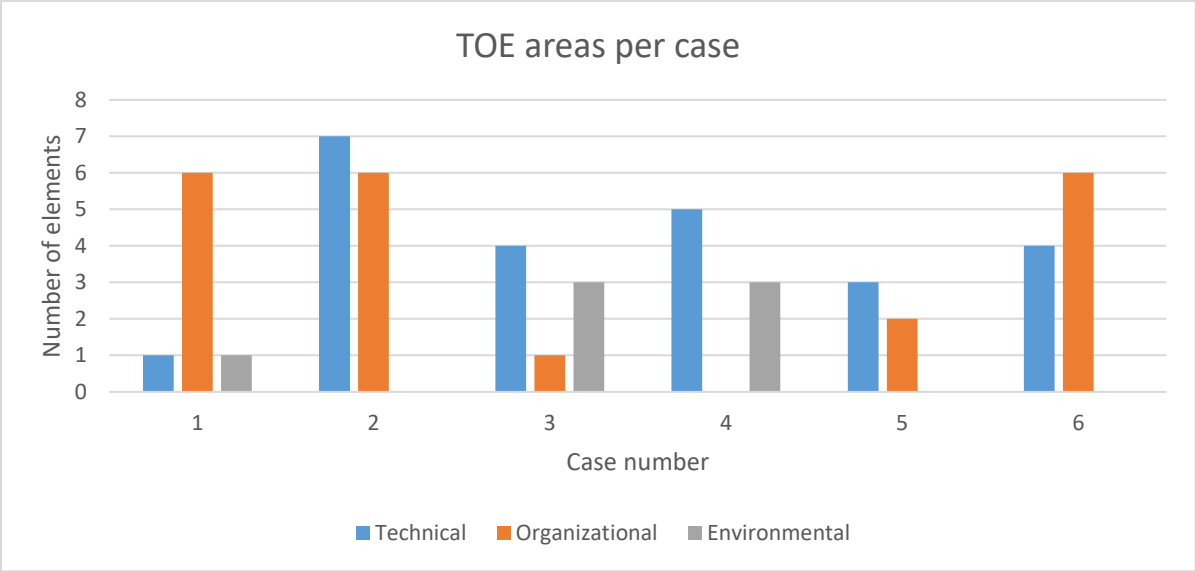


Figure 18: Number of complexity elements and their category per case

Project complexity and project performance : Nearly all project managers considered their projects to be complex. The main areas of complexity differed between projects. It is interesting to see that in four out of six cases, the project managers listed more technical elements of complexity than organizational elements of complexity. Intuitively, this does not seem right seeing as the engineering background and expertise of a contractor. However, more elements in a certain category compared to the other does not necessarily mean that the category with more elements had the most influence on project performance. In the fifth case for example, more technical elements of complexity were mentioned compared to the organizational, but both interviewees answered that the complexity of the project is mainly organizational. This might indicate a relation between organizational and technical complexity. The process manager in case 3 did not find the project to be inherently complex, but stated that Heijmans' estimates in the tender phase were incorrect. The project was underestimated and the organizational structure was formed based on an underestimation. This is similar to what happened in Case 1: the project team in the realization phase was put together based on a severe underestimation which led to the project team being understaffed, overworked and not experienced enough to deal with the resulting, induced project's complexity.

The process managers' perspective on complexity is evenly divided: two process managers stated more technical complexity elements than organizational and two process managers stated more organizational elements then technical. The same goes for the head-schedulers, one found more technical complexity elements than organizational complexity elements and vice versa. This can

be explained by the nature of the projects and structure of the planning process. Environmental complexity only played a relevant role in the fourth case, where the project was dependent on information and permits from stakeholders, and where there was uncertainty regarding the built environment (interference with existing site). The selected cases show a wide spectrum in elements contributing to project complexity, which makes generalization difficult. Then again, it is in line with the notion that every project is unique.

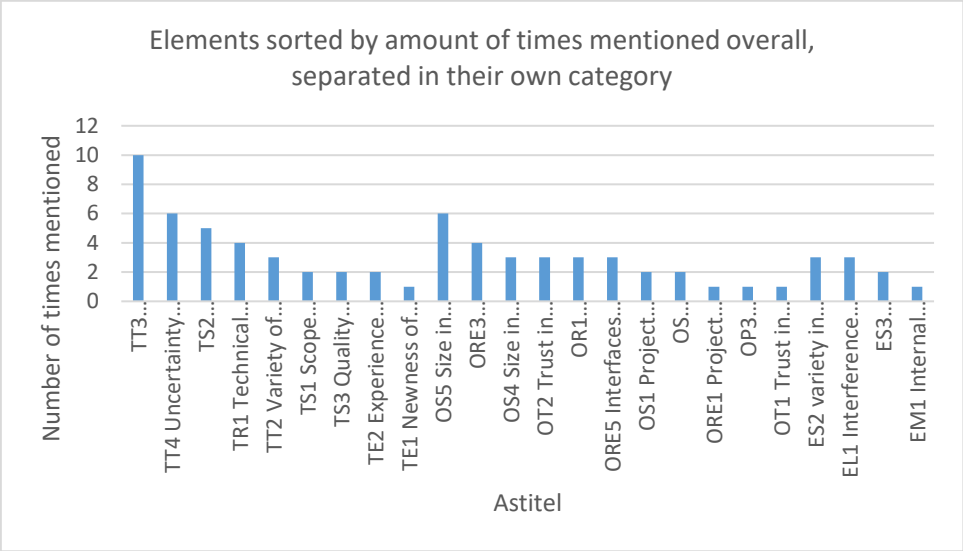


Figure 19: Project complexity elements that contributed to overruns and influence the planning process, sorted in their own category by most times mentioned

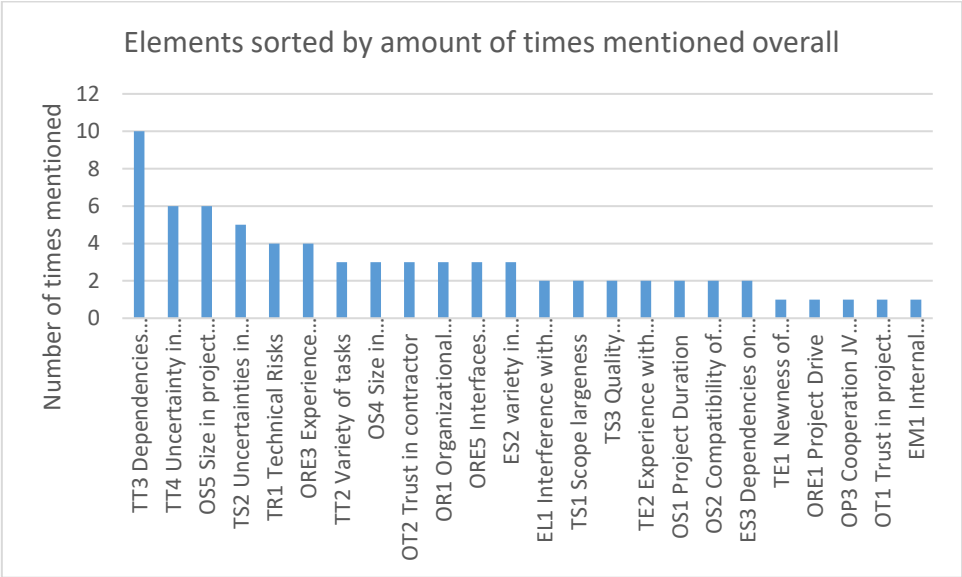


Figure 20: Project complexity elements that contributed to overruns and influence the planning process, sorted by most times mentioned

Figure 18 and 19 show all the project complexity elements taken from the TOE-Framework for project complexity as identified by the interviewees. The naming in the horizontal axis is identical to the way the element is named in the TOE-Framework, including the sorting code. This is done in order make it easier to find the element in the referenced framework. There is a general consensus between interviewees per case that mentioned the same element on how the element contributed to budget and/or time overrun.

The influence of these elements on project performance is direct and indirect. The influence of these elements on project performance are direct and indirect. Indirect influences of the elements on project performance are mainly in the area of inefficiencies. In cases 1 and 2, element "OT2 Trust in contractor" contributed to budget overrun. The reasoning given by the interviewees on how it contributed was by resulting inefficiencies in communication: requiring more time to communicate and requiring more time to validate the communication. The additional communicate delayed decisions, which contributed to budget and time overrun. Other elements influenced project performance directly. Due to uncertainties in scope in case 2, redesigns were done, making its influence on project performance more quantifiable.

Project complexity and planning process: In literature, a 5-level schedule reporting structure is recommended for scheduling in complex projects (chapter 3). The 5-Level schedule reporting model has been established as standard within Heijmans in 2014. There are only two cases out of the six that follow that model, the other four projects were realized in a period when there was no standard. In the four cases without a standard or an agreed upon schedule management process at the start of the construction phase, at least one of the interviewees stated that a lack of agreements and guidelines caused information and task uncertainty. The following elements have direct influence in the planning process:

- 'Dependencies between tasks' are presented in the schedule
- 'Uncertainty in methods' have direct influence on activity durations (buffers)
- 'Uncertainties in scope' have direct influence on the schedule density; the greater the certainty the higher the density
- 'Technical risks' are incorporated in schedule buffers
- 'Variety of tasks' are presented in the schedule
- 'Scope largeness' can be deduced from the overall-schedule

Project complexity increased information requirement and deficit in case 1-4 to maintain a schedule, which is the communication tool for the work to be done, and something the project team falls back on whenever there is uncertainty on what is to be done. For organizational complexity, the dominant element is 'Size in project team', which intuitively makes sense seeing as a large team has influenced project complexity in case 5 and 6, a too small and understaffed team influenced project complexity in case 1 and a team lacking knowledge on the project context added to organizational complexity in case 2 (due to a lack of in-house knowledge, multiple externals were hired, increasing the size of the project team).

Environmental complexity elements are relatively steady, but influence the planning process. Internal strategic pressure caused severe underestimation in case 1, while stakeholder dependence adds to uncertainty in methods in case 4, showing a possible connection in elements.

In the cases where there was a standard schedule reporting process, case 5 and 6, the organizational complexity referred to size of the project team and the way it influenced project performance was by communication inefficiencies.

Project complexity and key concepts:

Elements from the TOE-Framework	CASE	Relation to key concepts
TT3 Dependencies between tasks	All	**Information sharing:** Higher communication and information requirement to manage dependencies. **Role scheduler**: Proactive scheduler required to facilitate information sharing and monitor dependencies.
TT4 Uncertainty in methods	2,3,4,5	**Information sharing:** Higher communication and information requirement to cope with uncertainty. **Role scheduler:** Proactive scheduler required to facilitate information sharing
TS2 Uncertainties in scope	2,4,5,6	**Information sharing:** Higher communication and information requirement to cope with uncertainty. **Role scheduler:** Proactive scheduler required to facilitate information sharing
TR1 Technical Risks	2,3,6	**Information sharing:** Higher information and communication requirement to consider risks in planning process.
TT2 Variety of tasks	2,3,4	**Information sharing:** Higher communication and information requirement to manage variety of tasks **Role scheduler:** Proactive scheduler required to facilitate information sharing and integrate the varied tasks
TS1 Scope largeness	6	**Information sharing:** Higher communication and information requirement to break down and assess scope. **Role scheduler:** Proactive scheduler required to facilitate information sharing and monitor dependencies.
TS3 Quality requirements	3	*No relation to the planning process given by interviewees*
TE2 Experience with technology	2	**Information sharing:** Higher communication and information sharing intensity required.
TE1 Newness of technology	2	**Information sharing:** Higher communication and information sharing intensity required.
OS5 Size in project team	1,4,5	**Information sharing:** Higher importance of sharing correct information timely. Role scheduler: Proactive scheduler required to manage information required to make sure schedule is actual and integrated.
ORE3 Experience with parties involved	2,3,6	**Information sharing:** Information sharing should be facilitated due to different work ethics.
OS4 Size in engineering hours	1,2,4	**Information sharing**: Lack of effort in facilitating information sharing is caused by a shortage in engineering hours, making people focus on their tasks. Role scheduler: Proactive scheduler required to make sure the most actual schedule is being worked with.
OT2 Trust in contractor	1,2	**Information sharing:** A lack of trust in contractor hinders information sharing.
OR1 Organizational risk	2,6	**Information sharing:** Higher communication and information sharing intensity required due to minimize effect of organizational risk.
ORE5 Interfaces between disciplines	2,5	**Information sharing:** Higher communication and information sharing intensity required to monitor interfaces. **Role scheduler:** Proactive scheduler required to actively monitor interfaces and facilitate in information sharing.
OS1 Project Duration	1	**Information sharing:** When project duration is too short, information exchange should be facilitated to work as efficient as possible.
OS2 Compatibility of different PM methods and tools	6	**Standard process design:** A scheduling standard should be set per project to align scheduling methods and diminish inefficiencies.
ORE1 Project Drive	5	**Information sharing**: Project drive "time" can lead to inefficient working if information sharing is not managed.
OP3 Cooperation JV partner	6	**Information sharing:** Work ethics have to be aligned to facilitate and streamline information sharing. **Standard process design**: A standard schedule reporting process should be agreed upon. Role scheduler: A scheduler should have the status to mandate following of the standard process.
OT1 Trust in project team	1	**Information sharing:** Lack of trust in project team hinders information sharing.
ES2 variety in stakeholder perspectives	3,4	**Information sharing:** Importance of stakeholder perspectives should be assessed and communicated.
EL1 Interference with existing site	3	**Information sharing:** Higher information requirement on interferences with existing site.
ES3 Dependencies on other stakeholders	4	**Information sharing:** Increased information sources and information dependencies.
EM1 Internal Strategic Pressure	1	**General:** Internal strategic pressure in acquiring a project can influence the care with which a project is prepared, resulting into problems that influence the planning process in general later on the project.

Table 16: Influence of identified complexity elements on key concepts

Table 14 presents the influence of each project complexity element on the key concepts defined in literature (and validated in exploratory interviews). This table is a summary/consensus of the influence of these elements in the view of the individual interviewees (Appendix F).

This table shows a clear trend across the cases, but equally important, across the project complexity elements. This solidifies the importance of the key concepts. The overwhelming majority of project complexity elements contributes to a higher information and communication requirement. The interviewees across all cases mentioned that sharing of information is something that the planning process and the project in general is dependent on. The table also shows that there is a general agreement that in complex projects, it is increasingly becoming part of the role of being head-scheduler to proactive gather and manage information needed to make sure the schedule is the most actual representation of the work to be done.

The 5-Level schedule reporting model has been established as standard within Heijmans in 2014. Cases 5 and 6 were only ones where the 5-level schedule reporting structure was applied. A standard process is just that: a vessel. The project managers and process managers acknowledged that the vessel needs to be properly operated. This is where the role of the scheduler comes in. The managers in these project were satisfied with the proactive approach to scheduling by the head-scheduler and stated that this approach to scheduling is a necessity on complex project. A good standard scheduling process design is fit for structuring *where* to get the information and *from whom*. All interviewees agreed that is it is increasingly becoming the role of the scheduler in complex projects to manage the interfaces between disciplines and proactively gather the information, and communicate it to relevant disciplines.

The 5-level schedule reporting structure was received positively by the interviewees. The schedulers on these projects mentioned however that their role should be more central and independent. The scheduler in case 6 stated that reporting to the realization manager steered the schedule priority.

The managers and schedulers in cases 1-4 did not have experience with the 5-level schedule reporting structure and could not comment on it. In these projects, there was no specified schedule reporting structure to follow. Instead, various views on how to approach the planning and scheduling process were present. All the interviewees except the project manager in Case 3 and 4 mentioned that lack of agreement on how to approach the planning and scheduling process lead to uncertainties in responsibilities. The interviewees mentioned that making there agreements at the start of a project would be beneficial. It creates a vessel for communication and organizational clarity.

7.4 Answering sub-question(s)

- Sub-question 7 : Which project complexity elements of the chosen complexity model in sub-question 1 can be identified as contributing to project failure and having influence on the planning process?

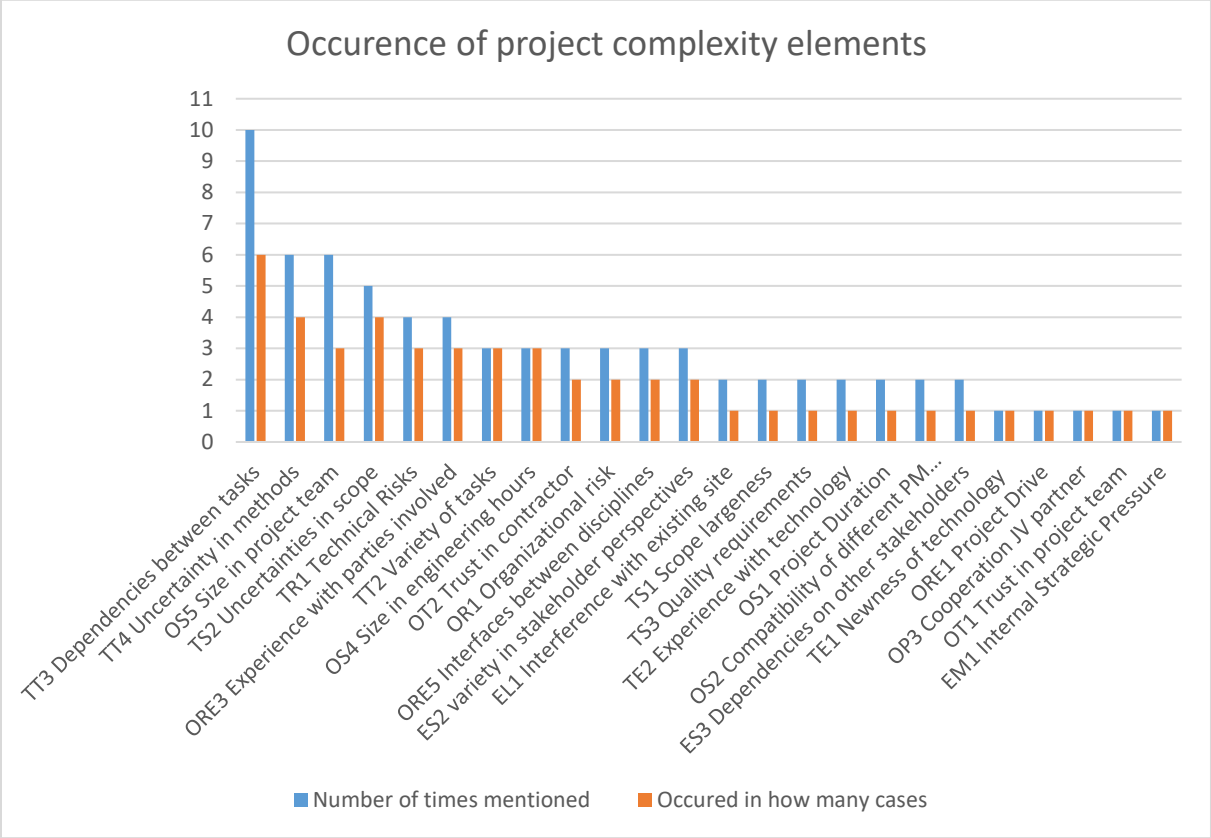


Figure 21: All mentioned TOE elements across all cases

Figure 21 shows the elements of complexity form the TOE-Framework that have been identified by interviewees as contributing to project failure and having influence on the planning process. Added to this figure is data in how many cases the element was identified as contributing to budget/ and or cost overruns. Table 14 of the cross case analysis (page 59) shows what the influence of these elements in on the planning process through the key concepts.

PART IV: EVALUATION

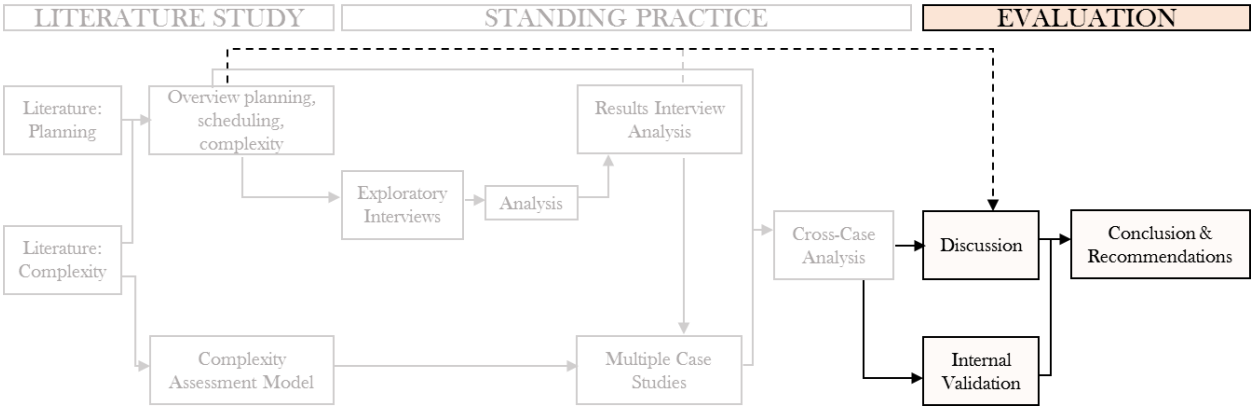


Figure 21: Research framework - evaluation

8. Discussion

8.1 Findings

8.1.1 Project complexity

Looking at figure 21 on page 61, the followings elements were mentioned in 4 or more cases: TT3 Dependencies between tasks (all cases), TT4 Uncertainty in methods (case 2,3,4,5) and TS2 Uncertainties in scope (case 2,4,5,6). These elements can be directly related to the definition of project complexity of Baccarini and the operationalizing by Williams (2002), that added the uncertainty dimension to this definition. This relation adds to the validity of the complexity assessment.

The case studies gave insight into the dynamics of project complexity. The dynamics of project complexity are reported in literature (Girmscheid & Brockman, 2007) where it is mentioned that project complexity generally reduces throughout the project except cases where a sudden rise in complexity occurs, usually, due to change orders. This was clearly evident in Case 2, where the design of the process installations Heijmans worked on had to be changed. Also, some cases saw an increase in complexity (cases 2, 3, 4). Underestimating or failing to recognize the complexity of the project tin early project phases, which is mentioned by the interviewees as well, seems to cause the increase in complexity. The importance of assessing project complexity in early project phases is stressed in research into managing project complexity (M. G. C. Bosch-Rekveldt, 2011)

In case 2, the complexity seems to be fully induced. The project manager also stated that the relatively easy project (Heijmans bread and butter), with proper management, should never have had budget and time overrun. Mismanagement is completely to blame for failure of this project. It's interesting to note that mismanagement not only caused the project to fail, but it induced project complexity which in turn caused the project to fail. In literature, induced complexity is also seen as mismanagement (Joana G. Geraldi, 2009)

Overall, three complexity scenarios can be distinguished across the cases:

1. Inherently complex: Project is perceived as inherently complex, with the perception that complexity decreased over time (cases 5 and 6)
2. Inherently complex, partially induced: Project is perceived as inherently complex, with the perception that complexity increased over time (cases 2, 3, 4)
3. Project is not complex, where complexity is fully induced (case 1)

Taking these scenarios into account, it seems that the total complexity of the project is a function of inherent complexity, management of the inherent complexity and induced complexity. Elements of project complexity were found to influence each other.

Complexity elements

Bosch-Rekveldt (2015) mentioned that the Technical, Organizational and Environmental project complexity are not mutually exclusive and may affect each other. This is observed across multiple cases.

In the first Case (1), there was only one technical complexity element: 'Dependencies between tasks'. This refers to the main projects tasks being heavily dependent on each other. The cables and piping team was dependent on the design team to know which cables and pipes to move in order to prevent damages. This is a crucial dependency, but not an uncommon one for road construction (infrastructure in general). This is the reason why the project manager stated the project at its core is not complex. The dependency sequence (simplified) was design, requesting permits for moving cables and piping, moving cables and piping and starting road construction. The design got delayed due to understaffing. Not enough time could be spent on design due to project duration, the effect of this delay could not be properly scheduled, monitored and mitigated due to the inexperience of the scheduler who wasn't a dedicated scheduler but also calculator, and the management team was hired externally part-time so they did not have enough time to sort out the problems. The induced organizational complexity contributed to the effect of the single inherent technical complexity element on the project performance. Based on this, it seems like induced complexity can influence the effect of an inherent complexity element on project performance. Also, mismanagement or failure to recognize inherent complexity can lead to more complexity elements having an influence on project performance.

In case 2, the technical complexity of the project (innovation, lack of experience) influenced the organizational complexity (increasing team size and with people Heijmans lacks experience with). In case 4, the technical complexity of the project (mostly uncertainties), influenced environmental complexity, as the dependencies on external stakeholders increased due to this uncertainty.

8.1.2 Findings: team continuity

In the exploratory interviews, transferring key management personnel from the tender phase of a project to at least part of the execution phase is unanimously mentioned as an area of improvement. According to the exploratory interviews, it should be standard practice. In the majority of the cases (1-4), a lack of team integration between tender and execution was mentioned as contributing to uncertainty and ultimately, project complexity. The importance of team continuity is confirmed in literature (Maurer, 2010), where it shown that it is beneficial for a project to involve team member that join the project throughout its duration and work full-time on the project, because they have greater interaction opportunities. A lack of team continuity is a major contributor to complexity in Case 2.

According to the interviewed managers, more effort in general should be spent in the tender phase to assess the potential areas of project complexity and adapt managerial efforts to that area of complexity. Bosch-Rekveldt et. al. (2011) proposed a similar approach as in applying value improving practices (VIP's) to adapt the Front-end Engineering and Design phase (FED) of capital projects to the particular project complexity.

8.1.3 Relation between findings

In the cross case analysis it is mentioned that the influence of the complexity elements on the planning process is perceived as direct and indirect. Indirect influences are related mostly to inefficiencies in communication and information sharing that lead to extra time required to make decisions. Therefore, it difficult to trace these influences. However, it is found that regardless of a direct or indirect influence, all the elements of complexity influence the key concepts that are important to the planning process. The influence of almost every element of complexity identified from the TOE-Framework on the key concepts is that it increases the information requirement. In total, 22 elements were identified. The influence of these elements on the key concepts is listed in Table 14 (page 59). Of these 22 elements, 21 influence the 'information sharing' key concept by increasing the information and communication requirement. For 6 of these 21 elements, it was mentioned that the head-scheduler should proactively manage information to cope with the information requirement to adequately plan and schedule a project. In order to do so, scheduler that are responsible for the overall project schedule (level 1-3, head-scheduler) should develop social, interpersonal, managerial skills. This is in line with the argument found in literature that this tool centric focus is not sufficient in complex projects as planning and scheduling are social activities requiring good interpersonal, managerial skills, which schedulers do not or insufficiently possess (Weaver, 2014).

It is found that the 5-level schedule reporting structure described in this research provided organizational clarity and structure that facilitates in information sharing in the cases where the structure was applied. In cases where no specific structure was followed, where the roles and responsibilities in relation to the planning and scheduling process were not clear, it is mentioned that this lack of structure and uncertainty hindered sharing of information relevant to maintaining the construction schedule. It also contributed to inefficiencies in communication. It is mentioned by the interviewees that making agreement on how to approach the planning process and discussing what the roles and responsibilities are in planning and scheduling facilitates in relevant and efficient information sharing.

Regardless of a fully induced or inherent nature of the complexity element, its influence on the key concepts is found to be the same. In both instances, an increased information and communication requirement occurs. The difference is that in a project where complexity is filly induced, it is might be more difficult to cope with its influence. A project that is not assessed as complex might not require the same competences as a project that is assessed complex. Thus, a project where complexity is fully induced might not have the competences to cope with complexity, because the complexity was not expected.

The interviewees were first asked to identify the project complexity elements form the TOE-Framework that contributed to budget and/ or time overrun, and were then asked to explain their influence on the planning process and key concepts. What's interest to note is that almost all elements (apart form 1) that were mentioned as contributing to overruns, were also mentioned as having influence on the planning process. The supports the notion that the planning process is of key importance to the successful delivery of projects.

Interestingly, what is found in the cases where no standard planning process was agreed upon (cases 1-4), is that a disregard for the planning process contributed to project complexity. In case 1, the scheduler role was fulfilled by a calculator, leading to inefficient and insufficient scheduling process where information sharing (key concept) could not be facilitated by the scheduler

In case 2, information sharing was crucial due to a lack of knowledge on Heijmans' part on the process technology aspect of the project. The scheduler did not facilitate in sharing information between disciplines or questioning schedule update requests. Additionally, when the project drive changed to cost, the planning process was disregarded almost completely and scheduling was done on an as built-basis. This led to negating the preparatory and monitoring nature of scheduling, which contributed to inducing project complexity.

In case 3, no agreement was reached on how to approach the scheduling process and what the responsibilities were. When problems occurred, the scheduling process was reset and a dedicated scheduler appointed. This shift as a result of undermining the importance of an agreed upon process (and disturbing continuity of the project team) contributed to induced complexity on the project.

In case 4, it is mentioned that a more proactive scheduler would have contributed to a better project performance, as small as the contribution may be, by aligning information across the different disciplines and question the information provided to maintain the schedule with.

These findings seem to imply that insufficient consideration for planning process (roles, responsibilities, scheduling practices) can induce project complexity.

8.2 Validity

8.2.1 Expert Validation

The goal of the expert validation was to assess the views of experts on the findings of this research to see if there is an agreement on these findings. Two experts were invited to an oral PowerPoint presentation:

1. head of the process and environment management department: responsible for schedule management policy within the organization and the source of knowledge on schedule management within Heijmans
2. A project coordinator, process manager and contract manager

<u>Case studies: complexity assessment</u>

A brief description of project complexity as assumed in this research was given to the experts. Afterwards, the exploratory interview analyses and (cross) case analyses presented. The project complexity areas of each case were presented to the experts (figure 17, page 66) without mentioning which figure belonged to which case. The experts were asked if based on the areas of complexity displayed, they could say which graph belonged to which case. Both experts correctly identified five out of six cases. This implies that the complexity assessment of this research is in line with intuition of the experts.

<u>Implication complexity</u>

After the complexity assessment, the cases were discussion in-depth: which elements of complexity contributed to budget and/ or cost overrun and what its relation was to the planning and scheduling process. There was full agreement on how the identified project complexity elements influenced project performance and what their relation was to planning and scheduling efforts.

Overall conclusion validation:

When asked if the findings were something new for Heijmans, the experts commented that the findings are not necessarily new. However, the findings of this research were something the experts felt intuitively. It was recognized that the role of the scheduler is complex projects in evolving, and it is recognized that the planning process needs structure (by making the 5-level scheduling structure standard policy) prior to this research. The experts commented that it's valuable that this intuition is confirmed by this research and insight is given on why the role of the schedulers is evolving in complex projects.

Additionally, it was found valuable that the overruns of the cases could be explained with project complexity theory. Overall, the experts validated that this research gives valuable insight into project complexity and serves as an argument to assess the complexity of future projects prior to execution in order to adapt the managerial efforts.

8.2.2 Research validity

The vast majority of the data in this report is gathered empirically through exploratory interviews and case studies. The following four concepts were taken into account to assess the validity of the research (Blaikie, 2009; Yin, 2009)reliability (the study could be repeated with the same results), external validity (the domain to which the findings can be generalized), internal validity (relation causal relationships to factors studied) and construct validating (use of correct operational measures to study the concept).

Contribution to reliability: In order to ensure reliability Interview and case study protocols were developed and repeatability of the analysis was ensured by storing (case study) Interview recordings and transcripts. The interviews themselves are not repeatable due to bias.

Contribution to external validity: The interview protocol, case study protocol and selection criteria were a concern and have been modified due to the high dependency on external data to generalize findings. Case selection criteria expanded to projects that were not yet delivered at the time of conducting the interviews in order to include more cases that were perceived as complex. This was in order to maximize the output of the available information (cases and professionals within Heijmans).

Contribution to Internal validity: Internal validity was contributed to by performing extensive and thorough analyses of the exploratory interviews and case studies and linking the findings to what is found in literature. The questions to be asked in the case studies were verified by the external and first supervisor of this research.

Contribution to construct validity: Anonymity for the exploratory interviews and case studies was ensured. A summarized understanding of the interviews was provided (orally, not in writing) during the interviews and at the end of the interviews.

Other than the literature study, the data gathering methodology during the consultation of standing practice was singular (interviewing). Thus multiple perspectives were involved in the form of participants with different roles in the projects to aid in data gathering. This research exclusively made use of a qualitative approach.

8.3 Scientific contribution

While this research did not intend to build or further expand on project complexity theory, it did find that there is a relation between the project complexity elements from the TOE-Framework. It if found that the presence of one complexity element can induce another. It is also found that the management efforts on induced complexity can influence the effect of an inherent complexity element on project performance. Also, mismanagement or failure to recognize inherent complexity can lead to more complexity elements having an influence on project performance. This solidifies the assumption that the elements might have influence on each other and are not mutually exclusive (M. Bosch-Rekveldt et al., 2011; M. G. C. Bosch-Rekveldt, 2011). This study also confirms the importance of a complexity assessment (BOSCH(, as it found in the case studies and validated by experts that a complexity assessment would have contributed to better project performance.

In terms of contribution to project management theory, this researched showed that indeed a scheduler with good interpersonal, managerial skills, which schedulers do not or insufficiently possess from their traditional role, is crucial to scheduling in complex project, as mentioned in literature (Weaver, 2014). This supports the suggestion of composing projects teams of competences to cope with a particular area of complexity (M. G. C. Bosch-Rekveldt, 2011; Hertogh & Westerveld, 2010).

Finally, this research addressed the research/literature gap defined in problem statement (Ch 1.2) by exploring the more recent understanding of project complexity on construction planning.

8.4 Limitations

8.4.1 Limitations literature study

The objective of the research is to identify the influence of project complexity on the planning process of infrastructure projects. This descriptive research objective is twofold: it dives into project complexity and the planning process. A lot of research is available on project complexity. Due to the scope of this research, research databases were used to find publications on project complexity in which aspects related to the planning process were mentioned. More specific: the literature search was done by using the keywords 'project complexity', 'construction scheduling', 'construction planning', 'planning' and 'scheduling' in alternating combinations. Construction planning is a broad concept and is in some cases used in context of project management as a whole. Seeing as construction planning is broad, by searching and filtering on complexity and planning, certain publications might have been overlooked that mention specific elements of construction planning that are affected by project complexity.

The choice for the TOE-Framework for project complexity as the tool to assess project complexity in this is research is based on recommendations in the master thesis research Measuring Project Complexity (Obdam, 2016). There might be other models that are better suited in the context of this research. However, Obdam's (2016) recommendations were used in the interest of time available for this research and to have a starting point to work toward planning. As always with any literature research, it is impossible to read all the relevant publications.

8.4.2 Limitations exploratory interviews and case studies.

The limitations in exploratory interviews and case studies are aligned with the subjective character of project complexity. The views on how project complexity affects the key concepts are influenced by experience but also personal character. The subjective character of project complexity was addressed by involving multiple people in the case studies and interviewing as many people as possible in the exploratory interviews given the available time. A brief description of project complexity as assumed in this research was given to all interviewees. Answers given could be based on a misinterpretation of this description, honest answers could be avoided or erroneous answers could be given.

The people that are interviewed and the cases are all from within one company: Heijmans. It cannot be assumed that Heijmans' project management practices are representative for the whole infrastructure construction industry in the Netherlands. Additionally, it is difficult to quantify project management efforts. A deeper understanding for the phenomenon at hand is required by conducting more case studies across different companies.

The exploratory interviews showed a recognition that a more proactive scheduler with social , interpersonal managerial competences is a contribution to any complex project. The key concept 'information sharing' is a broad concept. While the case studies showed that practically all elements that contributed to overruns in the cases also influenced the planning process in some way, it does not means that a different kind of scheduler is the sole solution. The focus on the role of the scheduler was initiated by findings in literature. Additional research is recommended to see in which organizational contexts a proactive scheduler van operate the best, if at all.

8.4.1 Limitations data analysis

Only a qualitative data analysis methodology was used, which is seen as a limitation in objectifying analyses results. The exploratory interview analysis was done by dissecting the transcripts in a software tool called ATLAS.ti and assigning codes and quotations to the transcripts (Appendix C). This qualitative data analysis for the exploratory interviews is the researcher's understanding of the interview data. Measures were taken in drafting the interview protocol to eliminate unconscious bias. However, unconscious bias can only be eliminated with experience (Emans, 2002).

9. Conclusion

The planning process is mentioned in literature as one of the most important aspects of project management because it does not only consider time, but also cost, quality, health, safety, design and production While it is mentioned that project complexity influences the planning process and contributes to project failure, very little more was found in literature on what aspect(s) of or how project complexity influences the planning process. Thus, the starting point of this research was the intention to explore the influence of project complexity, inclusive of the softer aspects of complexity accepted in more recent publications on the planning process of infrastructure projects, limited to the project phases post tender.

There is a lack of consensus in academic literature on a single definition of project complexity. In literature, two general approaches to project complexity are distinguished The first is in the area of perceived complexity, seeing complexity as subjective. The second assumed a project to be equivalent to a system and its characteristics, where theory on project complexity is applied to project management. Due to a lack of consensus on a definition and approach, The TOE-

Framework for project complexity was used to assess the areas of project complexity that influence project performance and the planning press.

With the regard to the planning process, it is found in literature that there are three aspects that are deemed important to planning and scheduling practices, referred to as key concepts. The first key concept is 'sharing of information'. This is crucial to planning in any context. There other two concepts are 'standard planning process design' and 'role of scheduler' are found in context of complex projects. A 5-level schedule reporting structure is proposed as a standard in literature to facilitate information sharing. The third key concept is the 'role of the scheduler', because it mentioned in literature that scheduling in complex projects requires good interpersonal, managerial skills, which schedulers do not or insufficiently possess from their traditional role.

These view of professionals involved in the planning process on these key concepts in light of project complexity showed an overwhelming support for the notion that project complexity increases the information requirement for successful planning and scheduling. While it was recognized that following a standard contributes to organizational clarity, it's the people that have to use the standard and comply to it. A proactive scheduler that has managerial competences rather than a software centric focus was mentioned as necessary in complex project. These statements are made based on intuition and personal experience.

Winch (2002) stated that "*The management of construction projects is a problem in information, or rather, a problem in the lack of information required for decision making.*". The six case studies showed that indeed, in complex projects the information and communication requirement for adequate planning and scheduling increases, regardless if the complexity is fully induced, partially induced or inherent. wo of the six cases schedulers that identified as non-traditional in their approach to scheduling: proactively gathering and managing information to make sure the schedule is the actual representation of the work to be done.

Project complexity assessment is important, because it is shown that a lack of recognition for the complexity of the project can induce other complexity elements that influence the planning process and project performance. The TOE-Framework for project complexity is seen as a valuable tool to assess project complexity.

It has been stressed numerous times across the cases by managers that a complexity assessment with this framework, or a complexity assessment in general, would have contributed to better project performance. Both in the exploratory interviews and in the case study interviews, awareness was shown for practices that could contribute to improving project performance. A complexity assessment is deemed necessary by professionals in an expert validation, where the framework, approach and results of this research was presented. It is validated that aligning managerial efforts and competences within a project team with the assessed complexity will benefit the planning process and would contribute to better project performance.

9.1 Answering sub-questions

The answers to the sub-questions are given in this section, leading up to the answer to the main research question:

What is the influence of project complexity on the planning process in the construction phase of Dutch infrastructure projects?

Sub-question 1 : How is project complexity defined in literature?

The is no widely held definition of project complexity. Various definitions are mentioned and used by academics. Baccarini's (1996) definition of complexity as "consisting of many varied interrelated parts that can be operationalized in terms of differentiation and interdependence" (1996) is most common. The diversity in project complexity definitions might be explained by its intuitive nature (M. G. C. Bosch-Rekveldt, 2011). These is also a lack of consensus on a project complexity approach, distinguishing two approaches: the first approach assumes that a relatively objective statement can be made from multiple subjective perceptions; second assumed a project to be equivalent to a system and its characteristics, where theory on project complexity is applied to project management. Based on these findings, in the subsequent sections, research is conducted to find a suitable model to assess project complexity in context of the present research (infrastructure projects). The model is used in assessing project complexity in the case studies and finding its interface with the planning process.

Sub-question 2 : W*hich project complexity assessment model(s) can be used to identify complexity factors?*

The TOE-Framework for project complexity can be used due to it being developed with engineering project in mind, and by having a balance of qualitative and quantitative elements. The intended application the framework is to prepare the project team for what complexities might arise, and it is proposed that it could be used to assess and evaluate the project complexity in different project phases.

Sub-question 3: *How is the planning process described in literature?*

There are various depictions of the construction project life-cycle, from inception to (post)completion. What all of the models have in common is the general phases of construction (Cooke & Williams, 2013): tender phase, pre-contract phase and the contract phase. The planning related efforts per project phase are shown in table 1 (p. 19).
The pre-contract phase and contract phase are within the scope of this research. The main concern of these phases is scheduling and the process of schedule reporting and maintenance (Baldwin & Bordoli, 2014; Cooke & Williams, 2013), which will be the focus of the subsequent chapters. A five-level schedule reporting structure is mentioned and advised in literature in context of complex projects. In this structure, a construction schedule is divided into five levels. Each levels has its own schedule density, which is the detail in which activities are scheduled. The closer the scheduled work is to execution, the higher the schedule density on the activities. This five-level structure also assigns roles and responsibilities in schedule reporting. The level 1 schedule is a low density executive summary intended for the project director and project management team. The level 2 schedule is the senior management report. The level 3 schedule is the project manager's report at medium density. In literature, a single scheduler is advised to draft the level 1-3 schedules. The level 4 and 5 schedules are medium to high density schedules drafted by the various disciplines, involving the work per discipline. The level 3 schedule sets the bandwidth in which the level 4 and 5 schedules are drafted. It is key to integrate the level 4 schedule with the level 3 schedule. A figure of this breakdown is shown in figure 8 (p. 21).

Sub-question 4: *How does Heijmans' planning process compare to literature?*
Heijmans' "Planningsmanagement - Handboek" (Heijmans, 2015) shows strong resemblance to the integrated and structured approach prescribed in literature and outlined in section 4.2. In literature, drafting and reporting the Level 1-3 schedule (overall-schedule) is advised to be done by a single person through multidisciplinary input. In practice, this is also done by a single head-scheduler, overseeing the schedules of the different disciplines.

Sub-question 5: *What is the present literature body of knowledge on the effect of project complexity on the planning process?"*
The following aspects, referred to as 'key concepts' in this report, are mentioned in literature to be important to the planning process.

- Sharing of information (Baldwin & Bordoli, 2014; Cooke & Williams, 2013; Curry, 1977):
- Standard planning and scheduling process design (Baldwin & Bordoli, 2014; CIOB, 2011)
- Role of planner and scheduler (Weaver, 2014)

The first key concept is 'sharing of information'. This is crucial to planning in any context. There other two concepts are 'standard planning process design' and 'role of scheduler' are found in context of complex projects. A 5-level schedule reporting structure is proposed as a standard in literature to facilitate information sharing. The third key concept is the 'role of the scheduler', because it mentioned in literature that scheduling in complex projects requires good interpersonal, managerial skills, which schedulers do not or insufficiently possess from their traditional role.

Sub-question 6: What are the views on the planning process in light of project complexity by the professionals involved?

Table 4 below presents the exploratory interview answers and consensus on the literature based key concepts. What is mentioned in this table is related to project complexity. Most of the answers given on the areas of improvement (question 4) and all of the answers given on areas of standardization (question 3) are not related to project complexity.

Literature based key concepts (Ch. 5)	Schedulers	Managers	Exploratory interview consensus
▪ Sharing of information		LEAN planning is seen as an information sharing enabler by the managers. In complex projects, this aids in bringing people together to share knowledge.	The information requirement to draft and maintain a construction schedule increases along with the number of information sources. Also, there was a consensus on the notion that key personnel involved in the tender should transition from the tender phase to at least part of the construction phase. This in order to transfer key knowledge from tender to execution.
▪ Role of planner and scheduler			Due to the increased information requirement, (head) schedulers should have a more proactive role in gathering the information needed to monitor, update and integrate the various schedules into the overall schedule.
▪ Standard planning and scheduling process design	**There is a lack of consensus between both managers and schedulers on this topic. The suggestions for standardization are related to schedule presentation and logic, no relation was mentioned to project complexity. **		
Additional topics			
View on improvements and bad practices		A complexity assessment should be done according to the managers in order to assess what areas to focus the managerial efforts on.	The vast majority of the suggested improvements are a result of (sub-codes) the proactive approach to scheduling, on which there is consensus. They are also related to the enabling of information and knowledge sharing.

Table 17: Exploratory interview consensus managers and schedulers

The takeaways from the interviews largely overlap the key concepts form the literature study. In the next chapter, six case studies are conducted into project that are over budget and/or time (failure). The goal of the case studies was to identify the influence of project complexity on the failure of these projects, what their relation is to the planning process and the key concepts

Sub-question 7: *Which project complexity elements of the chosen complexity model in sub-question 1 can be identified as contributing to project failure and having influence on the planning process?*

Table X below presents the elements of project complexity of the TOE-Framework for project complexity that are identified in the six case studies as having contributed to project failure and having influence on the planning process. The relation to the key concepts is also presented in the table.

Elements from the TOE-Framework	CASE	Relation to key concepts
TT3 Dependencies between tasks	All	**Information sharing:** Higher communication and information requirement to manage dependencies. **Role scheduler**: Proactive scheduler required to facilitate information sharing and monitor dependencies.
TT4 Uncertainty in methods	2,3,4,5	**Information sharing:** Higher communication and information requirement to cope with uncertainty. **Role scheduler:** Proactive scheduler required to facilitate information sharing
TS2 Uncertainties in scope	2,4,5,6	**Information sharing:** Higher communication and information requirement to cope with uncertainty. **Role scheduler:** Proactive scheduler required to facilitate information sharing
TR1 Technical Risks	2,3,6	**Information sharing:** Higher information and communication requirement to consider risks in planning process.
TT2 Variety of tasks	2,3,4	**Information sharing:** Higher communication and information requirement to manage variety of tasks **Role scheduler:** Proactive scheduler required to facilitate information sharing and integrate the varied tasks
TS1 Scope largeness	6	**Information sharing:** Higher communication and information requirement to break down and assess scope. **Role scheduler:** Proactive scheduler required to facilitate information sharing and monitor dependencies.
TS3 Quality requirements	3	*No relation to the planning process given by interviewees*
TE2 Experience with technology	2	**Information sharing:** Higher communication and information sharing intensity required.
TE1 Newness of technology	2	**Information sharing:** Higher communication and information sharing intensity required.
OS5 Size in project team	1,4,5	**Information sharing:** Higher importance of sharing correct information timely. Role scheduler: Proactive scheduler required to manage information required to make sure schedule is actual and integrated.
ORE3 Experience with parties involved	2,3,6	**Information sharing:** Information sharing should be facilitated due to different work ethics.
OS4 Size in engineering hours	1,2,4	**Information sharing**: Lack of effort in facilitating information sharing is caused by a shortage in engineering hours, making people focus on their tasks. Role scheduler: Proactive scheduler required to make sure the most actual schedule is being worked with.
OT2 Trust in contractor	1,2	**Information sharing:** A lack of trust in contractor hinders information sharing.
OR1 Organizational risk	2,6	**Information sharing:** Higher communication and information sharing intensity required due to minimize effect of organizational risk.
ORE5 Interfaces between disciplines	2,5	**Information sharing:** Higher communication and information sharing intensity required to monitor interfaces. **Role scheduler:** Proactive scheduler required to actively monitor interfaces and facilitate in information sharing.
OS1 Project Duration	1	**Information sharing:** When project duration is too short, information exchange should be facilitated to work as efficient as possible.
OS2 Compatibility of different PM methods and tools	6	**Standard process design:** A scheduling standard should be set per project to align scheduling methods and diminish inefficiencies.
ORE1 Project Drive	5	**Information sharing**: Project drive "time" can lead to inefficient working if information sharing is not managed.
OP3 Cooperation JV partner	6	**Information sharing:** Work ethics have to be aligned to facilitate and streamline information sharing. **Standard process design**: A standard schedule reporting process should be agreed upon. Role scheduler: A scheduler should have the status to mandate following of the standard process.
OT1 Trust in project team	1	**Information sharing:** Lack of trust in project team hinders information sharing.
ES2 variety in stakeholder perspectives	3,4	**Information sharing:** Importance of stakeholder perspectives should be assessed and communicated.
EL1 Interference with existing site	3	**Information sharing:** Higher information requirement on interferences with existing site.
ES3 Dependencies on other stakeholders	4	**Information sharing:** Increased information sources and information dependencies.
EM1 Internal Strategic Pressure	1	**General:** Internal strategic pressure in acquiring a project can influence the care with which a project is prepared, resulting into problems that influence the planning process in general later on the project.

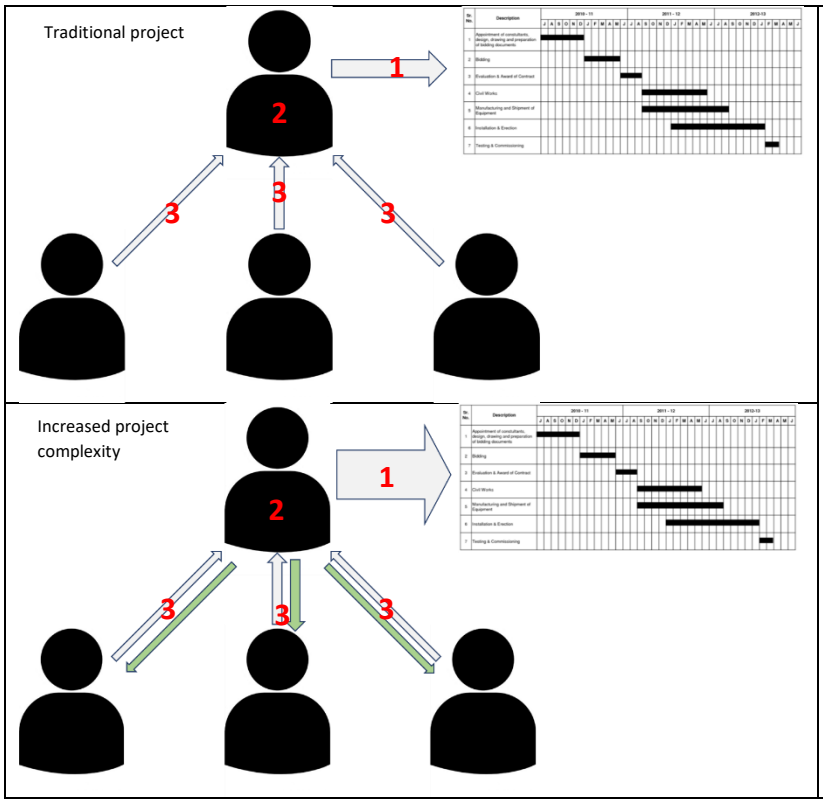
Table 18: Influence of identified complexity elements on key concepts

9.2 Answering main research question

Main research question: What is the influence of project complexity on the planning process in the construction phase of Dutch infrastructure projects?

Answer research question: The influence of project complexity on the planning process of infrastructure projects is that it increases the information and communication requirement to adequately draft and monitor the project schedule. This increased information and communication requirement necessitates the inclusion of proactive scheduler with good interpersonal, managerial skills to fulfil the role of the scheduler as an interface manager.

This concept is illustrated below:



Due to increased project complexity, the communication and information requirement (1) to adequately draft and monitor the project schedule increases. It is found that is this necessitates the scheduler (2) to gather the information proactively (3) to cope with this increased information and communication requirement.

Figure 22: Illustration of the research conclusion

10. Recommendations

10.1 Use of results in practice

The findings of this research are discussed and validated (ch. 8.2.1). The proposed recommendations for use of this research in practice are:

- Assessment of project complexity: professionals consulted in the case studies mentioned insufficient recognition of project complexity to have contributed to overruns. It was suggested that a complexity assessment would contribute to better project performance.
- Proactive scheduler: a proactive scheduler with good interpersonal, managerial skills and competences is recommended for the position of being responsible for the overall schedule (level 1-3, head-scheduler).
- Information sharing: it is found that the information and communication requirement needed to sufficiently draft and maintain the schedule and making decision increases in complex projects. Aside from the argument that the role of the (head)scheduler needs to evolve, it is recommended that the rest of the project organization should take more responsibility in providing information and better communication.
- Standard process design: It is recommended to make agreements at the start of the project on which planning and scheduling structure to follow and what the roles and responsibilities are in context of the planning process. It's a vessel for communication and provides organizational clarity.
- Organizational continuity: Organizational continuity is recommended to make available knowledge to manage the inherent complexity of the project and/or prevent the inducing of complexity.

12.1.1 Use of results for Heijmans

Most of the problems Heijmans' projects that were analyzed in the case studies endured could be related to an lacking complexity assessment. Heijmans has the tools to cope with the influence of project complexity on the planning process:

- Continuity of key personnel form tender to at least part of execution is a Heijmans policy
- The 5-level schedule reporting structure is standard practice for Heijmans Infra since 2014.

Additionally, the need for the proactive scheduler with interpersonal, managerial skills for complex projects is also recognized by project managers and most schedulers within Heijmans. Therefore, the main recommendation for Heijmans are:

- Assessment of project complexity: assessing the expected complexity of a project is recommended in order to focus managerial efforts to a particular area of expected complexity.
- Scheduler competences: Related to the recommendation to assess the expected complexity of the project, it should be assessed which type of scheduler the expected is best suited for the project. The notion that complex project require proactive schedulers with interpersonal skills is already recognized within Heijmans.

10.2 Further research

This research relied heavily on standing practice to gather data. The consultation of professionals in various research stages, analysis of projects and discussion of findings gave insights into concepts for further research.

- Research toward relation between complexity elements: induced and inherent complexity
  It was found in this research that the managerial effort to cope with inherent complexity can induce complexity. On page 63 of this report it mentioned that the total complexity of the project seems to be a function of inherent complexity, management of the inherent complexity and induced complexity. For example, if a project applies an innovation using technology the team has no experience with (inherent complexity), it can induce organizational complexity in the form of lack of trust in the project team and project size (growing the organization to cope with lack of knowledge). More research into the relation between induced and inherent complexity is recommended: which complexity elements can be induced by mismanagement of inherent complexity and how?

- Research into competence based team composition to cope with complexity
  In several case studies it was mentioned that certain figures in a project organization were limiting to the progress of the project. According to the interviewees, those people were not the right ones to fill that role given the project under consideration. Also, in several cases, changes in management personnel resulted in better project performance.

- Research into project scheduling
  Throughout this research, there is a consensus that a proactive scheduler benefits in coping with the increased information requirement influenced by project complexity to successfully draft and maintain a schedule. It is suggested that in certain interviews (not often enough to take into consideration in this research) that the ideal combination would be a scheduler with interpersonal, managerial competences to facilitate information sharing, and a scheduler which is an expert in software tools to assess the impact of the information on the critical path. This approach is a recommendation for further research.

- Research including the tender phase of projects
  The tender phase of infrastructure projects has been excluded from the research to manage the scope given the time available for this research. It is recommended to include this phase into research into project complexity and planning because the importance of the tender phase has been mentioned in the exploratory interviews and case studies.

- Further research on benefits of standardization of construction scheduling structure
  In the exploratory interviews, when asked about the views on standardization in planning and scheduling, the interviewees mentioned standardizations related to structure, layout and connection to project resources. It is recommended to research the benefits of these suggestions.

11. Reflection

This research consists of three data gathering segments: literature study, exploratory interviews and case studies.

Throughout the course of the research, it was challenging to separate the planning process from project management. This makes sense, because the planning process is an integral part of project management. However, this did make staying within scope more challenging. It was a good choice to focus on the key concepts, because they are mentioned as important specifically in the context of planning, scheduling in complexity. Without these elements, it would have been an almost impossible challenge to separate the planning process from project management theory for the scope of this research.

The exploratory interviews were suggested by the external supervisor and first supervisor of this research as a reaction to the struggles in linking what was found in literature to the problem statement. The goal was to explore three key concepts: information sharing, standard scheduling process design and role of scheduler in complex projects (with room for suggesting improvement and mentioning bad practice). In hindsight, these exploratory interviews should have been more structured. Setting up, conducting and analyzing the exploratory interviews has requirement an efforts that is equal to roughly a third of the research duration. Not only did it the exploratory review phase take a long time, it almost acted as a concussion grenade as well, destabilizing the focus of the research because many things have been mentioned by the passionate participants. It was an ongoing challenge to funnel the information and data through the research scope. Ultimately, the interviews were structured and analyzed in a way that is valuable to this research. The ATLAS.ti qualitative analysis of the data was an afterthought that turned out well because the interviews could be used in this report in a scientifically valid way. This has been a learning process for future interviews.

Something that I have learned throughout this research is scope management. If the slightest hint of a possible relation between something that is within my research scope and something that is outside the scope is mentioned anywhere, I went after it (initially). This is because of my personal nature of being a curious and thorough person. This approach was note sustainable because the scope would have kept growing endlessly.

Reflecting on this research, I can safely say that it has been a very valuable learning experience.

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APPENDIX A: Project complexity

Appendix A1 : Definitions

Author(s)	Definition/ Description
(Baccarini, 1996)	Project complexity consists of many varied interrelated parts and can be operationalized in terms of differentiation and interdependence **Organizational complexity by differentiation:** depth of the organization the amount of organizational units. **Organizational complexity by interdependence**: degree of operational interdependencies and interaction between the project organizational elements. **Technological complexity by differentiation:** refers to the variety or diversity of some aspects of a task. **Technological complexity by interdependence*:** interdependencies between tasks, within a network of tasks, between different technologies, and between inputs. (*interdependencies can be either pooled, sequential or reciprocal, where reciprocal interdependencies are dominant within construction projects)
(Gidado, 1996)	**Definition:** The measure of the difficulty of implementing a planned production work flow in relation to any one or a number of quantifiable managerial objectives.
(de Bruijn et al., 1996)	Breaks project complexity down into Technical, Social and Organizational complexity. **Technical complexity:** assumed to be related to amongst others technological uncertainty, dynamics and the uniqueness of the project. **Organizational complexity:** assumed to be related to amongst others the organization structure, the project team, and the actors involved. **Social complexity:** related to actors involved, their interests and the risks and consequences of the project in relation to its environment.
(Williams, 2002)	Project complexity exists of two components: Structural complexity & Uncertainty. **Structural complexity:** composed by the size (numbers of elements) and interdependence of the elements. The components interact in a complex way whereby the total is more than the sum of the parts. **Uncertainty:** Uncertainty is split up in Uncertainty in Goals & Uncertainty in Methods. Structural complexity is compounded by uncertainty.
(Hertogh & Westerveld, 2010)	Six categories of complexity are defined based on empiric research: technical, social, financial, legal, organizational and time, where social complexity is dominant. Also, two types of complexity are defined: detail complexity and dynamic complexity. **Detail complexity:** the view that defines complexity as many components with a high degree of interrelatedness. It is visible in three main subsystems: the stakeholder subsystem, the product subsystem, and the activity subsystem. **Dynamic complexity:** refers to situations where cause and effect are subtle, and where the effects of interventions over time are not obvious. Key to dynamic complexity is the fact that it can undergo major revision over the course of the project and it is related to the social complexity in the practitioners' framework.
(M. Bosch-Rekveldt et al., 2011)	The paper, part of a broader research into managing project complexity, presents a framework for characterizing project complexity in large infrastructure projects, which can be used to assess the complexity footprint of a project. The TOE framework for project complexity presents the elements that contribute to project complexity from a theoretical as well as a practical perspective. A high level definition of project complexity should include structural, dynamic and interaction elements. TOE stand for Technical, Organizational and Environmental complexity. **Technical complexity:** focused on the content of the project, includes the subcategories goals, scope, tasks, experience and risk. **Organizational complexity:** focuses on the softer aspects, includes the subcategories size, resources, project team, trust and risk. **Environmental complexity:** focuses on the influence from the environment, includes the subcategories stakeholders, location, market conditions and risk.

(Brady & Davies, 2014)	Structural and dynamic complexity are highlighted. **Structural complexity:** concerns the arrangement of components and subsystems into an overall system architecture. This should be managed by decomposing the project/program into more manageable sub-components, a systems integrator should manage technical and organizational interfaces, and collaborative arrangements should be made. **Dynamic complexity:** concerns changing relationships among components within a system and between the system and its environment. Experimenting, prototyping, trial and error learning, incorporating flexibility, feedback sessions and mutual adaption in response to unplanned events should manage this.
(Lu, Luo, Wang, Le, & Shi, 2015)	Task and Organizational model containing: **Task complexity factors:** amount and complexity of the task and the complexity of dependency among these tasks (the amount of tasks, task complexity and pooled/sequential/reciprocal interdependence. **Organization complexity factors:** amount and complexity of organizational members and the complexity of the organizational structure. It thereby involves: amount of organizational members plus their complexity and the degree of centralization, formalization and matrixing.

Appendix A2: Gidado's model

Gidado's model is singled out because it builds its own definition and model of project complexity rather than building upon popular foundations of project complexity, and aims to specifically apply it to construction time and cost planning. Gidado defines project complexity as "the measure of the difficulty of implementing a planned production work flow in relation to any one or a number of quantifiable managerial objectives" (Gidado, 1996, p. 218). The model uses this definition to numerically assess the effect of project complexity on project activity durations.

Gidado (1996) acknowledges increasing project complexity as one of the issues facing practitioners in planning. He notes that (at the time of publication) there is a lack available tools and techniques to assess project complexity. Gidado found that the managerial objectives in construction influenced by project complexity originate from: employed resources, the environment, the level of scientific and technological knowledge required and the number and interaction of different parts in the work flow (Gidado, 1996). These sources have been grouped into two categories, seen in table 4, and these are seen as sources for delay.

Category A	Dealing with the components that are inherent in the operation of individual tasks and originate from the resources employed or the environment
Category B	Dealing with components that originate from bringing different parts together to form a work flow.

Table 19: Sources of project complexity categorized (adapted from Gidado, 1996)

Category A components are inherent complexity and uncertainty factors. 'Inherent complexity' refers to the inherent complication or difficulty that is involved in conducting roles in a system work flow. In turn, three intersecting divisions sort the inherent complexity factors:

1. "That which is understood by current advances in construction technology, but requires all the skills, knowledge and attention of those involved" (p.5) (Technical Complexity TC)
2. "That which is not understood by current advances in construction technology and requires all the skills, knowledge and attention of those involved" (Analyzability AS) (p.6)
3. "That which is understood by current advances in construction technology and does not require special skills or knowledge, but it requires the use of unusual processes due to environmental constraints." (Task Difficulty TD) (p6)

'Uncertainty factors' refers to the unknowns in both design and production. The following four groups intersecting divisions encompass uncertainty factors:

1. Lack of complete specification for the activities to be executed (CS).
2. Unfamiliarity of the inputs and/or environment by management (UF)
3. Lack of uniformity of work (UN)
4. Unpredictability of the environment (UP)

The Category A factors are depicted in the aggregated model of inherent complexity and uncertainty factors in figure 3 on the next page.

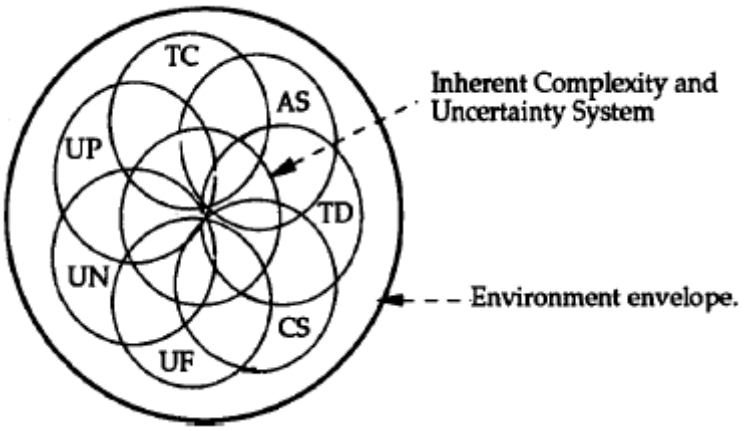

Figure 23: Aggregated model of inherent complexity and uncertainty factors (Gidado, 1996)

Category B components deal with sequencing of operations and underlying complications to form a work flow that brings together different parts. Gidado notes that the effect of project complexity in this context can be influenced, because managers can change the operations sequencing in a work flow. The components of category B can be grouped into three divisions:

1. Interdependences of different kinds of technologies with or without repetitive roles (TRI)
2. Rigidity of sequence (RS)
3. Overlap of construction elements (OV)

Gidado argues that the effect of project complexity on the success of a project van be influenced by implementation of managerial functions. Gidado believes that the Category B components can influence the effect of project complexity by applying fitting planning and control adjustments. On the left side of the balance are the project success criteria: project planning and cost control. On the right side is the project complexity. In Gidado's model, project failure may occur if project managers inadequately control project planning and costs. In this case, if the project complexity measure outweighs the invested managerial effort, then it is referred to as a positive failure: +ve. Adequate planning and controlling efforts are no guarantee for success, failure may still occur in a different form. This type of failure (overhead costs decreasing profits) is referred to as a negative failure: -ve. In a negative failure situation, there is a lack of knowledge of the effort required to achieve success.

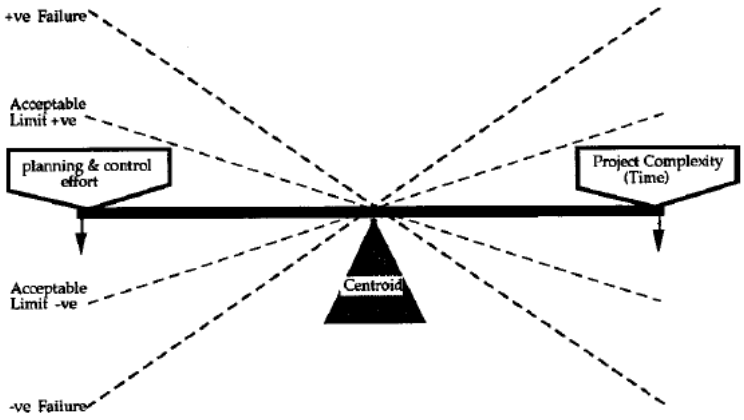

Figure 24: Balance of project success (Gidado, 1996)

This balance is illustrated in figure 4. If the effects of the measured project complexity can be mitigated by the appropriate planning and control effort, the project success within acceptable limits. Project complexity must be measurable in order to assess these acceptable limits (complexity contingency threshold).

APPENDIX B: Brief history planning and scheduling

For a long time, the bar-chart was the most common planning and scheduling technique (Weaver, 2006). The bar chart is good at showing when scheduled activities have to take place, but is limited in its capability to show inter-relationships between activities. In the 1950's, the issues regarding this limitation spawned the interest of the operational research community, as projects became increasingly complex (Weaver, 2006).

By 1957, the UK based Central Electricity Generating Board developed a technique that could identify the longest irreducible sequence of events. In 1958, the Programming Evaluation Review Technique (PERT) was published. In the same year, the Critical Path Method was being developed at E.I. du Pont de Nemours, a U.S. based company (Lockyer, 1974).

After the early success and adoption of these techniques, they came to be known as Critical Path Analyses. Critical Path Analysis (CPA) was emphasized by its ability to identify the shortest duration of a project formed by key project activities. CPA was adopted by clients and contractors in the 1970s as the standard for planning, scheduling, monitoring and control. At the time, CPA was mostly conducted manually due to the lack of mainstream computer access. The next decade saw the introduction and success of the IMB PC and it lead to a more widespread adoption of CPA, as software was available to conduct the CPA (Baldwin & Bordoli, 2014; Reiss, 1995). The development of computer systems exposed an important aspect of planning and scheduling: using computer systems for planning and scheduling required more than software packages and capable hardware. It became apparent that people, procedures and data were also very important. This lead to collaborative thinking where all involved in the project were expected to contribute to project planning and scheduling (Weaver, 2006).

In the late eighties, it sunk in that cheap, feature rich and approachable computing and adoption of project management systems was not a guarantee for project success. As a result, the nineties saw the development of Critical Chain Project Management (CCPM) and Last Planner, both important developments in planning and scheduling (Baldwin & Bordoli, 2014)CCPM focuses on schedule activities and uncertainty surrounding it. CCPM identified the key activities that form the critical chain for the construction work, based on resource and time constraints. Project managers can individually create and use buffer time allocated to their activities in traditional critical path methods. CCPM however uses a project buffer instead of activity buffer and argues that this buffer should be actively monitored on an on-going basis by making sure the critical chain tasks have resources allocated to them.
In light of resource management and allocation, according to Ballard and Howell (1998a), the CPM approach as basis for production planning was flawed. In their view, there should be a resource requirement before production can commence in order to assess what actually can be done (Ballard & Howell, 1998a).

Building Information Modelling (BIM) has been accepted since it emerged in the last decade. Along with Virtual Prototyping, BIM has achieved industry acceptance as the basis for design, production and maintenance of many new buildings. These technologies together with a focus on sustainable building developments and new procurement requirements are influencing the thinking of both public and private clients who are demanding new standards and new ways of working. The ability to model the building product and link the contents of the building model to other systems was first developed in the 1980s (Baldwin & Bordoli, 2014). With respect to construction planning this became known as 4D Planning and typically comprised the ability to link the elements and quantities from the computer model to project management software to

introduce the dimension of time and generate simulations showing how the construction would proceed throughout the duration of the project. (Similarly, using product model data to analyze cost has become known as 5D planning.

The use of digital product models for all aspects of building design and management is now known as building information modelling or BIM. The development of realistic graphical simulations for planning the broader aspects of physical and operational aspects of the building or facility is known as virtual prototyping or virtual construction. The benefits of these tools and techniques are already proven on large commercial buildings and infrastructure works, and they are increasingly being adopted on medium and smaller projects (Baldwin & Bordoli, 2014).

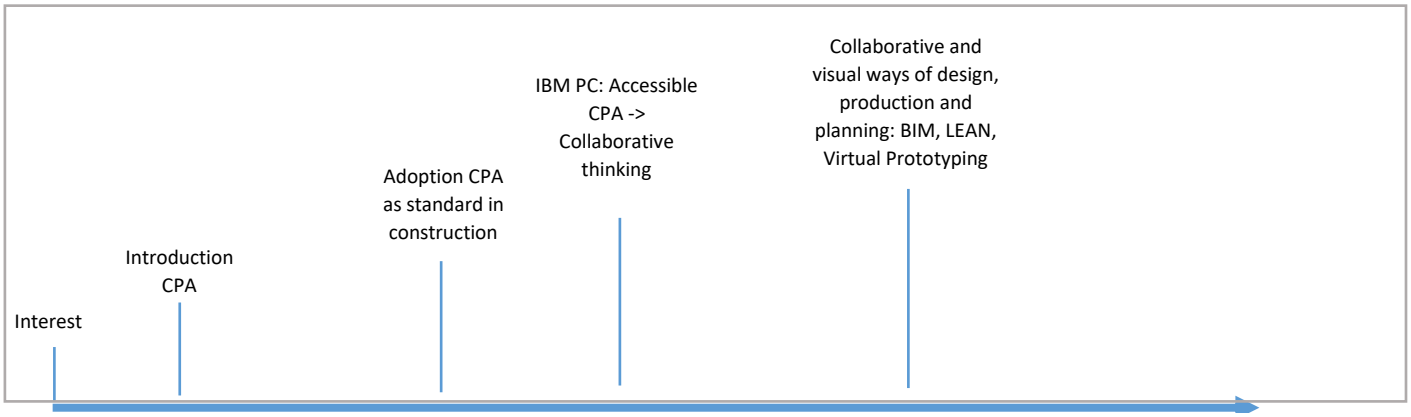

Figure1: Timeline development planning and scheduling

APPENDIX C: Project complexity

Appendix C1: Qualitative data analysis process

Table 3 shows the process steps of the qualitative data analysis applied to the exploratory interviews.

Process Step	Actions
1: Collecting data	▪ Semi-structured interviews
2: Organizing data	▪ Transcribing interviews ▪ Importing transcript into ATLAS.ti
3: Coding data	▪ Coding transcripts
4: Code sorting and grouping	▪ Grouping codes based on common properties
5: Code networking	▪ Visualizing relations between codes
6: Analysis	▪ Interpreting the relations between codes

Table 20: Data analysis process exploratory interviews

1. Collecting data : In the first step, data is gathered though semi-structured exploratory interviews (see previous sections for the interview protocol and main questions to be asked).
2. Organizing data : The data is organized to facilitate a qualitative data analysis. The interview transcripts were imported into ATLAS.ti. ATLAS.ti is a software tool that organizes data and facilitates in qualitative data analysis. It is used as the interview and case-study analysis tool. The software works with codes and quotations. It defines a code as a conceptual construct through which data is accessed. It intends to capture meaning in the data. The codes are linked to quotations. Quotations are defined as a segment from a document that is interesting or important to the users.
3. Coding data : After importing the data in the software, the transcripts are coded. The main interview questions serve as primary codes. The full answers to the interview questions are designated as quotations. Open coding is applied in order to identify, name, categorize and describe phenomena found in the interview answers. The codes that are assigned to the main questions are found in the third and fourth columns of Table 2 (p. 27). The main questions for schedulers and for managers are assigned different codes in order to sort the answers given. It's worth to mention that open coding is an approach in which the researcher assigns codes to the documents at hand. The networked view is a result of the researchers understanding of the interview data. The key codes (main interview questions) and the relations are described.
4. Code sorting : After coding the transcripts, the codes were sorted and grouped based on common properties. This is to prevent multiple codes describing the same phenomenon.
5. Code networking : The second to last step is the visualization of the relation between codes. A visualization in the form of a code network gives direct insights into the code relations.
6. Interpreting : Finally, the relations between codes are interpreted and analyzed.

The use of ATLAS.ti in this process is illustrated by an example.

1. Collecting Data: An interviews in conducted

Q1: How do you fulfill your role in the planning process

A: What is expected of the scheduler is to process the information that is provided to him or her, update the schedule and report it to management. What I have noticed throughout the years is that as projects get more complex, I need more information from more people to do this. That's why I go into the organization, set up meetings with people I want information from and assess if their schedule is aligned with the overall project schedule. I also log key communications regarding schedule activities in the schedule that is available for the whole project organization to see. That way, people can the history of what influences the change of the scheduled activities. I kind of see it as information management. In any case, it's fundamental to do this in complex projects. People are simply too distracted by other aspects to timely provide you schedule related information. Too often people are sitting information that gets lost, but is crucial to making sure the schedule is actual and feasible.

Q2: What aspects related to planning and scheduling should be improved in your view and why?

A: Sometimes when I start with setting up the overall schedule after project is awarded, I find that information is missing on why certain choices were made in tender phase. What this leads to is that certain choices made in the tender phase are reconsidered in preparing for construction. Quite often, the changes made to the points of departure from the tender have to be reversed back to the initial points of departure, which is counterintuitive and simply bad practice. People make choices for a reason, if you think you can do something more efficiently, it has probably been discussed in the tender phase. That's why I think that key management personnel that operating in the tender phase should transition to the execution phase, or at least part of the execution phase to be accessible when extra clarification or information is required.

2. Organizing Data: Importing transcript into ATLAS.ti

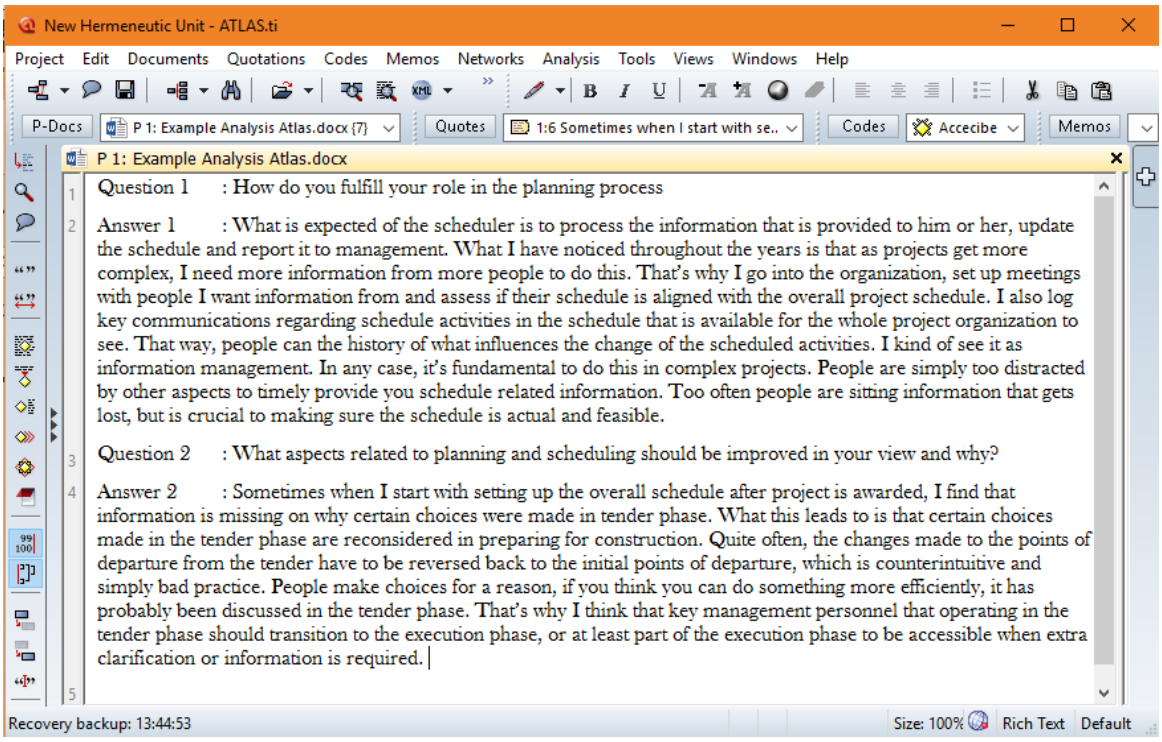

Figure 2

3. Coding data: Applying codes to the interview answers

The whole question is the primary code. Additional concepts mentioned in the interview are coded by means of open coding.

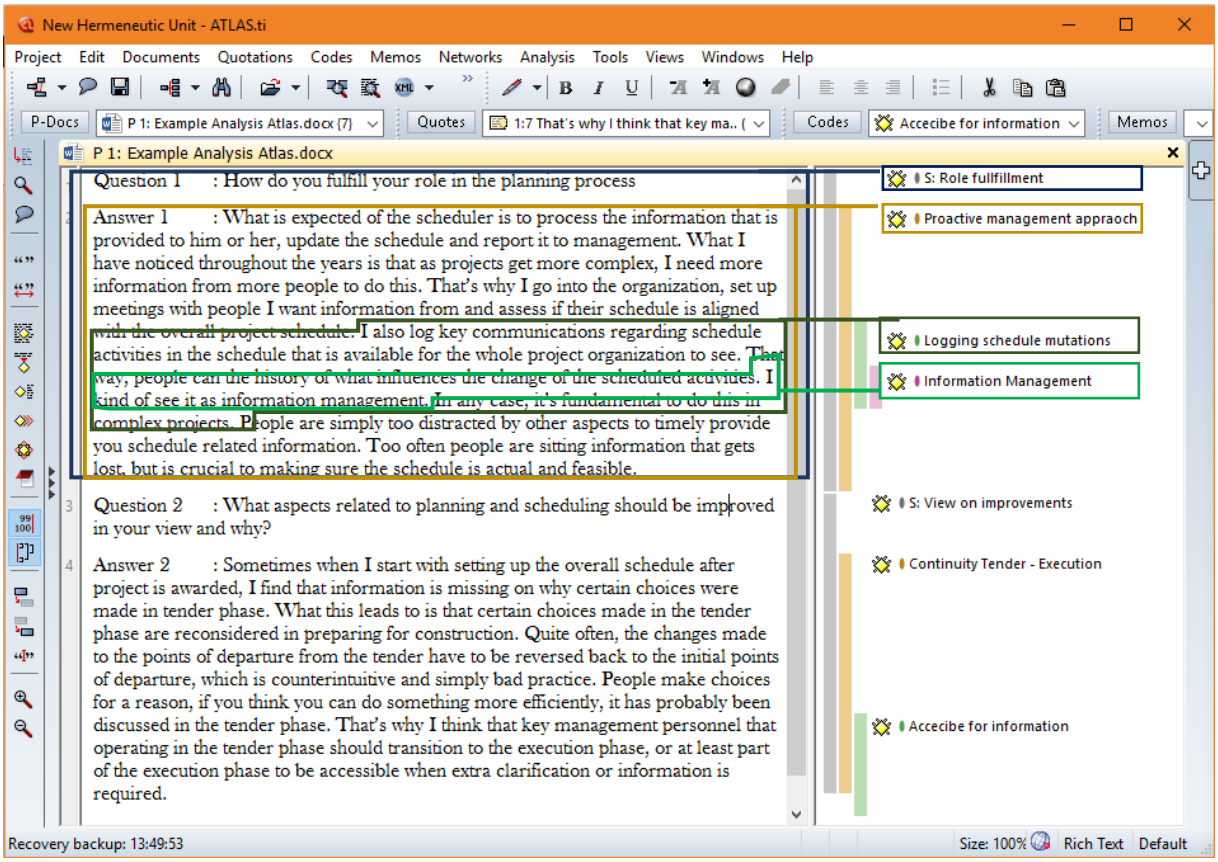

Figure 3

In Figure 3, the answers given are coded. The interviewee described his role fulfillment as deviating from the traditional approach and being more proactive, which is coded as 'proactive management approach'. Additional concepts mentioned in this answer are coded as well, such as 'logging schedule mutations'. All the transcripts from the 12 exploratory interviews are coded in this way.

4. Code sorting

In the first answer, the 'information management' code is linked to a part of the answer. In the second answer, 'accessible for information' is linked. Both codes describe the same phenomenon, information sharing, and are thus are replaced with this common code group. All the transcripts are reviewed in order to sort and group codes based on common properties. This is to prevent multiple codes describing the same phenomenon and to better structure and present the analysis. When it is believed that two codes describe something similar, but are more valuable as separate, they are kept as unique codes.

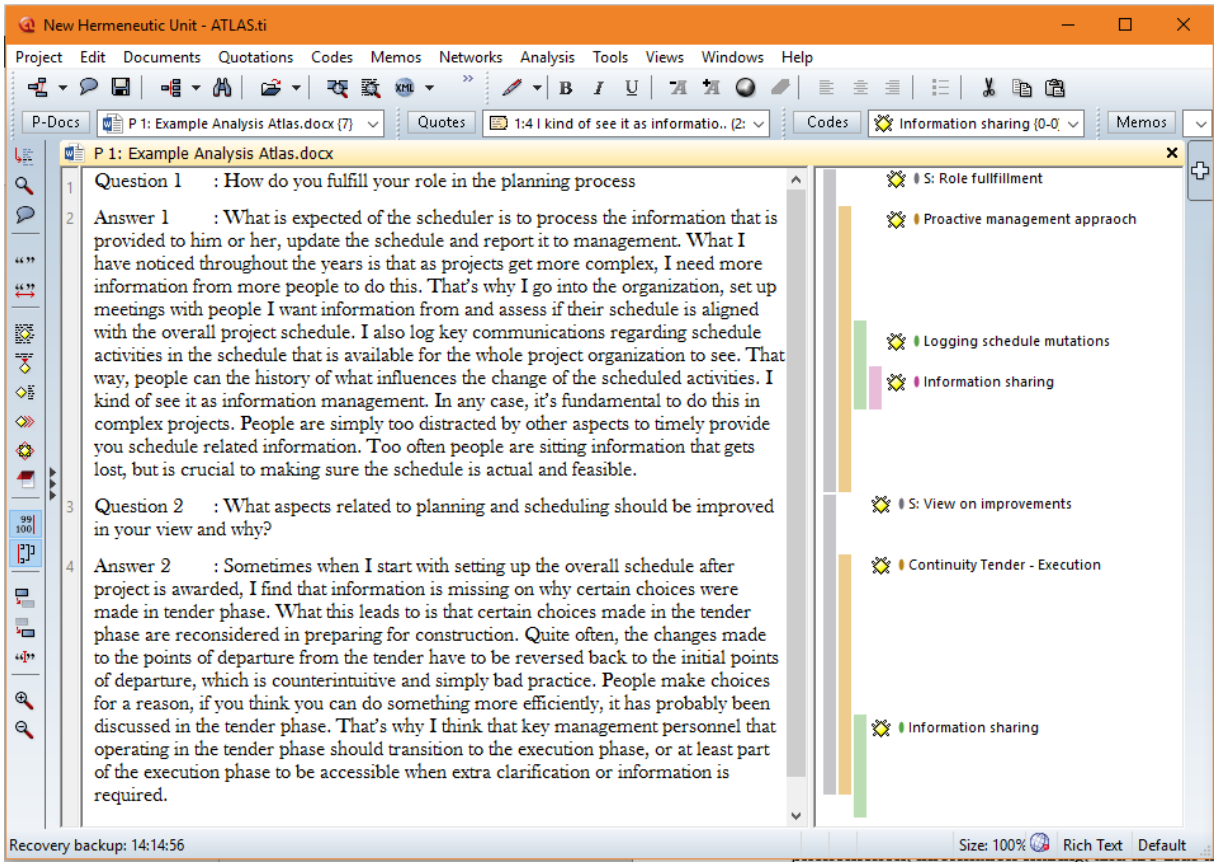

Figure 4

5. Code networking

The final step in using the software in the analysis is visualizing the relation between codes through a network diagram. A visualization in the form of a code network gives direct insights into the code relations. The visualization occurs in two steps: the first step is to import the codes into the network view manager, the second is to manually link and interpret the relation between the codes. The software does not do this automatically. Figures 5a shows the import of the codes into

the network view manager, figure 5b shows the code networking and figure 5c shows the final network.

(a)

(b)

(c)

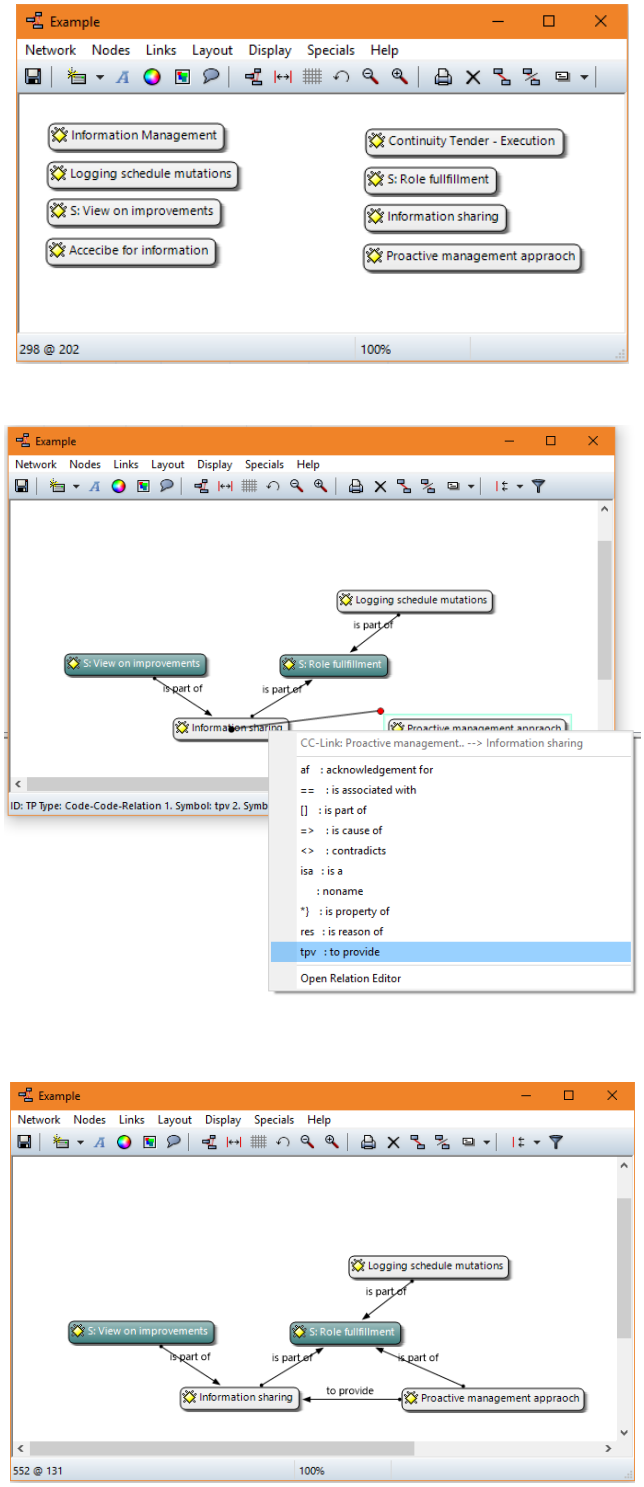

Figure 5: Code networking process (a-c)

6. Interpreting: Finally, the relation between codes are interpreted and elaborated.

Appendix C2: Elaboration codes

Code	Elaboration
Structure and strategy planning process	This code is assigned to an answer or part of an answer where it is mentioned that the (head)scheduler should be responsible for the overall structure and strategy of the planning process.
Management competence	This code is assigned to an answer or part of an answer where it is mentioned that (head) schedulers should have management competences.
Availability planning logic	This code is assigned to an answer or part of an answer where it is mentioned that the planning logic should be readily available. This means that information should be available on the reasoning behind the choices made in the process and scheduling.
Central position: heart of the project	This code is assigned to an answer or part of an answer where it is suggested that a scheduler should not report to a discipline manager, but be independent and only report to the overall project manager.
Code	Explanation
Complexity assessment	This code is assigned to an answer or part of an answer where it mentioned that an assessment of the complexity of the project should be done.
Coupling level 5 to level 4 by the disciplines	This code is assigned to an answer or part of an answer where it is mentioned that the higher density schedules (level 5 and level 4) should by coupled/ integrated by the detail-schedulers, not the head-scheduler.
Feasibility analysis	This code is assigned to an answer or part of an answer where it is suggested that a feasibility analysis should be conducted when new schedule parameters are transferred to the scheduler in order to update the schedule.
Integrated knowledge sharing	This code is assigned to an answer or part of an answer where integration of knowledge is described
Integrated schedule management	This code is assigned to an answer or part of an answer where the role of a scheduler is described as a schedule integration manager.
LEAN	This code is assigned to an answer or part of an answer that refers to LEAN planning.
Necessity approach	This code is assigned to an answer or part of an answer where
Passive scheduling approach	This code is assigned to an answer or part of an answer where the traditional approach to planning is described.
Planningmanagement	This code is assigned to an answer or part of an answer where the scheduler is proposed as a person responsible for management of planning and scheduling processes..
Proactive approach	This code is assigned to an answer or part of an answer where the scheduling practices are described as proactive: the scheduler takes the initiative to gather information and does not wait till the information is provided. The schedulers in that way makes sure that the schedule is the most actual representation to be done.
Recourse allocation	This code is assigned to an answer or part of an answer where resource allocation to scheduled activities is advised/ suggested.
Scheduler: interface manager	This code is assigned to an answer or part of an answer where the scheduler is described as an interface manager.
Scheduling and monitoring preparatory events	This code is assigned to an answer or part of an answer where it is suggested that not only activities should be schedules, but the preparation toward that activity.
Scheduling design requirements	This code is assigned to an answer or part of an answer where it is suggested that readiness of documents needed to commence design tasks should be added to the construction schedule.
Standard activity ID's	This code is assigned to an answer or part of an answer where it is suggested that the name of schedules activities and their associate ID's should be standardized.
Standard schedule model and logic	This code is assigned to an answer or part of an answer where it is suggested that the model of the schedule and its logic should be standardized across Heijmans.
Tender to execution	This code is assigned to an answer or part of an answer where it is suggested that key project personnel should transition from the tender phase to at least a part of the pre-contract and contract phase.

Appendix C1: Analysis exploratory interviews schedulers and managers

Schedulers

The seven interview transcripts were open coded and the result is shown in a network view in figure 10.

Role fulfillment: When the schedulers were asked about how they fulfill their role as a scheduler, they responded that the role of the scheduler is to present the actual project information in a schedule. However, they acknowledged that projects are getting more complex, leading to an increase in information and communication required to make sure the schedule is the actual representation of the work to be done. This increasing communication requirement and information dependency necessitates the schedulers to work in a pro-active way, which is coded as 'active management approach'. The following aspects are part of this active management approach:

- Decision making: The schedulers think that when in position of head-scheduler on complex projects, they should have some form of decision making authority. This is more efficient in their view to manage the schedule.
- Efficiency in work and communication, to provide clarity, resulting in efficiency
- Proactive gathering of information : It no longer suffices to depend on the information provided without asking for it, it is required to proactively gather information. Personal, direct communication is also required to shorten communication lines.
- Integrated schedule management : The level 3 and level 4 schedules need to be integrated. The level 4 schedules, as described earlier in this text, is a detailing of the bandwidth provided by the level 3 schedule. These integrated schedules need to be managed more to ensure that the detail schedules remain within the bandwidth of the higher level milestones.

The result of an active management approach is efficiency in work and efficiency in communication. These is general support from project managers for this approach to scheduling, and the reason for this support is the view that it's necessary on complex projects. According to the schedulers, complex project are getting more interdisciplinary, introducing more interfaces. This requires the schedulers to be positioned in the role of interface manager to align the information with the disciplines.

Interesting to note is that while all the schedulers agreed that the role of scheduler changes in complex projects, they also acknowledged that might now be interested in being a scheduler in a complex project. Four out of seven said to be interested in a more actively managerial, interface management role, while the other three noted that it is not within their interest to perform their role in such a way, they are more interested in optimizing the critical path of a schedule and coming up with schedule optimizations. Ideally, both type of schedulers work on the same level on the same project.

Information/ knowledge transfer: It was acknowledged by all schedulers that information is of utmost importance in order to maintain and understand the schedule. This starts in the tender phase. Usually, the schedulers that have schedules a project in the tender phase are not the same as the ones the schedulers that are active in the realization phase. There is already an interface there. In complex project, when it comes to the transition of a schedule (level 1 to 3) from tender to realization, is it important to have the information on what how the schedule was set up in the tender, according to which logic. This information can be textual in terms of logging, or:

transitioning of key management personnel from the tender phase to realization. That way, knowledge lost form tender to realization gets minimized.

When it comes to sharing information and transferring knowledge in the realization phase, the role of the scheduler is important. In complex projects, it is tied to pro-actively gathering information. This is touched upon in the 'role scheduler' paragraph. The reason for this is that there might be disciplines that are sitting information that is relevant for the schedule, but is not shared yet. The reason for this according to the schedulers might be loss of oversight due to project complexity. The scheduler recognized the interrelations and the information dependence and facilitates in that.

Standardization: When it comes to standardization, it was agreed upon by all schedulers that standardizing a schedule is not feasible, as all projects are unique. The following is proposed as to be standardized:

- Activity ID's : An activity ID is the name of an activity. This can be standardized.
- Standard schedule logic and model: Presenting the schedule according to a standard model. This is not a template, as projects are unique. This is referred to as the elements in a schedule that are recurring, which is usually its set-up.
- Standard, updated activity database: An activity database is suggested, from which a schedule can be set-up. In this database, there are average lead-times per activity. This average lead-time is the best practice across all projects for that specific activity. That way, there is a starting point for discussion and optimization.

Areas of improvement: The areas of improvement largely coincide with what has been said about information sharing, standardization and role of scheduler. Resource allocation was mentioned by nearly all schedulers. According to 4/7 Schedulers, a schedule should not only incorporate time, but also project resources (finance, working hours) etc. That way, resource can be allocated to the activities that need it the most. Integration has been mentioned in the form of integrated knowledge sharing, and integrated schedule management. Integrated schedule management refers to improvements in integrating and managing the level 3 and 4 schedules. That can be improved (by for example, agreeing on the software used per level). Integrated knowledge sharing is suggested as an improvement because complex projects are usually executed in multidisciplinary teams where information/ knowledge is key. Any information needs to me shared with the whole organization, which is a challenge in complex projects with large project teams. A scheduler in an active-management role can facilitate in this aspect.

Schedulers: code relations

- The scheduler **is** an interface manager
- The following aspects **are part of** an active management approach
    - Decision making
    - Efficiency in work and communication, to provide clarity, resulting in efficiency
    - Personal, direct communication
    - Proactive gathering of information
    - Integrated schedule management
- An active management approach plays part in information and knowledge transfer.
- Efficiency in work and communication is **a result of** an active management approach

- There is general **support** for this approach by planners and managers on large projects, as long as the scheduler does demand too much autonomy
    - Necessity for the approach **is the reason** of this support
- There is appreciation for the approach by the project team

The main concepts coinciding with information/knowledge transfer:

- The transition from tender to execution is associated with transferring information, sticking to the tender plan, and transitioning core management personal from tender to execution
- The following aspects are part of the sharing information and knowledge:
    - Making available the planning logic: what are the reasons for the choices made
    - Integrated knowledge sharing: communicating new knowledge to all involved
    - An active management approach in scheduling is required to gather information and share it, rather than wait on information and incorporate it

The main concepts coinciding with views on standardization:

- The following aspects **are part of** the view on what should be standardized
    - Activity ID's
    - Standard schedule logic and model
    - Standard, updated activity database

The main concepts coinciding with areas of improvement:

- All the following aspects **are** areas of improvement
    - Standard schedule logic and model
    - Standard, updated activity database
    - Organizational uniformity
    - Recourse allocation
    - Integrated schedule management
    - Scheduling design requirements
    - Integrated knowledge sharing

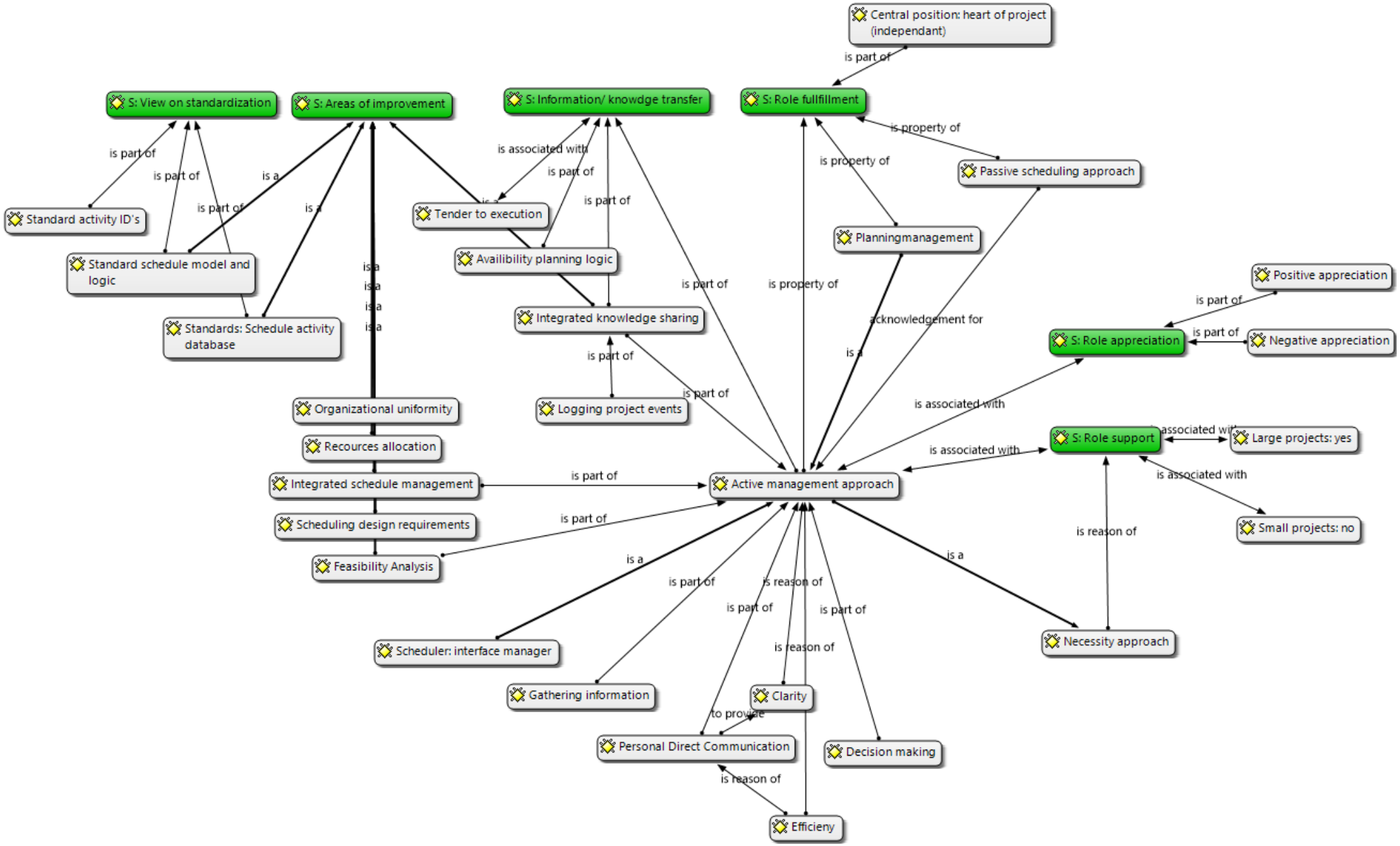

Figure 25: Code network - schedulers

Managers

Role fulfillment: All interviewed management personnel agreed that in complex projects, it is unreasonable to expect the management team to know what is going on a project at a high level of detail. This necessitates a middle-man to stand between the management team and the project team, the middle man being a scheduler that reports progress to the management team. According to the managers, project complexity introduces more interdependencies within project teams. It is thus important to monitor if the activities/information required to commence another activity that is dependent on it. According to the managers, it should be the role of the schedulers to monitor the progress of certain activities that other activities depend upon by approaching the relevant people. This approaching is incited by the schedulers themselves, coinciding with the active management approach.

The managers also agreed that in complex projects, in order to materialize this approach, the schedulers need to have management competences in order to be able to act as an interface manager. The managers also acknowledged the importance of a scheduler that assists the scheduler that acts as an interface manager. This assisting scheduler is the one that is the expert in running simulations and mathematical optimizations of scheduler. Ideally, in complex projects, there should be two schedulers monitoring the overall schedule (level 3): one that communicates with the organization and collects information and one that runs mathematical optimizations based on the information gathered.

Information/knowledge transfer: All managers agreed that transitioning key management personnel from tender to realization is crucial in transferring knowledge, even if it is for a short period. The project team in the realization phase needs to know what the reasoning is behind the choices made in the tender phase. According to the managers, it happens too often that in the realization phase that the tender plans are deviated from. The managers think that this is because this would happen less if there would be information available on why certain choices were made.

In the realization phase, the managers think that information sharing should not only be something the schedulers are after, but everyone in the project team. This needs to be facilitated through a standard process. According to the managers, in every project decisions should be made on process management. This gives clarity to responsibilities and requirements.

Standardization: In terms on standardization, the managers were more focused on habituation. Where there are certain standards within the planning process that are recurring over different projects, then the organization can adjust to that. According to the managers, resources should be a standard part of the schedule and be coupled with activities. A schedule then does not only give insight in time management, but also cost management. Current software tools allow for the resource management and time management to be integrated into a single schedule.

- Standard schedule models and logic should see standardization.
- Recourse coupling should be standard is schedules
- Activity ID's should be standardized

The main areas of improvement: According to managers, in complex design and construct projects, the design team is heavily information dependent, but the rest of the project team is dependent on the design team. Thus, the design team should schedule their design requirements: what information is needed and when. Then the designing can commence. It happens too often that it is found out too late that certain information is lacking for design tasks, leading to inefficiencies in retrieving that information.

Having worked with different schedulers over their careers, all managers stated that the project team should be composed based on the competences with a team, nor abstract roles. It's not sufficient to have a scheduler on a project, it needs to be assessed what type of scheduler a project needs. This is again linked to the role of a scheduler in a complex project: the scheduler needs to be able to communicate with the organization and proactively retrieve and manage information. Three of the five managers mentioned that a complex project nog only requires a management capable scheduler, but also another scheduler doing the analytical analysis of the scheduler, which decisions should be based on. An interesting area of improvement is that three managers mentioned that the complexity of a project should be assessed prior to realization and the project team adapted accordingly.

Managers: code relations

The five interview transcripts were open coded and the result is shown in a network view in figure 12. The key codes (main interview questions) and the relations are described below.

The following aspects should be **part of** the role of a scheduler in complex projects:

- He/she should have a central, independent position in the project
- A scheduler should be an adviser, to aid in providing structure and strategy planning
- Scheduling and monitoring preparatory events

The following should be **properties of** schedulers in complex projects

- Management competence
- Active management approach to scheduling (for which there is managerial support), of which the following are **part of**
    - Integrated knowledge sharing
    - Integrated schedule management to;
    - Provide insight and overview in the schedule, which is associated with complexity of a project
    - Coupling and monitoring resource allocations to schedule

- The following are active management approaches
    - Schedulers are interface managers, which helps with coping with complexity and interdependence is an aspect of project complexity
    - Scheduling and monitoring preparatory events

The main concepts coinciding with information/knowledge transfer:

- Active knowledge and information transferring as part of the role of a scheduler
- Key staff and planning logic should transfer from tender to execution to not lose knowledge
- Standardization of scheduling model and logic to facilitate information transparency and habituation

The main concepts coinciding with views on standardization:

- Standard schedule models and logic should see standardization.
- Recourse coupling should be standard is schedules
- Activity ID's should be standardized

The main concepts coinciding with areas of improvement:

All of the following are seen as something that should be improved:

- Scheduling design requirements
- Analytical approach to scheduling
- Scheduler fit for project (competent, management focused schedulers on complex projects)
- Recourse couple with schedules
- Integration of level 5 schedule to level 4 schedule by the disciplines/ trades
- Integrated knowledge sharing
- Complexity assessment: what areas are expected to be complex (technical area or stakeholders/ environment)
- Scheduling and monitoring preparatory activities

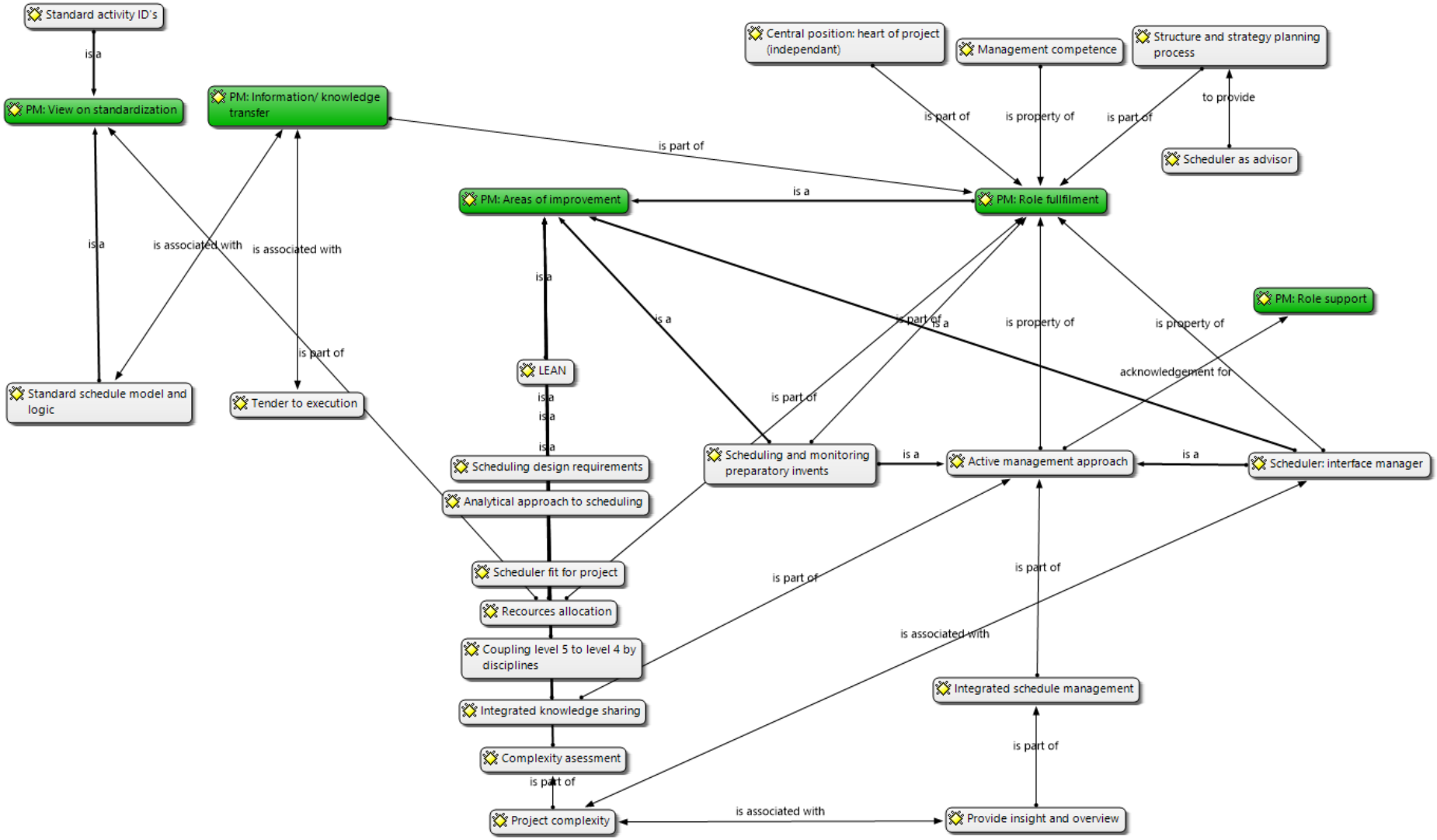

Figure 26: Code network - managers

APPENDIX D: Delay and disruption analysis

The following techniques are documented in literature as the most common types of delay analyses (Braimah, 2013) :

As-planned vs. as-built

As-planned schedules are schedules as they were drafted prior to the work commencing. It is the first schedule of the work to be constructed. As-built schedules as schedules of how the construction of the project actually occurred. As built-schedules are completed when projects are delivered. The as-planned vs. as-built in its simplest form predates the use of scheduling software and visually compares the as-planned and the as-built schedules and analyzes the differences. It does not depend upon critical path analysis.

Impacted as-planned method

This delay analysis relies upon the critical path. This method can be conducted in single insertion or individual insertion. The single insertion inserts all the delaying events that occurred during the course of a project into the as-planned schedule, at once. Then, the critical path is recalculated and the analyzed which events affected the critical path. Individual insertion inserts delaying invents to the as-planned schedule in chronological order. After each indicidual insertion, rescheduling of the networked schedule occurs and the impact of the event on the critical path analyzed.

Impact analysis

This method is similar to the impacted as-planned method, but differs in the fact that multiple baseline schedules are analyzed rather than the initial as-planned schedule. The delaying events are inserted in the updated baseline schedules. The reason for using update (multiple) baselines is that the analysis will reflect the effect of the events on the up to date schedule at the time of the delaying event occurring.

Collapsed as-built

The collapsed as-built method can be seen as the opposite as the impacted as-planned method. The networked as-built schedule is the basis for this method. The delaying events and their effects are included in the networked as-built schedule. In single extraction, all the delaying events are extracted from the networked as-built schedule at once and rescheduling follows. Individual extraction reschedules the as-built schedule after extraction of single delaying events in reverse-chronological order.

The feasibility of these analyses depends for this research depends on a number of aspects (Braimah, 2013):

1. **The contract requirement**
   Some forms of contract require a specific type of delay analysis
2. **Availability of schedule records and information**
   The availability of certain records dictate which methods can and cannot be used. For example, an analysis comparing scheduled as-planned and as-built cannot commence if either of the date is not available.
3. **The nature of the delaying events and the complexity of dispute resulting from it**
   If the delaying event is a caused by an obvious delaying event on the client side, like change of specification, a complex analysis is not required. However, in-depth analysis is required when interconnected delayed events occur simultaneously.
4. **The technique used and the analysts familiarity with the technique**
5. **Time and resources available to perform the analysis**

These methods can produce valuable information on what caused delaying events to occur. Looking at the considerations on what method to choose, it becomes apparent that certain methods cannot be conducted in delay analysis. The conflicting factors are time and resources available for conducting the research (the present research is conducted in a limited amount of time). Getting familiar with the techniques and tools to do the analyses requires time as well. The chosen research method in case of time delays is as-planned vs. as-built, as it does not depend on critical path analyses. In order to conduct an as-planned vs. as-built analysis for complex projects (rather than simple projects of short duration for which the method was designed), professionals involved with the delaying events of the specific projects will be consulted and process reports read. These analyses often take months and require professional, in-depth knowledge on scheduling logic. Based on criteria 4, 5 and the constraints of the present research, a delay and disruption analysis is not feasible.

APPENDIX C: Interview questions case studies

All the interviewees across the six cases were asked (at least) these questions. The first columns described the category of the questions, the second column shows the question ID (GP1 stands for General Project Information, first question) which was only relevant in analysis of the interviews. The question ID is no importance to the reader of this research.

Categorie	ID	Vraag
"GENERAL PROJECT INFORMATION"	GP1	Naam participant
	GP2	Achtergrond participant
	GP3	In welke fase van het project in de participant betrokken geraakt?
	GP4	Wat is het doel van het project?
	GP5	Achter u dit project een succes?
	GP6	Waarom acht u dit project wel/geen succes?
	GP7	Is de organisatie van het project transparant, m.a.w. weet u wie waarvoor verantwoordelijk is en waarom?
	GP8	Heeft scope verandering een rol gespeeld in de uitvoering van het project?
	GP9	Hoe is de kennisoverdracht van tender naar de uitvoering gewaarborgd op dit project?
	GP10	Welke moeilijkheden bent u tegenaan gelopen die het resultaat beïnvloed hebben?
	GP11	Wie is eindverantwoordelijke voor de planning op dit project?
	GP12	Wie zou eindverantwoordelijk moeten zijn voor de planning in uw visie en waarom?
	GP13	Hoe is de planning op dit project tot stand gekomen?
	GP14	Wie is verantwoordelijk voor het bewaken van de planning op dit project?
	GP15	Wat is de rol van de planner in het opstellen van een planning?
	GP16	Wat is de rol van de planner in het bewaken van een planning?
	GP17	Hoe zou/had de planning op dit project bewaakt moeten worden?
	GP18	Heeft de planner in uw visie de middelen en aanzien om de planning te kunnen bewaken en er op te sturen?
	GP19	Hoe bewaakt u de voortgang op dit project?
	GP20	Is dat een eigenschap van u of iets wat bij uw functie hoort in uw optiek?
"COMPLEXITY"	C1	Acht u dit project complex?
	C2	Hoe zou u project complexiteit omschrijven (de benadering van project complexiteit in dit onderzoek is besproken na het beantwoorden van deze vraag).
	C3	Is de complexiteit van dit project technisch, organisatorisch of omgeving gezind?
	C4	Wat maakt het technisch/organisatorisch/omgeving gezind complex?
"PROJECT OUTCOME"	PO7	Is de complexiteit van het project veranderd gedurende de uitvoering van het project? Zo ja, hoe heeft u dat gemerkt?
	PO1	Welke elementen van complexiteit van het TOE raamwerk hebben bijgedragen aan budget en/of tijd overschrijding op dit project, waarom en hoe?
	PO2	Met welke functies/ disciplines hebben deze elementen raakvlak?
	PO3	Met welke van deze elementen heeft uw functie raakvlak en hoe?
	PO4	Per element, heeft u iets gedaan om de invloed hiervan op het projectresultaat te beperken?
	PO5	Per element, had u überhaupt iets kunnen doen om de invloed hiervan op het projectresultaat te beperken?
"VISION"	V1	Gaat u in de toekomst anders om met complexiteit? Zo ja, hoe en waarom?
	V2	Had de planner de gebeurtenissen waar zijn discipline raakvlak mee had kunnen voorkomen?
	V3	Welke type planner vereist dit?
	V4	Hoe zou u de rol van de planner op complexe projecten omschrijven?

APPENDIX F: Overview complexity elements and key concepts

In the table below, the consensus per case on the influence of an element of complexity is gathered and combined. This overview provides insight into the influence of an element of complexity on project performance and the key concepts. The influence of an element of complexity is generalized based on the data in this table.

Complexity elements:	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
TS1 Scope largeness						High communication and information requirement. Proactive, management oriented scheduler required to manage information.
TS2 Uncertainties in scope		Information is crucial to addressing uncertainties. Scheduler should contribute to information sharing.		High information requirement.	Information requirement increases due to uncertainty. The scheduler should facilitate in information sharing.	High communication and information requirement to clear uncertainties in scope. Proactive, management oriented scheduler required to gather this information.
TS3 Quality requirements			*No direct relation to the planning process given by interviewees*			
TT2 Variety of tasks		A proactive scheduling approach is required to align the variety in tasks.	High communication and information sharing intensity required to manage task variety.	High information requirement to facilitate coordination		
TT3 Dependencies between tasks	Due to the high task dependency, the need for sharing information increases. It's the role of the scheduler to make transparent the task dependencies. The scheduler on this project was not a dedicated scheduler.	Information requirement increased to manage dependencies. A proactive scheduler is required to manage the dependencies.	High communication and information sharing intensity required to identify dependencies, with a standard schedule reporting structure and dedicated scheduler.	High information requirement to coordinate and manage task dependencies. A proactive schedule should facilitate in making dependencies transparent and gather information to manage them.	Due to the high task dependency, the need for sharing information increases. It's the role of the scheduler to make transparent the task dependencies.	High communication and information requirement to manage dependencies. Proactive, management oriented scheduler required to manage information and dependencies.
TT4 Uncertainty in methods		High information requirement.	*No direct influence on the planning process given by interviewees	Uncertainty leads to a high information requirement.	The method uncertainty contributed to the increase in information requirement.	

TE1 Newness of technology		High communication and information sharing intensity required.				
TE2 Experience with technology		High communication and information sharing intensity required.				
TR1 Technical Risks		High communication and information sharing intensity required.		High information requirement to incorporate risks in planning process.		High information requirement to incorporate risks in planning process.
OS1 Project Duration	An underestimated project duration makes sharing of information in order to maintain schedule crucial. When project duration is too short, information exchange should be facilitated to work as efficient as possible.					
OS2Compatibility of different PM methods and tools						Integration inefficiencies between MS Project and Primavera: standard should be proposed.
OS3 Size in CAPEX	x					
OS4 Size in engineering hours	Information sharing could not be promoted due to overcoming issues resulting from a shortage of engineering hours. People were concerned with their own tasks rather on how it fits in greater picture.	High communication and information sharing intensity required.				Project drive 'time' pressures increases importance of sharing correct information, as time is lacking to correct the result of false information.

OS5 Size in project team	Planning process neglected due to understaffing. No dedicated schedule was present on the project.				The information and coordination requirement increases to the size of the project team. A proactive scheduler with management competences should	High information sharing and communication requirement. Proactive, schedule management oriented scheduler required to manage schedule information requirements within the team.
ORE1 Project Drive		Change in project drive introduced different priorities. The planning process got less important as project drive "cost" overtook "time".				
ORE3 Experience with parties involved		High communication and information sharing intensity required, but not operationalized due to different work ethics.	Communication inefficiencies.			Inefficiencies due to lack of experience with partners
ORE5 Interfaces between disciplines		High communication and information sharing intensity required to manage interfaces, to which a proactive scheduler must contribute.			The information and coordination requirement increases due to interfaces between disciplines. The proactive scheduler needs to consider the interfaces and manage schedule dependencies between the disciplines.	
OP3 Cooperation JV partner						Differences in approach to planning process contribute to inefficiencies.
OT1 Trust in project team	Information sharing not optimal between team member due to lack of trust in competences.					

OT2 Trust in contractor	Gathering information from the client was inefficient and slow.	Information sharing and communication inefficient and.				
OR1 Organizational risk		High communication and information sharing intensity required due to high organizational risk.				The organizational risk in planning context is integrating and sharing information between departments, and making sure the correct information is being worked with. A proactive scheduler is crucial to facilitate this.
ES2 variety in stakeholder perspectives			More information sources.	Increased information sources.		
ES3 Dependencies on other stakeholders				Increased information sources and dependencies.		
EL1 Interference with existing site			High communication and information sharing intensity required.			
EM1 Internal Strategic Pressure	Project understaffed due to underestimation of the project as a result of internal strategic pressure, leading to neglecting of the importance of the planning process.			High information requirement		

Table 21: Overview of influence of the identified complexity elements on the key concepts, per case