What lies beneath

Bounded manageability in complex underground infrastructure projects

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What lies beneath

Bounded manageability in complex

underground infrastructure projects

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1. Introduction

1.1 The problem with complex infrastructure engineering projects

On March 3rd, 2009, the German city of Cologne's historical archive building collapsed into the north-south subway tunnel, which ran in front of the building and was under construction. The disaster, which caused two fatalities, was probably the result of the building works. Unfortunately, the Cologne example is not unique. Problems with complex infrastructure engineering projects are among the most persistent of our times. Most countries have their own examples of projects plagued by poor performance or unexpected incidents. Most occurrences are fortunately not as tragic as the Cologne incident, but problems with cost and implementation time seem even more persistent.

Yet, many comparable projects proceed without event. So why emphasise poor performance? Unforeseen incidents occur in every large project, though some are more catastrophic than others. Most have limited consequences, perhaps affecting only bystanders, though they invariably set back project management. No matter the severity, unforeseen events are considered problematic. They demonstrate that some aspects of complex projects are, apparently, still outside our ability to control. Furthermore, our growing experience in building complex structures has not succeeded in removing the uncertainty. Implementation problems keep recurring. This is possibly because project difficulty and complexity grows in parallel to improvements in management capabilities.

There appears to always be some grade of problematic manageability. The larger the project, the more issues can be expected (cf. Collingridge, 1992). The pace of society does require these projects though, which urges us to keep searching for solutions, rather than just abandoning these projects altogether.

This study is an attempt to understand complex projects better and to find solutions. Its particular focus is on underground projects, because building underground often entails considerable risk. Risk is generally defined as the chance of an event happening multiplied by the consequences of that event. Some definitions multiply this again by the chance that the circumstances will arise in which the event could occur. Underground construction projects usually involve technical systems with many components, connections and interfaces with elements that cannot always be controlled. This means there are many circumstances with a relatively high risk of failure. Moreover, in underground projects the consequences of such failure are generally considerable, as in the Cologne example. In addition to risk, project implementation involves uncertainty; that is, situations and events that are unknown or for which the probability and impact are ambiguous.

This introductory chapter starts by positioning the research amidst other studies involving complex construction projects (section 1.2). It then presents the objectives of the research (section 1.3). Section 1.4 defines the concept of bounded manageability, while section 1.5 sets out the research questions to be addressed. Section 1.6 summarises the organisation of the rest of this thesis.

1.2 Research domains in management of complex construction projects

This section explores the domains in which research has been done thus far on the manageability of complex infrastructure. Three domains, in particular, can be distinguished: civil engineering, project management and planning/decision-making. Starting from the assumption that limited manageability results from the manifestation of uncertainty inherent to these projects, all three domains explain management problems in their own way.

The first domain regards technology itself and the work of engineers in complex projects. Development of infrastructure projects is facilitated by continually expanding civil engineering skills. Key questions asked in this research domain are how technological innovations can best be applied (cf. Utterback and Anthony, 1975; Utterback, 1994; Maidique and Hayes, 1996; Payne et al., 1996; Hargadon, 1999; Hartmann and Myers, 2001) and how existing technologies can be improved. But also, typically after an incident with a technical system, the culprit is first sought in the technologies used and in the vigilance of the designers, managers and operators.

We must indeed understand technical systems and learn from events in order to make designs more reliable in the future. Crashed planes, for example, are meticulously salvaged by any means possible, to analyse debris and improve technology to prevent future mishaps. The main downside is that studies adopting this approach cannot explain *why* deviance occurs in the first place and, when it occurs, why the technology was not applied adequately from the start.

The second research domain is project management. It focuses predominantly on the application of tools for scheduling, budgeting and exchanging information. This domain, which aims at optimising work processes, has developed relatively independently from technology. It has produced tools like the critical path method (CPM), the programme evaluation and review technique (PERT) and processes for requirements management, risk analysis and general management. These tools are now commonly used to keep projects efficient and effective.

Project management's contribution as a research field to the manageability of projects lies in its instruments, tools and techniques, which are now commonly applied in the daily procedures of project managers (cf. Grigg, 1988; Morris, 1994; Miller and Lessard, 2000; Winch, 2002; Maylor, 2005; Lessard and Lessard, 2007; Nicholas and Steyn, 2012). These tools are helpful for keeping a project on-track. Some tools and literature even focus specifically on project performance in terms of time and cost management (cf. Baker and Baker, 1992).

A whole field of study has developed around systems engineering as a way to improve and optimise processes and projects, including complex technical projects (cf. Foulconbridge and Ryan, 2003). Still, budgets are overrun and technical failures creep into designs. Project management techniques and tools invariably assume that the real world of projects can be captured in models and figures, which in reality is not the case. Many project managers acknowledge this shortcoming, while justly pointing out that the techniques nonetheless help them and full control is illusory. The current research, indeed, seeks to find out why anomalies persist, despite the existence of useful models.

The third area of research regards decisions made *on* projects rather than *in* projects. Studies in this field mainly examine problems related to investment and value creation (cf. De Jong, 1996). Their point of departure tends to be the difference between what is expected of a project at the time of decision-making and what is actually achieved during implementation. This puts a strong focus on implementation time, costs and functionality. As a result, causes for possible bounded manageability are found in the decision-making phase.

Hall (1980: 5, citing Friend and Jessop 1969) explained bounded manageability in terms of three types of uncertainties that hamper forecasting:

- Uncertainty in the planning environment. Uncertain data and changing conditions, for example, lead to errors, such as in projections of numbers of people, jobs and production.
- Uncertainty in related decision areas. Failure occurs because forecasts fail to take sufficient account of externalities.
- Uncertainty about value judgements. Decision-makers fail to anticipate shifts in values among other actors.

Hall's solution was to reduce the uncertainty. He suggested two ways to accomplish this: improved forecasting and proper evaluations. Flyvbjerg et al. (2002), however, found that, despite improved forecasting techniques, the performance of projects was not improving. The authors explained this as due to misrepresentations of the truth, a phenomenon also described by Wachs (1989, 1990). Planners deliberately present unrealistic figures in order to get projects approved. Once the real numbers come to light, the project is already built or almost complete (Wachs, 1989, 1990; Flyvbjerg et al., 2002, 2003a+b, 2003, 2004, 2005). Overpromising seems to be firmly rooted in market economics and democracy. Yet, this explanation does not rule out that the lack of improvement in project performance could also be caused by the growing complexity and uncertainty associated with these projects. Complexity and uncertainty might even expand apace with advances in forecasting techniques. This may even be a reason to suggest use of appraisal criteria other than financial cost and benefit (cf. Atkinson, 1999).

The current research therefore begins from the assumption that opportunities for reducing uncertainty are limited, so it would be more fruitful to better understand the uncertainties by studying the interfaces between the domains (Figure 1.1). A variety of scholars (cf. Baccarini, 1996; Williams, 1999; Stacey et al., 2000) make a distinction between technology and organisation in the complexity of technological projects. Important for the current study is the interconnectedness of these two. Vaughan's (1996) analysis of the Challenger space shuttle disaster is an example of the value of such research. Problems with the vital sealing function of the shuttle's O-rings in cold weather conditions were known before the Challenger was launched for its last, ill-fated mission. Vaughan explains the process by which the managers and engineers involved decided nevertheless to proceed with the mission that ended in an explosion shortly after take-off. Vaughan's extensive analysis incorporates a range of circumstances and conditions under which the space shuttle programme evolved. As such, she sketched the circumstances that influenced the managers' and engineers' verdicts. She did not confine her account to the technical explanation of the O-ring failure. Rather, she crossed the interface between research fields, taking that one step further that is often lacking in post-event analyses. Certainly, then, that step is even more seldom taken before a project is carried out. Vaughan delved into the occurrence of a technical failure by looking at the multi-actor network that, unwittingly, produced the circumstances for it to occur.

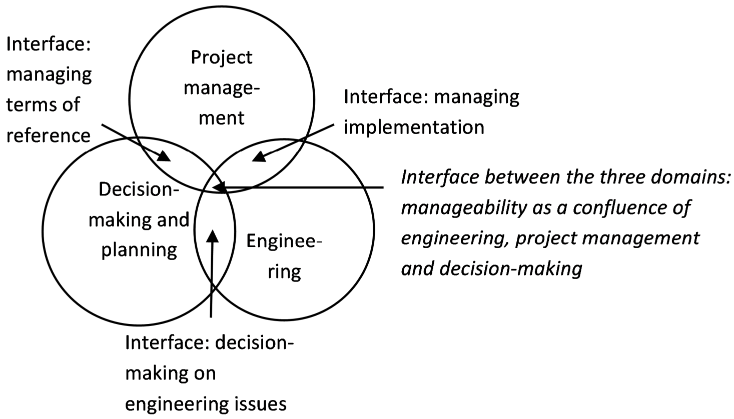

Figure 1.1 Domains and interrelations in research on projects.

1.3 Research objective and object of research

The purpose of this study is to better understand **the occurrence of bounded manageability in the implementation of complex underground construction projects**. "Implementation" in this respect means the whole turnaround time, from front-end development (design and preparation) to execution (construction and commissioning). "Bounded manageability" as a concept is further explained in the next section. Meanwhile, a new way of looking at and evaluating complex projects is explored, diverging from the way we have done so far, to seek new insights into how these projects could be made better manageable. The choice to adopt the interrelation of technology and organisation as the point of departure stems from dissatisfaction with the idea that preventing poor project performance is predominantly a matter of adequate planning and approval processes. This research proposes that manageability problems in implementation are an important – maybe even more important – cause of poor performance than deficiencies in planning and approval trajectories. Specifically, this study pursues the following aims:

- To identify the most important aspects to consider when studying the bounded manageability of complex underground construction projects
- To describe the way bounded manageability occurs in practice
- To make suggestions for how undesired outcomes of bounded manageability can be minimised

Underground projects were chosen as the object of this research for two reasons. First, much new urban infrastructure is built underground. Densely built-up land often simply lacks space for new above-ground structures.[1] Second, these subsoil projects impose extreme technological challenges, and if failure occurs the effect is often quite disruptive. Moreover, there are many physical interfaces underground, and deviations from plans can have massive impact, as the Cologne example showed. These affect not only the project itself, but its environment as well. Moreover, deviations are often unobservable, because they occur underground, out of sight from managers and engineers. Underground projects also have prominent interfaces with other physical systems, such as other projects, transport systems, abutting structures and soil conditions. These magnify the manageability problems typically encountered in infrastructure projects. Chapter 4 further details the selection of projects studied.

1.4 The concept of manageability and bounded manageability

The concept of “manageability” is the focal point of this research. It encompasses three aspects: monitorability, predictability and controllability.

- Monitorability: managers’ ability to keep track of events and measure performance. Control as a constituent of Max Weber’s rationalisation has been used, for instance, by Ritzer (1996), to describe the automation and standardisation necessary to enable management to keep processes within an organisation on-track. Monitorability implies that the manager overseeing a system understands the things that happen and can detect deviance.
- Predictability: the ability of managers to foresee the consequences of decisions, actions and emerging situations (cf. Winch, 2002: 186, 426).
- Controllability: the ability of managers to intervene if necessary, for instance, in case of deviance. Etzioni (1991) used the concept of guidability in reference to society for similar purposes. The same idea of ability to intervene can be applied to the micro-society of a project organisation.

Bounded manageability occurs when there is a lack of monitorability, predictability or controllability. It becomes particularly relevant when it negatively affects the performance of a project. Bounded manageability typically manifests in symptoms of poor performance: time or cost overruns, inability to deliver the promised scope and functionality or inability to deliver the promised quality (reliability, robustness, safety).

1.5 Research questions

The current research seeks an explanation for the occurrence of bounded manageability in complex infrastructure projects. The research is explorative, meaning that it does not pose a research question that can be answered with a yes or a no. Nor does it aim at proving anything. Its outcome, rather, should contribute to build new insights. The research question is formulated to reflect the study's quest to clarify a phenomenon of which the symptoms are clear and recognisable, but for which there is still limited understanding of the causes:

1. *What explains the apparent bounded manageability of many complex underground infrastructure construction projects?*

The previous sections explained the concepts of manageability and bounded manageability in relation to complex underground infrastructure projects. The "what explains" part still needs to be further operationalised. When seeking an explanation for the occurrence of a phenomenon, one can look at where it comes from (find the origin) and why it occurs. Only with that knowledge can one get a grip on the phenomenon and understand it, as well as perhaps doing something about it. This study's main research question is divided into two subquestions:

1a. How does bounded manageability emerge? It cannot be explained by any one thing. Innovation, for instance, does not create bounded manageability or dictate its possible ramifications (e.g., in terms of project dynamics and problematic coordination). The answer, rather, lies in the relation between challenge and effort. This research sought to answer this subquestion by exploring the occurrence of tension between the required effort and the performance of the project organisation.

1b. Why does bounded manageability emerge? Once one knows how bounded manageability occurs, the next question to answer is why it occurs. This would be a crucial step towards better understanding the mechanisms underlying it.

A final step would be to try to establish where improvements can be achieved:

2. *What can be done to respond to the boundedness of manageability in a project?*

These research questions are rather explorative, therefore necessitating a specific methodological approach, which will be explained below.

1.6 Methodology and research set-up

1.6.1 Research approach: Semi-grounded theory

Despite this study's intention to provide guidance on how project manageability may be improved, it cannot identify determinants that will in all cases predict success or failure in a project. This is because valid determinants can only be identified with very extensive statistical research. While such a study might point out what kind of organisation is statistically most likely to be successful, it would be too superficial to provide a good look at the mechanisms of projects that explain manageability. Nor would it help identify the main management dilemmas. In short, statistical research would not answer the "why" questions that this study aims to elucidate. Another constraint is that each complex underground infrastructure engineering project is unique, not only in design and functionality, but also in its physical and institutional context. This makes the drawing of generic conclusions unproductive.

This research is instead intended to be inductive. It considers manageability at a higher level. Hence, it is set up as an exploratory study of the origins of manageability, or the lack thereof, in complex underground construction projects. This study set out to deduce patterns of bounded manageability in projects and explain these in a generically applicable way.

The analysis sought to develop a theory that explains manageability in a practical sense in projects. For that reason, a grounded theory approach was used (Glaser and Strauss, 1967). Taking bounded manageability in complex underground projects as the point of departure, a sensitising concept was developed (Verschuren and Doorewaard, 2004: 180-181). Using case study research, axial coding was implemented. A typology of typical management dilemmas was formulated by looking at how managers have dealt with bounded manageability in actual occurrences in projects. The focus here was on conditions and context, the set of actions applied and the consequences of those actions. In the last step, these factors were evaluated and patterns between dilemmas sought (selective coding). These steps are elaborated below.

This research set out using existing theories on uncertainty. Thus, the researcher did not start completely from scratch, but instead used a semi-grounded theory approach, building a new theory taking into account research that has been done already, in many cases, in other research domains as well (cf. Strauss and Corbin, 1990).

The reason to deviate from the original grounded theory method was that the substantial amount of research already been done on the complexity and management of projects and on uncertainty in general has not yet provided a definitive answer on why bounded manageability arises, as proven by the lack of performance improvements noted by Flyvbjerg et al. (2002). Hence, a broadened view was deemed necessary. It is very possible that other fields of research related to uncertainty could provide new insights on the manageability of projects.

1.6.2 Literature review for open coding of the sensitising concept

The first part of the research was an exploration of the concept of bounded manageability, aimed at answering the first research question. By decomposing the main aspects of complex construction projects, a clear view was gained of the challenges these projects pose to the organisations responsible for controlling them. Manageability was explored in relation to these specific features of the projects. As noted earlier, manageability is determined by monitorability, predictability and controllability. All three have two main variables: the challenge that the features of a system impose on the people and organisations working with them and the capabilities of those people and organisations to deal with the system's challenges.

This part of the research was the first step to answering the subquestion on how bounded manageability can occur and why. It provided an overview of what is already known about the origins of bounded manageability and how aspects relate to one another to produce bounded manageability. So, the theoretical part of this research was not aimed at constructing a theoretical framework to be tested in the empirical part of the research, as that would not be consistent with the grounded theory approach. Instead, the theoretical part was designed as a first step in coding: sensitising the concept of bounded manageability. This theory-building on manageability was based on literature research, using existing theories on complexity and manageability. It was not a typical approach for pure grounded theory research, as the step of open coding is normally done using empirical data and without executing a literature review first. Ramalho et al. (2015), however, argued that a constructivist grounded theory approach can be done with the use of a literature review, as long as the data are prioritised over any other input.

The exploration of the origins of bounded manageability in this research built upon an analysis of two main concepts. The first concept is *system complexity,* which concerns both the technical system and the organisations (multi-actor systems) working with the system. This focus provided a framework for characterising bounded manageability as a result of the plain technological and organisational features of a project. Chapter 2 reports on this part of the study. The second concept is that of *uncertainty,* as described by Friend and Jessop. Some scholars of complexity in project management have stated that the bounded manageability of projects is not the result of complexity itself. Technology, for example, always complies with the laws of physics. However, technology does set the conditions for (un)manageability, though it is the human operators who fail to understand technology and make trade-offs and decisions regarding it. Thus, important uncertainty features have a predominantly socio-organisational basis.

The approach of the empirical research and the analysis will be explained in chapter 4.

1.7 Summary

This introductory chapter started with a brief analysis of the typical manageability problems that appear to haunt complex underground construction projects. Moreover, it identified an area of research that seems promising for explaining why, despite increasingly advanced techniques, the practice of managing projects has not seemed to improve. The phenomenon this research investigates was labelled "bounded manageability", the key features of which are limited monitorability, predictability and controllability. The remainder of this chapter describes the approach used to explore the occurrence of bounded manageability on an empirical basis. At the core of the approach lie the basic research questions of why and how bounded manageability occurs and what can be done to improve projects' manageability.

The explorative nature of the research suggests the use of a semi-grounded theory approach. In this approach, existing knowledge on the key features of complexity in projects is first codified in a theoretical framework (chapters 2 and 3). Then empirical research is done using real cases to build new knowledge on the bounded manageability of complex underground construction projects.

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[1] See, e.g., Habiforum (2000). Habiforum, the Dutch expertise network for multiple space use, was founded to deal with the challenges of this ambition.

2. Projects as complex systems

2.1 Introduction

What explains the occurrence of bounded manageability in projects? Projects are usually complex endeavours, and complexity appears to be the driver of bounded manageability. This suggests that the characteristics of complex projects is a good place to start seeking an answer. Complexity, and hence bounded manageability, occurs in both the technical system to be created by the project and the organisation managing the project. Bounded manageability in projects occurs at the interface between the technical system and organisational systems.

This chapter, and Chapter 3, further explore complexity and bounded manageability in underground construction projects through a literature survey. Seven project management problems are identified that contribute to bounded manageability. The point of departure is the complexity features of projects, explored in this chapter. These can be considered the root cause of the other six project management problems, which relate to uncertainty and are formulated in Chapter 3.

The current chapter starts with an exploration of projects as an endeavour to create a technical system for which an organisational system is created (section 2.2). The features of these technical and organisational systems are then analysed in more detail (section 2.3), focusing respectively on the technical system and on the organisational system. Section 2.4 expresses the main findings as operational variables that can be used for the detailed study of real-life projects, to help identify explanatory variables for manageability in complex underground construction projects.

2.2 Projects

This section demarcates projects in a manner that enables further exploration of complexity and, ultimately, manageability. Morris and Hough (1987: 3) delineated projects as “an undertaking to achieve a specified objective, defined usually in terms of technical performance, budget and schedule”. A project imposes a time constraint (it has clear beginning and end dates), has a pre-assigned budget and predefined deliverables (as opposed to operations and programmes). The endeavour, in terms of the tasks to be done, typically sets the requirements for the organisation.

Cleland and King (1983: 21) visualised an abstract system model of the organisation that implements a project. In essence, the project organisation transforms inputs into outputs.

The inputs are things like physical resources, human energy and information. The output is a product, in the case of the current research, a physical object such as an edifice or infrastructure, and other transformations of the resources. Then there is an element called “goals”. In the case of a construction project, these would include the objectives, cost-effectiveness and usability of the physical system to be created. According to Cleland and King (1983: 22), “the goals established internally feed back into the organisation and serve to direct and focus its efforts”. This means that the organisation can make its actions dependent on the level to which they contribute to achievement of the goals. This can be visualised as feedback loops (Figure 2.1).

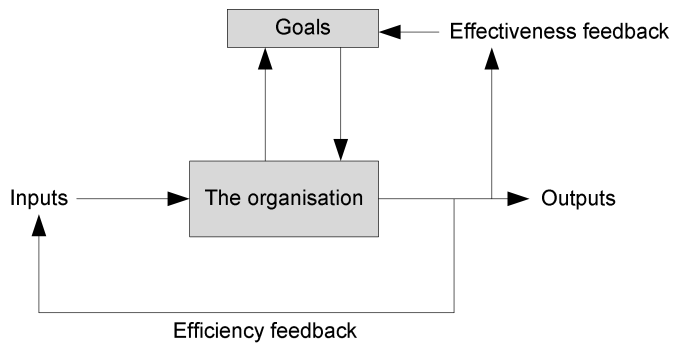

Figure 2.1: Abstract systems model of the organisation (source: Cleland and King, 1983: 21).

The goals define the project and are set by project owners or sponsors, under the influence of politics (in the case of public projects) and external stakeholders, which have demands and requirements. The output of a project encompasses the results that can be measured and evaluated. There are two possible means of evaluation. The first calculates the financial and social costs and benefits, estimating the value of the structure built by the project as compared to the effort and cost that went into it (cf. Flyvbjerg et al. 2002, 2003a+b, 2003, 2004, 2005). The second evaluation means centres on the results of the project as a temporary endeavour, such as its organisational coherence, efficiency and optimisation and goal achievement. This study focused on the latter, since the former is, as Flyvbjerg et al. showed in all the above publications, more suited to the study of the quality of the decision-making process *on* a project, rather than the success or failure of the project and decision-making *in* the project.

Turner (1993: 12) defined the output of a project in terms of time, cost and quality. The result to be achieved refers to the scope defined for the project. The scope can, however, be considered one of the output performance benchmarks as well, since a project’s scope can be changed throughout implementation, pending exogenous impacts, or as a means to achieve goals associated with other resources, such as time and money. As such, scope can be traded off against the other benchmarks. Moreover, time and budget extensions can sometimes be explained by scope, which is a reason to consider it as an equal value. Output has two dimensions: the projected outcome of the project in terms of time, money, quality and scope, as formulated in the terms of reference, and the performance of the project, i.e. the actual outcome in terms of time, cost, quality and scope.

2.3 Project management as the interaction of technical and organisational systems

Providing that projects are endeavours to create technical systems, in the case of this research, complex underground infrastructure, it is necessary to explore what a system is and what makes it complex. This section defines systems and complexity. Then the system configurations that occur in both the technological and the organisational aspects of projects is further explored.

2.3.1 Systems

Nicholas and Steyn (2012: 47) defined a system as “an organised or complex whole; an assemblage of things or parts interacting in a coordinated way”. In addition, parts of a system affect the whole system and are affected by it, implying that systems are holistic.[1]

Systems strongly link the technology involved in a project and the people or organisations working with the technology. Thus, projects involve both technical systems and organisational systems (networks of involved actors), the latter being the organisations handling the technological system. But systems exist in the eye of the beholder (Nicholas and Steyn, 2012: 48). Views on a system depend on the disposition of an organisational system member towards the system. Specialist engineers view a system mainly as the part they are responsible for, whereas project sponsors view the system mainly as the value they intend to create with it (more on this below).

2.3.2 The relation between ambitions and complexity

According to Winch (2002: 5), a project’s purpose is to create new value in society. What this value should be depends on the project. It is often defined in terms of project objectives, such as financial profits, economic benefit and infrastructure functionality. The project purpose may also include how value creation is to be achieved: its requirements and what demands must be met to create the value (Robertson and Robertson, 2000; Davis et al., 2004; Nicholas and Steyn, 2012: 48). These requirements and demands are reflected in project attributes (Nicholas and Steyn, 2012: 49). Is there a fixed completion date with important external dependencies? If so, implementation time will probably be an important driver.

Though time, cost, scope and quality (Turner, 1993) are important attributes or drivers, there are others as well, such as protection of the project environment. The value creation that is defined and aimed for determines the complexity of a project. Because many underground projects are located in densely built-up areas, mitigation of any kind of nuisance is a recurring driver, though it may conflict with other values, such as implementation speed and cost. Also, many project ambitions relate to political goals of the project client or sponsor organisation. The value drivers may impose challenging constraints or require complex, perhaps novel technologies. As this and the next chapter will show, this complexity introduces uncertainties in the project.

2.3.3 System decomposition

Systems vary in their level of complexity. Dörner (1996: 38) defined complexity as “the label we will give to the existence of many interdependent variables in a given system”. Baccarini (1996) identified two main contributors to complexity as *differentiation* and *interdependence*. Differentiation indicates the number of varied elements (tasks, specialists and components). The higher the number of components or actors and the larger their variety, the more complex the system is (cf. Perrow, 1999). Interdependence, or connectivity, indicates the degree of interrelatedness between the elements. The more elements and connections and the more variable these elements and connections are, the more difficult the system will be to oversee and, hence, the more *complex* the system is. This is in line with Rycroft and Kash’s (1999: 54-55) view of complexity. They focused both on the number of components and their integration into a whole. As Baccarini (1996) explained, these complexity features apply to both technological systems and to organisational systems.

2.3.4 Technical system decomposition

Technical differentiation: Components
All of the elements listed above have the common characteristic that they can be hierarchically decomposed, starting with the system, activities, budget or project organisation as a whole and ending at the smallest possible unit that is not further decomposable. For technical systems, Perrow (1999) referred to the different levels as “the system”, “subsystems”, “parts” and “units”. Units are the smallest indivisible elements. That means, apart from units, all system elements are systems themselves as well. Variety in technical systems is easy to visualise. For example, a steel beam is a

completely different product with completely different technical specifications than, for instance, a concrete wall.

Veeneman (2004) elaborated on the concept of complexity by focusing on interfaces. Interfaces are the places in the system where decomposed system elements come into contact and mutually influence each other. This can be both physical and functional. For example, the strength of a pillar defines the weight of the roof that can be built on top of it. As Morris and Hough (1987) underlined, this requires good designers who can tie subsystems together into an integrated technological whole.

Veeneman (2004) distinguished four fields of interface-related complexity in projects, based on the domain in which they occur (technological or social/organisational domain) and the location where they occur (internal or external to the project). The latter can be geographical, such as the interface between the physical system or project and its environment, or it can be functional, such as decisions taken outside the project. These domains correspond with the distinction made above between the technical system (Product/Work Breakdown Structure) and the organisational system (Organisation Breakdown Structure). The location (internal or external) is an added dimension. Following Morris and Hough, one could add another dimension that represents the interface between the technical system and the organisational system (Table 2.1). A typical example would for instance be link between certain actors and the development of technology to be applied.

Table 2.1 Complexity at project interfaces (adapted from Veeneman, 2004).

	Internal	**External**
Within technical system	Subsystem to subsystem	System to environment
Within organisational system	Actor to actor	Actors to environment
Between technical and organisational systems	Actors to internal technical subsystem	Actors to external technical subsystem

External interfaces are particularly multifaceted. An acronym often used to encapsulate the relevant factors is “PESTLE”, which stands for Political, Economic, Social, Technical, Legal and Environmental (Association for Project Management, 2012). This greatly expands the required focus of the project manager (Hanisch and Wald, 2011). The underground construction projects in this research are among the most complex because of these interfaces. Not only do underground construction projects have many interfaces, the interfaces also have a few particularly nasty characteristics:

- Many of the interfaces are external and hence wholly or partly beyond the control of the project managers.
- Some technical interfaces, particularly those between the technical system and its physical environment, are partly invisible, because they are underground. Hence, they have high uncertainty features.
- Social interfaces are typically associated with those external technical interfaces. For example, abutting premises that physically connect to the technical system are often owned, occupied or used by people or companies external to the project. This creates an additional social interface between the project organisation and stakeholders.

The remainder of this section further explores the complexity features of both technical and organisational systems. For both, the occurrence of differentiation and interdependence will be elaborated.

Technical interdependence: Technical interfaces

Systems consist not only of elements or components, but also of connections between these elements. Perrow (1999: 72-79) called these *interactions*. They are the functional interfaces mentioned above. Interactions exist in many forms. Imagine two steel beams linked by a bolt. The bolt may seem to be the connection here, but in fact, it is just an element, like the steel beams. The interaction is in its connectivity *function*, which is to hold together the two steel beams. The importance of the interaction is in the phenomenon that the characteristics of one element can influence the characteristics of the other. For example, a crack in one steel beam may cause a structure to collapse if it extends to a bolt that connects the cracked beam to another beam, connected in turn to many other parts, units and subsystems. Only the elements tend to be visible. The interactions are visible only implicitly, that is, if we know that the interactions exist. They may not be visible at all if interactions are hidden and unknown to the people managing the system. This makes interactions more or less *gestalt*. Perrow (1999: 72-79) identified this as a source of complexity. Some interactions can be rendered visible with the help of dials, warning lights, alarms and the like. System designers determine which interactions should be visible and therefore require such instruments. Practice shows that they often do not include all events that could happen.

Perrow (1999) pointed specifically to invisibility as a source of unpredictability of interactions that can make systems complex. An interaction can have a common-mode function; that is, it can serve more than one purpose. This too makes interactions complex rather than linear. If an interaction fails, it fails in multiple functions. Failure can thus spread through a system. Interactions can be unanticipated, too, though according to Perrow's (1999) definition of linearity,[2] this is not the case in linear interactions.

2.3.5 Organisational system decomposition

According to Cleland and King (1983), managing technical interfaces requires, in particular, management of the engineers responsible for these subsystems, rather than management of the subsystems themselves. Complex systems cannot make do with a single designer managing the whole system design. They require management of cooperation between many engineers of very specific subsystems, producing a shared design for the whole system. Yet, strong diversity of roles can lead to conflict (cf. Kahn et al., 1964; Jones and Deckro, 1993).

Cleland and King (1983) distinguished the role of the project manager from that of the functional manager. Project managers oversee the outlines; that is, what is to be accomplished and by when. They monitor performance criteria, such as cost and time schedules, in relation to master plans. This is comparable to Jones and Deckro's (1993) role identification. They defined the project manager as having primary responsibility for achieving project objectives (Jones and Deckro, 1993: 217). Functional managers provide operational directions; that is, who will perform tasks and how. They monitor whether concrete tasks are accomplished in accordance with the performance criteria, overseeing the functional specialists assigned to the project for their specialist skills (Jones and Deckro, 1993). The tasks and approaches of both types of manager interface at specific points. Cleland and King (1983: 345) called this project-functional conflict a "deliberate conflict" in the matrix organisation. Comparable interfaces may exist with, for example, line managers, staff managers and subcontractors. The socio-technical approach to project management, such as described by Kline (1991), focuses on the interface between manager (project manager) and engineer (functional manager).

Figure 2.2 presents the actors as more or less detached entities, each doing their bit for the whole. Naturally, however, there is a strong interconnectivity among them. Interactions are inevitable, not only within the project organisation, but also within the operating environment and the general environment. These interactions of organisational elements come in different and variable forms, such as contracts, trust and consultation. Each represents some degree of interdependence. In the figure, we also see various actors that can somehow be linked to the PESTLE factors, which contribute to complexity, particularly external complexity.

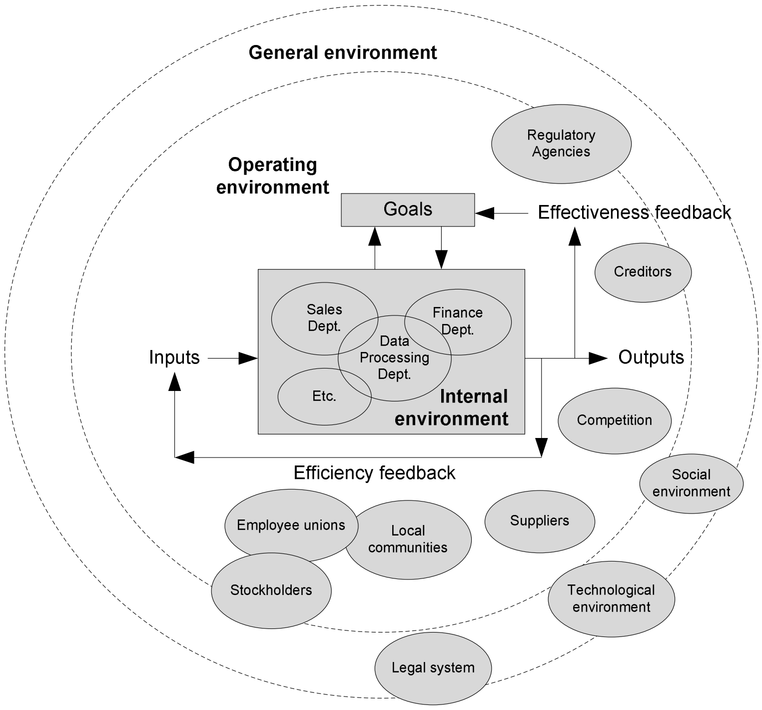

Figure 2.2 Complex systems model of the organisation (source: Cleland and King, 1983: 23).

Organisational differentiation: Actors/tasks

Complexity in the organisational system stems, first of all, from a high variety of actors and tasks to be executed. Part of this complexity may also relate to the variety of tasks, corresponding to the variety of actors:

- A network may have strong variety in the characteristics and tasks of the actors involved (De Bruijn and Ten Heuvelhof, 2008: 14-18).
- A network may exhibit a degree of "closedness" to interventions (De Bruijn and Ten Heuvelhof, 2008: 18-20).
- A network may have a large number of tasks to be attended to by a small number of actors.

The remainder of this section presents the most common tasks in construction project management as used in this study.

Project client/sponsor. A project client is the entity with ultimate responsibility for the project. It is usually this entity that formally initiates the project.[3] The project sponsor is responsible for providing a project staff and budget and setting the objectives and business case to be achieved with the project. A central element of project clientship in public projects is the *responsible tier of government*. In public projects, this is the actor that assumes project sponsorship and responsibility for overseeing the project to meet functionality and efficiency requirements. In non-public projects, the responsible tier of government may still have a role, for example, in providing permits.

Related to the project ownership, two other roles can be distinguished:

- *Higher tiers of government.* Many projects and project schemes that include underground aspects are owned by decentralised government entities. Often, there is some involvement of higher tiers of government, particularly in larger projects. In many cases, this stems from funding being made available by federal or national programmes. In such cases, there is often some form of engineering oversight to ensure that the money is well spent.
- *Champions and interested parties (affected stakeholders)*. Project sponsors are often influenced by actors that are not formally involved in the project but do have an interest. This group of actors may range from affected abutters and citizens to environmental parties and even lower government tiers, such as municipal entities that are not project owners but do seek to attract the project to their area of jurisdiction.

Project organisation. The actors forming the project organisation are those directly involved in the physical creation of the technical system. Their acts and decisions are directly related to achievement of performance benchmarks. It principally concerns two types of actors:

- *Owner.* This is the actor assigned by the client/sponsor organisation to implement the project. This actor has day-to-day responsibility for the project, procures contractors on behalf of the client/sponsor, is responsible for financial management and has formal decision-making competence on substantive aspects of the project. The project managers, following Cleland and King (1983), in this study are the managers that work for the owner organisation. In some cases, the owner may also provide functional managers. The sponsor's position is between the responsible tier of government and the contractors.
- *Contractors*. This term encompasses all actors hired by the sponsor. The most common are the construction firms employed to build the technical system and the engineers who design it. But other actors can be found as well, such as

insurance companies and consultants. The project organisation's staff provided by contractors usually consists of functional managers and functional specialists. The work of the latter is most closely tied to the actual technical system. In some types of contracts contractors can assume (part of) the project management role as well.

Within the project organisation projects differ in their exact allocation of tasks and responsibilities. As mentioned earlier, authors such as Cleland and King (1983) and Jones and Deckro (1993) distinguished project managers and functional managers. Functional managers are responsible for tasks such as procurement and finance or for certain geographical project areas and subsystems. In addition to Cleland and King's (1983) distinction between project managers and functional managers, a distinction must be made between supervisors and functional specialists (cf. Jones and Deckro, 1993). Supervisors focus mainly on oversight of performance benchmarks for the owner. The functional specialists formally play a subordinate role and focus on physical implementation. Functional specialists usually report to functional managers, but they nonetheless have to consider the policies established by project managers, for instance, regarding general project goals.

Complexity problems occur particularly at the interfaces between the different tasks. There are strong interdependencies both between the owner's and the sponsor's project managers and between the sponsor's project managers and the contractors' managers. Friction can arise as a result of diverging interests, information availability, information sources, personal disagreements, financial relations, etcetera. Chapter 3 discusses this as an uncertainty factor. Interfaces may occur, for instance, in the development of a contracting strategy and definition of the number of contractors and subcontractors to be hired.

Organisational interdependence: Relationships

Interdependence is another characteristic of actor networks mentioned by De Bruijn and Ten Heuvelhof (2008: 20-22). Actors need each other to complete a project. They depend on each other's resources and powers. Kazanjian et al. (2000) distinguished three types of interdependencies between individuals or groups *within* organisations:

- *Within-team cross-functional interdependencies*. For proper integrated systems, multifunctional teams are considered preferable to single units. This means, however, that interfaces occur within teams between individuals and groups attending to different subsystems.
- *Across-team interdependencies*. It is inevitable that work will be spread over multiple units or teams. Each team must coordinate and reconcile their tasks with

those of others. In construction projects, this spread crosses the boundaries between companies and organisations, such as between a design engineer and a construction contractor. It requires a handover of work, in this case from design to execution.
- *System-level interdependencies*. In all construction projects, system-level requirements will be imposed on multifunctional teams.

Resnick-West and Von Glinow (1990) distinguished between organisational and professional managers. The tasks of the organisational manager correspond largely to those of Cleland and King's (1983) project managers, and those of the professional manager align with the functional manager. Resnick-West and Von Glinow (1990) took another approach, based not on tasks, but rather on their empirically-found behaviour. They characterised the interface between the two types of managers as a clash in culture, expertise, autonomy and standards. The divergence can in infrastructure construction projects be found between managers involved in decision-making (often sponsor-related, sometimes even politicians or other administrators) and managers of the engineering tasks.

In addition, there are interdependencies *between* organisations. Interfaces in the organisational field are found between actors. At numerous interfaces, tasks, objectives, values and interests meet and, potentially, conflict. Some examples are the following:

- Interfaces between the sponsor and contractors (usually between supervisors and functional specialists)
- Interfaces between designers and contractors in cases of separate contracts (between functional specialists)
- Interfaces between the project leader and management teams (between supervisors and functional specialists)
- Interfaces between the project client/sponsor organisation and the project management

Last, there are interfaces with organisations that are beyond the control of the managers in the project organisation. The most common external organisational interfaces are those between the project organisation as a whole and abutters, interest groups, grant providers and lawmakers. In most cases, these actors set conditions, but they do not actively influence the daily processes of project implementation. Their conditions can be influential however, because they determine to a substantial extent the requirements of the project, in terms of time, cost, scope and quality. They are for instance the earlier mentioned PESTLE factors.

2.3.6 Dealing with complexity

As indicated by the above, complexity as a result of differentiation and interdependence is multifaceted. Table 2.2 sets out the primary aspects that must be considered.

Table 2.2 Elements and connections in the technical system and organisational system.

	Differentiation of elements		Interdependence of elements		
	Extent	**Variety**	**Links**	**Variety of links**	**Strength of links**
Technical system	Number of physical components	Degree to which the physical components are different	Connections between physical components	Extent that occurrences of interrela-tedness are different	Degree of connectivity between physical components
Organisational system	Number of tasks and actors involved	Multiformity of the tasks and of the networks of actors involved	Task interdependencies and relationships between actors	Extent that relationships are different	Strength of the task interdependencies and relationships between actors

Differentiation and interdependence lead to challenges for project managers. The greater the number of components and actors, the larger their variety and the stronger their interdependence, the greater the span of control required. Yet, the complexity of a project can outstrip the span of control of a project management organisation. Galbraith (1977: 74-76) suggested reducing the complexity of works by reducing the number of items to be attended to; in other words, reducing the required span of control.

Galbraith (1977) used an example to illustrate how a reduction of the span of control works. Restaurant owners can simplify their work by reducing the number of items on the menu. The problem faced by managers of large construction projects is that, no matter into how many pieces it is cut, the whole project has to be completed. These managers at some point have to weld the components into a whole. In the restaurant analogy, the components remain principally separate, even though they may share ingredients. In addition, restaurant owners are predominantly free in their choice of dishes and can change the menu based on, for example, the availability of ingredients. The engineer of a technical system is bound to a limited number of engineering features and cannot just create a unique individual system. Moreover, the engineer must abide by the terms of reference drawn up by people not directly confronted with the ramifications of the complexity. Project managers and engineers may therefore have to resort to more intricate activities to reduce complexity. Chapter 3 explores such activities.

2.3.7 Uncertainty

Williams (1999) added a third factor of complexity in systems: uncertainty. This can be seen as the tailpiece of complexity in the technical and organisational systems in projects, as it is what is left after differentiation and interdependence have been identified. Most of the aspects considered in the field of risk management relate to differentiation and interdependence, such as the PESTLE factors. But occurrences of bounded manageability may lack a clear relation to these characteristics or be unforeseen, even if they are associated with differentiation or interdependence. This places them beyond the scope of risk analysis and management. Think, for instance, of the hidden interfaces addressed by Perrow (1999). The same applies to components or interactions between components with innovative or otherwise unique features, or when conflict occurs between actors in a project organisation.

Another general uncertainty is actors' behaviour in a project. In fact, it is not so much complexity itself that causes bounded manageability. After all, differentiation and interdependence do not limit monitorability, predictability and controllability. Rather, it is the uncertainty involved in differentiation and interdependence that imposes the limitations. In the case of high differentiation, for instance, bounded manageability arises from the uncertainty involved in the coordination effort or from configuration issues, and failure can easily spread through systems with high interdependence. Table 2.3 recaps the categorisation of complexity in project management. Chapter 3 further explores uncertainty as an origin of bounded manageability.

Table 2.3 Categorisation of complexity in project management.

	Differentiation	Interdependence	Uncertainty
Technical	1. Many subsystems, parts, units with large variety	2. System parts are strongly interrelated	3. Unknowns (hidden interfaces, innovations)
Organisational	4. Many actors with large variety	5. Actors depend on each other	6. Behaviour

Recap

Technical and organisational complexity have three main features:

- **Differentiation (degree of segmentation and variety of components and tasks)**
- **Interdependence (degree of interrelation of components and tasks)**
- **Uncertainty, particularly in the differentiation and interdependence features of the system**

Bounded manageability occurs at the interface between the project organisation and the complex technical system.

2.4 Conclusion: Towards further theoretical and empirical analysis

This chapter took a first step in defining an analytical framework for empirical research on manageability in complex underground engineering projects. It summarised findings on project complexity from the literature, providing a starting point for the empirical research. As noted earlier in this chapter, the concept of uncertainty merits further exploration. This is done in Chapter 3.

2.4.1 Systems and their complexity as an explanatory variable

This research's first step in understanding bounded manageability explored the concepts that primarily describe the challenge that project managers face. This chapter took the following line of reasoning:

- A project is an endeavour by an organisational system to create a technical system.
- Systems, both technical and organisational, have a certain degree of complexity.
- The requirements of project management are determined by the complexity of these systems, which is defined by the concepts of differentiation and interdependence.

Its main conclusions are four:

- The complexity of a technical system defines the challenge to be dealt with.
- The larger the number and variety of components and interdependencies, and the stronger the interdependencies, the greater the complexity.
- The complexity of an organisational system is heightened by dependence on other actors to achieve the defined end result.

- It is not so much complexity itself that causes bounded manageability. Rather, it is the uncertainty created by complexity that causes bounded manageability.

This chapter suggested that an empirical study to assess of the occurrence of bounded manageability in complex infrastructure projects should include several key factors: differentiation, interdependence and uncertainty. That last is further explored in Chapter 3, prior to its use in the analysis. These elements, furthermore, must be explored in both the technical and organisational systems of such projects with special emphasis on interfaces.

2.4.2 Identifying differentiation and interdependence empirically

The final question to answer in this chapter is how differentiation and interdependence in technical and organisational systems can be identified. Differentiation can be established rather objectively, by looking at the number of components and interfaces or actors and handovers, and considering the level of variety. It is impossible to explicitly measure the impact of interdependencies as hidden or unknown interactions, considering that they may go unseen. The unsatisfactory conclusion must therefore be that complexity is impossible to establish objectively. Nevertheless, the differentiation and interdependence features that are visible do give an indication of complexity and some other, possibly hidden, aspects can be made a bit more objective with the help of some assumptions related to the four areas of complexity defined by Veeneman (2004):

- *Technical-internal*. Bounded manageability could occur as a result of the complexity of the system to be created in terms of differentiation (number and variety of systems) and interdependence (characterisation of interfaces).
- *Technical-external*. Bounded manageability could occur in the project environment through interfaces, involving both physical characteristics and social values (usage, acceptability of temporary closure and the like). This relates to the complexity of the physical and functional environment, and so is partly identifiable as the PESTLE factors.
- *Organisational-internal*. Bounded rationality can occur as a result of the number of different actors (e.g., specialists) involved in getting the job done and their variety (e.g., with diverging interests or backgrounds). This requires coordination effort, evident in handovers, and possible dependence relationships as a result of specialisms and the inputs they produce. This is a key topic of Chapter 3. Specific to complex projects like those involving underground construction, specific engineering features are very knowledge dependent.
- *Organisational-external*. Bounded rationality can occur as a result of the number and variety of policymaking institutions and other stakeholders that are directly

or indirectly implicated in decisions on and in the project. Consideration of the dependence of a project on these institutions is important. Complex projects, particularly those with a strong interface with the (physical) project environment, depend to a certain extent on actors outside the project. Some of these actors may have productive power, such as governmental institutions. Others may have blocking power, such as interest groups and abutters. Aspects to be examined are the external interests surrounding a project, openness of a development process to impulses from outside and the impacts of these on the project, all usually identified as PESTLE factors.

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[1] Nicholas and Steyn (2012: 47) refer to Naughton and Peters (1976: 8-12)

[2] Perrow (1999: 78) defines linear interactions as "those in expected and familiar production or maintenance sequence, and those that are quite visible even if unplanned". He defines complex interactions as "those of unfamiliar sequences, or unplanned and unexpected sequences, and either not visible or not immediately comprehensible".

[3] In many cases ideas for projects emerge in less formal bodies, are adopted by formal bodies and then reach the political agenda.

3. Uncertainty and bounded manageability

3.1 Introduction

Chapter 2 determined that the technical and organisational systems which together form a project create a potential for bounded manageability, as a result of their complexity and uncertainty. To better understand the manageability of underground construction projects, it is key to understand uncertainty's influence on manageability. Chapter 1 defined manageability in terms of three elements: monitorability, predictability and controllability. Bounded manageability implies deficiencies in one or more of these. Unmonitorability means that a project manager cannot oversee the activities of other actors. Uncontrollability means that a project manager cannot effectively intervene to change the situation in the project for the better. Unpredictability means that a project manager cannot foresee to a reasonable extent the consequences of events or decisions. All these situations represent a degree of bounded manageability and cast an uncertain light on management's ability to achieve the project's terms of reference regarding implementation time, costs, scope and quality.

The theories presented in Chapter 2 converged into the general problem of a possible mismatch between the level of complexity of a project and the span of control of the project organisation. This chapter identifies six further manageability problems in complex projects. The complexity discussed in Chapter 2 confronts the organisation with incognition-driven uncertainty: difficult decision-making and the need for information. This chapter begins by introducing uncertainty and distinguishing it from more commonly used concepts of risks. Then, the occurrence of uncertainty is categorised into six types, across two main manifestation forms: the incognition-driven form, i.e. the uncertainties inherent in planning a future effort without having full knowledge of what the future holds, and the behavioural form, i.e. the inability to predict the behaviour of others in a project. This is followed by presentation of a tool for determining uncertainty in a project and common strategies for dealing with uncertainty, to keep underground construction projects manageable. Limitations of these strategies are also examined. In practice, uncertainty is often addressed with a strategy of increasing the available information. This strategy, however, goes hand in hand with fundamental problems that lead step by step to bounded manageability, as will be discussed. Finally, a guide is presented for empirical analysis of manageability – or the lack thereof – in complex underground construction projects.

3.2 Risk and uncertainty

This section explores why, according to Williams (1999), uncertainty is the foundation of the concept of bounded manageability. To that end, the notion of uncertainty will be offset against the concept of risk. After all, it is project complexity that drives much of risk management, but project managers do not generally apply "uncertainty management" (Ward and Chapman, 2001). This section explains why.

3.2.1 Introduction to risk and uncertainty

The profound complexity that characterises most underground construction projects prevents decisions on particular design issues from always being made rationally. Rational action, after all, requires clear goals and objectives (maximum payoff or utility) (cf. Engwall, 2002). To make rational decisions, clear alternatives are needed, alongside an understanding of the consequences of the various alternatives and freedom of choice; that is, selection of the alternative with the consequence that ranks highest in the decision-maker's payoff function (Allison, 1971). Rationality is based on the ability to make an optimal choice, but many project managers have limited power to do this.

Two things hamper rationality. First, many decisions made on the future of a project are subject to risk. Second, future situations are inherently uncertain. This puts complex underground construction projects in context with the grand challenges of our "risk society", in which the future cannot be known (Beck, 1993). On a less grand scale, many uncertainties relate not just to technology or the organisation, but to the interaction between the two: how organisations deal with technology (Johannessen and Stacey, 2005).

The Project Management Institute (2013) defined a risk as "an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more of the project's objectives, such as scope, schedule, cost or quality" (PMBoK, 2013; an almost identical definition was used by Hillson and Simon, 2012). On the basis of the PMBoK definition, Ward and Chapman (2003: 98) identified their main concern with the term "risk" as follows: "there is […] a tendency for practitioners to think of risk in largely down-side, threat terms […] and project risk management as primarily threat management". Indeed, upside risks exist as opportunities (cf. Hillson and Simon, 2012). Since the current study focuses on bounded manageability and its downside effects, upside risks are further ignored. On an academic level more instrumental definitions are used to describe risk. Jaafari (2001: 89), for instance, defines it as "the exposure to loss/gain, or the probability of occurrence of loss/gain multiplied its respective magnitude". The next section explores the phenomenon of risk further, distinguishing it from the concept of uncertainty as used in this study.

3.2.2 Risk and manageability

The prominent position of uncertainty in addition to risk presses us to look closer at this phenomenon in project management. Risk analysis and risk management are common project management practices, even though dealing with uncertainty seems a persistent and uncontrollable problem in many projects. Quantitative risk analysis covers common uncertainties, such as prices and interest rate fluctuations and variability (as some identified risks will come to pass, whereas others will not). By modelling the running of a project multiple times using varied schedules and budgets derived from possible variance and deviance, one can develop an idea of the probability and impact of risks and how a project will perform in reality.

So, project managers execute risk analyses and risk management to keep control of the implementation of their projects. This requires risks to be identified, alongside indications of their probabilities and impacts if they do occur. The implication here is that actions can be taken to reduce the chance of risks occurring or to mitigate their impact (cf. Hillson and Simon, 2012). Many risks stem from the differentiation and interdependence characteristics of the technical and organisational systems in projects. Causes of risks are usually beyond the project manager's direct control.

In one of the most influential studies of risk, Kahneman and Tversky (1979) approached risk as a situation in which the decision-maker considers the potential gains or losses that could be achieved with an action or decision (defined relative to some neutral reference point) and the probability of occurrence of the gain or loss. Similarly, Jaafari (2001: 89) defined risk as "exposure to loss/gain, or the probability of occurrence of loss/gain multiplied by its respective magnitude".

A common means of analysing risk, is to execute a survey in which the risk analyst is briefed by the main engineers on a project regarding what they consider the largest threats to successful implementation.[1] Based on that information, the analyst quantifies the chance of a mishap's occurrence. Reactive policy would than focus on these threats, seeking to reduce their chance of occurrence or to reduce the impact in the event of an occurrence (see, e.g., Jaafari 2001: 91-93). The "bow-tie model", often used in risk response planning, suggests that, unless risks are avoided (by doing something completely different), accepted or transferred to another party, responses to "acts of nature" should focus on treating the event–consequence(s) relation. This typically means reducing the impact of a risk event. For risk factors that can be influenced, responses should focus on the cause or causes, reducing the probability of the event occurring (cf. De Dianous and Fiévez, 2006).

There has been criticism of the effectiveness of risk management practices.[2] However, risks are, in essence, events that can be responded to and therefore are not valid reasons for bounded manageability. A critical factor that cannot be ignored in this regard is that risk is not objective. Identification of risk is influenced by an individual's personal frame of reference, and estimates of probabilities and impacts are largely in the eye of the beholder (Slovic et al., 1980, 1986; Douglas and Wildavsky, 1983; Sjöberg, 2000).

As noted in Chapter 2, Williams (1999) added uncertainty to Baccarini's (1996) differentiation and interdependence in characterising complexity. The terminology of probability research is not always univocal in its use of the concepts of risk and uncertainty though. The key difference between risk and uncertainty, as the concepts are used in the current study, is in the level of predictability. For a risk, one can reasonably estimate the probability and impact. But for an uncertainty, one cannot do so, or at least cannot do so for one of the two.

Ward and Chapman (2003) went so far as to suggest switching from risk management to uncertainty management in projects, broadening the exercise. Williams (1999) referred to Jones and Deckro's (1993) characterisation of technical complexity as a threefold concept, consisting of the variety of tasks (comparable to Baccarini's (1996) organisational differentiation), the degree of interdependency within these tasks (comparable to Baccarini's (1996) interdependence or interrelatedness) and "the instability of the assumptions upon which the tasks are based" (Jones and Deckro, 1993: 219). This includes two aspects of uncertainty: instability and assumption. Instability implies that conditions can change over time, creating a situation of uncertainty for project management. Assumption implies that each different actor may think differently about tasks, which makes centralised management uncertain; or they may share a (later to be proven) wrong assumption. Jaafari (2001: 89) defined uncertainty as "the probability that the objective function will not reach its planned target value". Further on, Jaafari (2001: 89) referred to situations of uncertainty as implying that "not all of the project variables are always identifiable at the outset or new variables surface during project life or their probability of occurrence may shift over time".

As indicated, the concept of uncertainty is strongly related to the lack of predictability and monitorability, which are two of the three pillars of bounded manageability. The remainder of this chapter links this unpredictability and unmonitorability to the typical complexity that project managers deal with in complex underground construction projects. Building on the distinction between technical and organisational complexity, this lack of predictability can be found in knowledge (on the technical system and external organisational factors such as political or economic risks) and behaviour (in the collaboration required between actors in the project). This results in two main categories of uncertainty, elaborated in section 3.3 and 3.4, respectively: incognition uncertainty and interaction uncertainty. Further distinctions will also be made drawing on existing theory on uncertainty. These are then relabelled for the specific situation of the project manager.

3.3 Incognition uncertainty

3.3.1 Variance in cognitive aspects variability, information, knowledge and incidents

Lack of predictability and monitorability related to knowledge about the technical and organisational systems can be elaborated in four categories of knowns and unknowns: instability, incompleteness, inconceivability and inscrutability.

Instability uncertainty
First, there is a kind of "natural" instability in the work of project managers. This concerns situations in which, despite equal circumstances, things go differently each time a project is done. This kind of uncertainty can be stochastic (random) or parametric (unplanned deviations). It includes variation in prices, interest rates, exchange rates and inflation. Sometimes this is referred to as "objective uncertainty" (Helton, 1997) or "aleatory uncertainty". In literature on risk and uncertainty it is also referred to as variability (Ward and Chapman, 2003: 99-100). In the broadest sense, it can include events that are possible but for which managers cannot produce reliable quantifications of probabilities or impacts, in line with the distinction made earlier between risk and uncertainty.

There is also a general variability aspect: the variability in risk exposure. Of the whole list of possible risks, some will come to pass and some will not. Such uncertainty harks back to the work of the seventeenth century mathematician Jacob Bernoulli. It is typically dealt with using quantitative risk analysis in which a statistical test of risk occurrence is conducted. It can be considered a *known*, because experiences and analytical models point to this type of uncertainty, and managers can thus include it in their risk management procedures.

Incompleteness uncertainty
Second, there is uncertainty that results from incomplete information. Uncertainty theories also label this "epistemic uncertainty", "ambiguity" or "subjective uncertainty" (Helton, 1997). This type of uncertainty typically leads to bounded rationality (March and Simon, 1993), which will be further explained in section 3.6. It concerns deviations that in

principle could be known – for instance, if an inexhaustible data set were available – but which are not known, for instance, because gathering such data is not practicable (too expensive, too time-consuming). These occur as discrete risk events. So it concerns situations in which a project manager must make due with incomplete information. For instance, adequate estimates of the probabilities and impacts of risks may be unavailable. For some risks, it is especially difficult to satisfactorily determine probabilities and impacts without prohibitively expensive research (cf. Van Asselt and Rotmans, 2002). Ward and Chapman (2003: 99-100) also mentioned, in this regard, the variability of estimates and uncertainty as to the basis of estimations, such as any assumptions made.

Scholars have found information incompleteness less straightforward than it is often assumed. It cannot always be solved simply by acquiring the information that appears to be missing. Statistical and psychological factors, for instance, play a role in information production. The "flaw of averages" is an often overlooked factor in this regard: people tend to focus mainly on averages and disregard the potential devastating effect of outliers. To get a reliable view of the impact of a project's exposure to risk, one should look not at the average chance of an event occurring, but at the size of the impact on the project if the event does occur. For this reason, Savage (2012) suggested that risk in the face of uncertainty is generally underestimated.

Moreover, a typical problem related to incompleteness uncertainty is the "Gettier problem", named after Edmund Gettier (1963). This holds that knowledge tends to be perceived as true if the actor assessing it believes it to be true and that actor is justified in believing its truth based on underpinning information. In reality, however, this does not necessarily mean the knowledge is true. Something can seem true by coincidence. One might justly assume by looking at their watch that it is six o'clock, not knowing the watch is broken; though the actual time at that moment might in fact be six o'clock, by coincidence (see also Weinberg et al., 2001). The result is that even information that *is* available may be delusive.

Inconceivability uncertainty

Third, there is inconceivability uncertainty. This concerns incidents that can only be known and understood after the event (Lane and Maxfield, 2005). These types of incidents are also referred to as "black swan" events. Taleb (2001, 2007) introduced the concept of the black swan, defined as an extreme "outlier" in probability and impact distribution: "nothing in the past can convincingly point to its possibility" and "it carries an extreme impact". Another important characteristic is that "in spite of its outlier status, human nature makes us concoct explanations for its occurrence *after* the fact, making it explainable and predictable" (Taleb, 2007: xvii-xviii). So, this type of event is not on the horizon of the manager, because such an event has probably never occurred before;

precisely because of its extremely low likelihood. The manager is therefore unaware of the threat it poses to the project.

Inscrutability uncertainty

Fourth, there is the inscrutability problem. This concerns sources of information that are to some extent inscrutable to the project manager, because they draw on tacit knowledge possessed by involved actors. Tacit knowledge is a concept elaborated by Polanyi (1966). The idea in essence is that we know more than we can tell, because some of our knowledge has built up over time (e.g., by experience) and never been made explicit (see also Nonaka and Takeuchi, 1995). This knowledge is unknown because "memories are *not* like copies of our past experience on deposit in a memory bank. Instead, they are constructed at the time of withdrawal" (Plous, 1993: 31, citing Loftus, 1980; Myers, 1990).

3.3.3 Four categories of uncertainty

The above analysis suggests the four typical categories of uncertainty presented in Table 3.1.

Table 3.1 Four categories of uncertainty, resulting from variance and the knowledge of the manager.

	Ever-present uncertainty	Potential uncertainty
Knowable to manager	Instability uncertainty (variability)	Incompleteness uncertainty (discrete risk events)
Unknowable to manager	Inscrutability uncertainty (tacit knowledge)	Inconceivability uncertainty (black swans)

Bounded manageability occurs in situations in which many more or more severe risks come to pass than statistically likely, in which information incompleteness led to reduced control, in which the available knowledge was inscrutable or events happened that simply were entirely inconceivable.

Then there is a behavioural aspect; that is, uncertainties in the interactions between the actors on which the project organisation depends. These are discussed in section 3.4.

3.4 Interaction uncertainty

3.4.1 Introduction

This section explores uncertainties that result from the fact that managing projects is work of humans and hence behavioural aspects come into play. The uncertainties presented indicate, among other things, the troublesome relation between information and decision-making in projects. Yet, as this section will show, because the interests of information owners and decision-makers diverge, attempts to reduce uncertainty may create conflict and new uncertainties. Decision-makers must then seek handholds in a context of bounded rationality.

3.4.2 Diverging and conflicting roles

Organisational coping strategies are applied in multi-actor settings. In these settings, conflict is a key element of interdependencies and relations. Project organisations are junctions of interests, tasks, values and backgrounds. Jones and Deckro (1993) identified conflicts that could occur in these project management organisations. They focused on the relation between project management and functional specialists. These authors derived their categorisation from role theory, which defines a role as a set of desired and undesired behaviours of an individual occupying a position. Associated with this position is a set of activities that make up the individual's role (Jones and Deckro, 1993: 218). Conflicts can, for instance, originate in internal and external organisational politics, split authority, lifecycle-related changes and differing viewpoints concerning the technical complexity of a project. Conflict mainly emerges as impediments in communication and strategic behaviours.

3.4.3 Communication between the knowing and the unknowing

Even without leading to actual conflict, conflicting roles are inevitable in a project organisation. The most dominant one mentioned is the divide between information owners and decision-makers. Information owners are typically contracted parties. In fact, they are often contacted for their knowledge and expertise. The main decision-makers can be found in the role of the sponsor. The contracted parties execute work on behalf of the sponsor, which is why the relationship between the two can also be conveyed as "agent" and "principal", corresponding to the typology of Jensen and Meckling (1976), to be discussed later. Due to different backgrounds and positions in a project, different actors not only look at the job to be done from different angles, but they also have different quantities of knowledge and information available to them. The content of actors' information may even differ.

Winch (2002: 209) identified the information problems of construction projects in what he called the "briefing problem", using the "Johari Window" developed by Luft and Ingham (1955) (Figure 3.2). Winch (2002) focused on the relationship between the sponsor and the design team, but we take a broader perspective and apply it to the general agent and principal roles in projects. Figure 3.1 presents the four possible occurrences of conflict that have their origin in information availability.

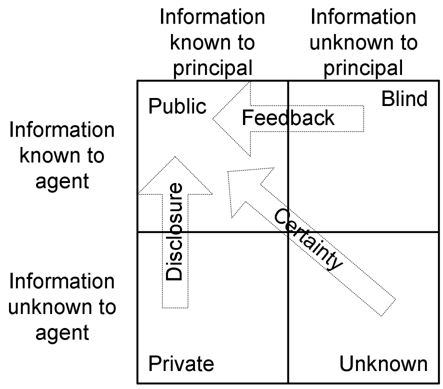

Figure 3.1 Johari Window of information availability and problem-solving (adapted from Winch, 2002: 209).

Four types of information are found in the Johari Window: public, private, blind and unknown.

Public information, also called the "arena" in the Johari Window, is information both available to and commonly understood by both the principal and the agent; that is, it is shared and typically not opportunistically manipulated.

Private information, or the "facade" in the Johari Window, is information known by the principal but not communicated to, or understood by, the agent. There are multiple reasons for this, related to the ownership role of the principal (Winch, 2002: 209):

- The principal did not appreciate that the agent needed the information.
- Internal disagreements within the principal body prevented it from arriving at a clear position, and the restricted disclosure hides this state of affairs.
- The principal does not give its representative the authority to make decisions, and so the disclosure process is slow and insecure and decisions taken are overridden later by senior management.
- The principal does not have the organisational capability to clearly communicate its needs to the agent.
- The principal does not devote enough resources to being a principal.
- The principal behaves opportunistically towards the agent; that is, information is withheld because the principal does not trust its agents.

Blind information, or the "blind spot" in the Johari Window, is information known by the agent but not communicated to, or understood by, the principal. Reasons for the agent to withhold information from the principal are, according to Winch (2002: 211):

- The agent thinks that the principal does not want the information.
- The agent is incapable of clearly communicating the possible range of solutions.
- The agent is searching for ideas, and needs more time to bring them to maturity.
- The agent's scarce resources are being deployed on other contracts.
- The agent behaves opportunistically towards the principal; that is, information is withheld because the agent does not trust its principal.

Unknown information is not available to any of the parties. Winch (2002) calls this the zone of uncertainty. In the analysis presented here, it encompasses the four uncertainties in Table 3.1.

3.4.4 Variance in interaction: Strategic interests and the principal-agent problem

A role-related complicating factor in information processing for decision-making in a network of actors is found in private and blind information. This relates to opportunistic behaviour of principals and agents, and occurs in the typical hierarchical relations of a project. Jensen et al. (2004: 6-7) labelled it as "vertical uncertainty". Different actors have different interests and values (cf. De Bruijn and Ten Heuvelhof, 2008: 23). The actors depend on each other to execute the project, but do not want to be harmed in any way while doing so. On the contrary, their main assets in the project are related to the realisation of the system as such (not necessarily to the functionality the system should provide when finished) and to the pursuit of their own interests (see also Jones and Deckro, 1993). This means they have an incentive to maximise the project for their own good (see also Perrow, 1986; Laffont and Martimort, 2002). Winch (2002: 211) also pointed out the opportunistic behaviour that this may produce. Such behaviour can strongly influence decision-making.

According to Morris and Hough (1987: 216), it is highly contestable whether knowledge is objective. Subjectivity may influence both the production of knowledge and its interpretation. This is often the result of the frame of reference of the involved actors and the diverging interests that actors have in realisation of a system. In complex construction projects, engineering specialists such as contractors and designers (agents) typically have more specialist information than the sponsor (principal). The engineering specialists are also commonly responsible for the secondment of functional specialists to a project. How can the project organisation be sure that these actors will always react adequately to the situations they face (Galbraith, 1976: 23)? And, how can higher-tier managers be sure that the "work floor" assesses, decides and acts in accordance with higher-tier managers' interests?

Intention uncertainty

Jensen and Meckling (1976) studied strategic behaviour related to the diverging and often conflicting roles in principal-agent relationships (in which an agent carries out a task on behalf of the principal). It appeared to be difficult for the actors with the least specialist information – mostly managers on the principal side – to retain control of actors with more specialist information – particularly functional specialists, often agent-related. The dependency therefore appears to be largely unilateral: the principal depends on the agents. However, the principal is usually, despite its weak information position, the actor with ultimate decision-making authority. As information has major strategic value, agents typically use it to pursue their own interests. Agents' interests are likely to diverge from the principal's interests. The potential result is conflicts related to technical complexity and to internal organisational politics. Tannert et al. (2007) called this "moral uncertainty". It is most prominent in a "blind information" context.

Jensen and Meckling (1976) mentioned two common problems in principal-agent relationships:

- *Adverse selection*. The sponsor cannot know all the properties and motives of the (potential) contractor. However, the most adverse contractors are most likely to be selected by the principal, for instance, because they have reason to bid low. Motives, for example, may be a bad reputation that would impede selection elsewhere or a lack of knowledge or experience, which the contractor wants to rectify with the job.
- *Moral hazard*. Agents have different interests than principals, and pursuing their own interests is their primary value.

The strategic value of information creates some jeopardy in project management relating to two uncertainties found in the Johari Window: private information and blind information. Actors can be expected to protect private information. As De Bruijn and Ten Heuvelhof (2008: 18-20) noted, they may conceal information resources in possible hierarchical interventions, usually with a strategic purpose. But this "closedness" may work to their disadvantage. Information is one of the main strategic tools from which actors derive power in their network. Sharing information could thus weaken their position. As a result, agents may have valid reasons for this behaviour; it does not necessarily result from a moral deficit. Therefore, this type of uncertainty is labelled here "intention uncertainty".

Interpretation uncertainty

Closedness and measured information provision also occurs the other way around, as the Johari Window shows, because of politics within the owner's organisation and uncertainty about the behaviour of agents. These uncertainties result from the fact that tasks are transferred from the principal to the agent. Knowledge creation is strongly dependent on the sensory processes and perceptions of the receiver (cf. Dretske, 1981). Reason (1990) argued that technology has become so advanced that we have now reached a point where improved safety can only be achieved by better understanding human error mechanisms. Taking all mechanisms into consideration would be unnecessarily broad for the purpose of this research. The focus here is on the opposite end of the principal-agent relationship, discussed above under intention uncertainty.

Berger and Bradac (1982: 7) called this cognitive uncertainty and described this as a problem of communication (e.g., between agent and principal). In particular, uncertainty about the beliefs and attitudes of others can impact the information sent. Meanwhile, however, the beliefs and attitudes of the principal impact the way the principal interprets information. There is a risk in the relationship between agent and principal that inputs provided by the agent are misinterpreted by the principal. This could happen, for instance, due to heuristics within the principal's organisation, possibly as a result of dominant political views or experiences from earlier projects. This will be called "interpretation uncertainty".

3.4.5 Resuming: six types of uncertainty

The discussion up to now has provided a total of six uncertainties that can be distinguished along two axes: whether information is knowable to the manager and the type of variance (incognition-driven, either ever-present or potentially present, and interaction-driven). These are summarised in Table 3.2.

Table 3.2 Six types of uncertainty, including interaction-driven uncertainties.

	Incognition-driven uncertainty		Interaction-driven uncertainty
	Ever-present uncertainty	Potential uncertainty	
Knowable to manager	**Instability uncertainty** (aleatory uncertainty, i.e. stochastic uncertainty and parametric variability)	**Incompleteness uncertainty** (epistemic uncertainty as a result of incomplete information)	**Interpretation uncertainty** (sponsor-instigated deviations in assessments and decision-making)
Unknowable to manager	**Inscrutability uncertainty** (tacit knowledge)	**Inconceivability uncertainty** (black swan events)	**Intention uncertainty** (strategic behaviour)

Recap

There are six types of uncertainty in the management of complex projects, to be distinguished on the basis of

- **whether uncertainty is incognition-driven or interaction-driven**
- **within the incognition-driven uncertainties, whether it is ever-present or potentially present**
- **applying to all uncertainties, whether it is mostly knowable to the manager or not**

3.5 Tools to cope with uncertainty and the limited resolution of these

3.5.1 Introduction

This section examines how the occurrence of uncertainty in a project can be measured. It then elaborates two categories of coping strategies used in concrete trade-offs in which uncertainty plays a role: coping strategies to increase the information available and coping strategies to reduce the information required. Finally, the question of why these strategies have not eliminated the manageability problems of complex underground construction projects is addressed.

3.5.2 The uncertainty gap

How can one measure the occurrence of uncertainty in a project? Galbraith (1977) defined the occurrence of uncertainty as the gap between the information required and the information available. This can be related to the degree to which the manager understands the potential for variance (see Table 3.1). Figure 3.2 presents Galbraith's (1977) visualisation of this.

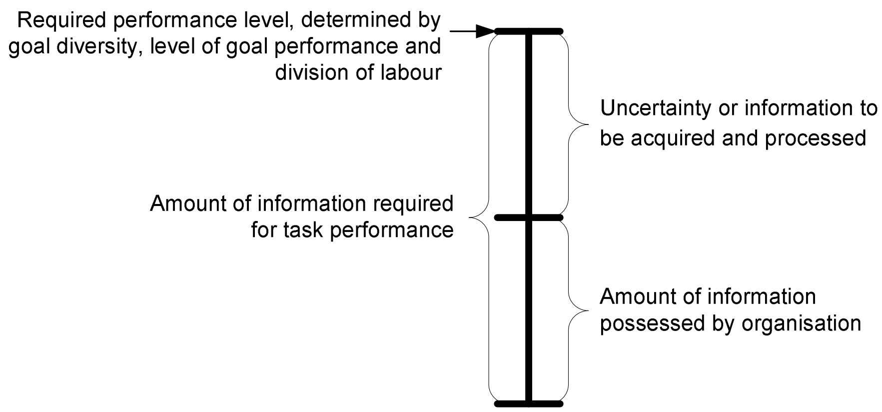

Figure 3.2 Uncertainty and information (source: Galbraith, 1977: 38).

Galbraith noted two sources of information-related uncertainty:

- *Complexity*. Galbraith referred mainly to information complexity. He used the term to describe a condition in which information in essence is available, but is too costly or time-consuming to collect and analyse. This corresponds to incompleteness uncertainty. Relevant to this study is a possible situation in which managers have an insufficient span of control over the sheer number and variety of elements and interrelations; that is, the system complexity elaborated in Chapter 2, which concerns a similar phenomenon. Complexity of the system to be developed or its environment – i.e. the topics discussed in Chapter 2 – often lie at the basis of this uncertainty.
- *Unpredictability*. This is a condition in which the past is not a reliable guide to the future. Although the future is by definition unknowable, past experience can be a valuable guide in many situations. Experience can provide clues, for instance, on variability beyond the expected variance established through quantitative

analysis of risks and unknowns. Unpredictability includes the behaviour of other actors as well.

So, Galbraith looked only at known uncertainties; that is, occurrences where managers understand the potential variance. This disregards the variance that is not understood; that is, inscrutability uncertainty and inconceivability uncertainty. In inscrutability and inconceivability uncertainties, managers are unaware of the existence of an uncertainty gap.

3.5.3 Dealing with uncertainty

Galbraith's definition of uncertainty focuses on information as the main aspect in managing uncertainty. Many project management tools do in fact aim at the processing of information. From this we can deduce that information is considered a primary tool for successful project management. Information is also a key tool for knowledge development, in addition to, for instance, experience and skills. The latter are cultivated over time, based on information. Information comes at a cost though, such as money and dependence on others who can provide it.

Galbraith (1976: 25) proposed two strategies for reducing uncertainty:

- Reduce the information required
- Increase the information possessed

A reduction of the information required can be achieved, for instance, by reducing system complexity. This can be done by disentangling subsystems or reducing the number of components or their variety, which would diminish the information needed. There is, naturally, a limit to such simplification, and that limit may still be greater than the managers and engineers in the project can handle. More importantly, it usually requires a reduction of scope or quality, and hence diminished ambition. This may be difficult to achieve from a political perspective. Reducing the information required as a response to uncertainty is most suitable for addressing instability and inconceivability uncertainties.

An increase of information possessed is usually achieved by making use of the knowledge of others, for instance, through procurement, or by building up knowledge within one's own organisation. The greater the uncertainty, the larger the amount of information that must be processed (Galbraith, 1977: 36). This is a typical response to incompleteness uncertainties. Information is the means that leads to knowledge. The function of knowledge in the decision-making process is to determine which consequences follow upon the various alternative approaches (Simon, 1997: 78).

Two remarks when linking this to the six categorised uncertainties:

- Both strategies aim to improve understanding of variance. However, while increasing information is a promising strategy, it is in essence useless if the actors in the project organisation cannot handle it. That is, they must be able to interpret and use the information properly for decision-making. Without such ability, the understanding of variance is still hampered, despite attempts to bridge the uncertainty gap. This topic will be explored later in this chapter.
- Neither of the strategies works for inscrutability uncertainty, because managers are unaware of the knowledge involved; it emerges only at the moment it is needed. The strategies similarly are of no use for inconceivability uncertainty, because this concerns matters that become known only after their occurrence. This suggests the matrix in Table 3.3.

Table 3.3 Strategies to reduce the uncertainty gap.

	Technical system	Organisational system
Increase the information available	Introduce information about the technical system into the project organisation	Make sure the main decision-makers can interpret the information properly
Reduce the information required	Avoid technical uncertainties	Adjust expectations or simplify the project organisation

Recap

- **There is a difference between risk and uncertainty**
- **In case of uncertainty, possible final assets and the probability of occurrence are, unlike to risk, unknown**
- **Many manageability problems occur due to uncertainties**
- **Uncertainties can be dealt with by increasing the information available or reducing the information required**

3.5.4 Coping tools to increase the information available

This section explores tools that are typically used to increase information available.

Technical coping tools

Dörner (1997: 71-105) identified tools to reduce uncertainty by *increasing the information available* on a technical system. **Computing models**, for example, can provide statistics on the chance of failure of a technical system or subsystem. These statistics can then be used in decision-making. An important disadvantage of such a tool is that only known potential failures can be modelled, which mostly comes down to risks. Uncertainties can hardly be modelled, as their possible outcomes and probabilities are unknown. Among uncertainties, statistical inaccuracies and general fluctuations – i.e. known unknowns – are easiest to cope with; typically through contingencies. Unknown unknowns (inconceivability uncertainties) cannot be modelled.

Another possibility is use of **references** and **analogies**. Engineers and managers can look at earlier applications of the same technology (references). They can also look at the technology as it has been employed previously in a different application (analogies). The tool can also be applied for budgeting and scheduling purposes. These instruments can be applied to complete projects, for example, to obtain a more reliable view on costs, benefits and effects. This technique is known as "reference class forecasting" (Flyvbjerg, 2008). It is important to be able to analyse the extent that earlier applications are comparable to the new one. The more often a technology or application has proven itself, and the more comparable the applications are to the present design, the less uncertainty. Unfortunately, this instrument can also only elucidate known effects. It will never bring out information on unprecedented effects, such as inconceivability uncertainties.

Although not specifically mentioned by Dörner, there are other comparable ways to increase information. To reduce uncertainty caused by application of an unproven technology or the conditions in which it is to be applied, **tests** can be conducted as part of a verification process. Tests before starting operations can help match technology to requirements before construction and ascertain the actual performance to be expected after construction (Nicholas and Steyn, 2012: 67, 394). In this instrument there is a need to be aware of the similarities and differences between the test case and the real application, particularly for pre-construction tests. Although this instrument does produce new information, and therefore can help reduce uncertainty as well as risks, tests are rarely executed under the exact same conditions as the real case. Each simplification or change of location can affect probabilities and final outcomes. This makes tests predominantly risk analysis tools as well, rather than uncertainty reduction instruments.

In addition to the concerns raised above, serious risks are involved in the use of an increase of information as a strategy for dealing with uncertainty. As Dörner (1997: 100) pointed out, there is a "positive feedback" in the relationship between uncertainty and information which may make decision-making more difficult, as new information may "muddy" the picture. New information may be ignored if it does not confirm existing ideas, or its importance may not be understood. Ignoring in this situation corresponds with the use of heuristics in decision-making (Kahneman and Klein, 2009). It might therefore be advisable to extend the scope of possible strategies to organisational coping tools.

Organisational coping tools

Beyond coping strategies involving the technical system, the organisation can be the focus of coping, essentially **moving the issue up in the hierarchy**. The first organisational tool concerns the problem of information being scattered throughout the project organisation; rather than an information lack. Usually, each actor substantially involved in a project owns part of the information required to make good decisions. The easiest way to steer them is to establish rules, programmes and procedures for the behaviour that is required in implementation (March and Simon, 1958: 142-150; Galbraith, 1976: 20). If the actors encounter situations that diverge from those laid out in rules, programmes and procedures – for example, situations that cross interfaces between designated work tasks – a higher management tier is required to make decisions on the basis of information from both sides of the interface. Problems that cannot or should not be solved at one tier can then be passed to a higher tier. The most persistent problems and the most important decisions are sent all the way up to top management. This way, a hierarchy arises. If, however, the information conveyed to higher management tiers is too plentiful, the hierarchy is overloaded. The communication upwards and the feedback downwards may then experience delays. The hierarchy then has to develop new processes, in the form of additional rules, programmes and procedures (Galbraith, 1976: 22-23).

Uncertainties emerging here concern what information is used and what is not. Information from different sources within an organisation can be contradictive. There may be unawareness of what information is available within a project organisation (a sort of organisational tacit knowledge). Limitations may be experienced in the transferability of information and the conditions under which it is to be provided (interpretation uncertainty and intention uncertainty). Coordinating managers, therefore, always make their decisions in conditions of uncertainty.

An alternative strategy would be to retain decision-making competence at the higher tiers, but to base decisions on inputs from other actors. This implies relying on engineering specialists' **professionalism**. Managers may, for example, rely on assessments by the most skilled experts available in the network of actors. They may hire specialised professionals to increase the information available in the network. These could be independent consultants or specialist staff for the sponsor organisation. This does, of course, raise costs and interdependencies, and it is uncertain whether the "professional" will make the best effort possible (intention uncertainty due to the "blind information" introduced earlier). Also, alternatives based on specialist professional standards may not be ideal for the organisation as a whole (cf. Galbraith, 1977: 44-47).

3.5.5 Coping tools to reduce information required

Measures to reduce the information required aim not at gaining knowledge, but at designing the technical system or organising the project in a less complex way, so that more information is not necessary. Measures therefore centre on the development of the technical system and the organisational system.

Technical coping tools

Quality assurance is an organisational verification tool to ensure that project management follows correct procedures to deliver the quality required (Nicholas and Steyn, 2012: 326-327; Winch, 2002: 294-295). In its most basic form, it concerns drawing up a project quality management plan and ensuring that it is followed during project implementation (cf. Huemann, 2004). Verification is “procedural”; that is, it is aimed at adherence to the right procedures rather than characteristics of the outcome itself (design, performance). This is, at the same time, its primary weakness in dealing with uncertainty. Quality assurance seeks to reduce deviance from defined standards, so it can only assess the management of a project against known practices. Novel and unknown situations do not yet have standards.

Dimensioning and tolerancing in design engineering are ways to account for variability in projects (Drake, 1999). A “safer” design increases the chance of successful implementation and functioning and is likely to reduce uncertainty and the potentially adverse effects of variability. This can be achieved by overdimensioning (increasing robustness) and by using smaller tolerances. This usually raises costs, however. It then becomes a trade-off between certainty and expenditure. This trade-off is often influenced by current trends in process management, such as “Six Sigma”, a set of guidelines for process improvement (Drake, 1999: 1-6; Nicholas and Steyn, 2012: 324).

Divisibility or decoupling is a means of dividing a project into detached subsystems. In so doing, a project’s management reduces project size and entanglements, diminishing the complexity of the system as a whole. Once complexity is thus minimised, there are fewer interfaces, meaning there is less that managers need to know about possible interactions. In addition to cutting their project into pieces, managers can simplify their work by reducing the number of items requiring their attention. However, a divided project must at some point be welded into a whole. Divisibility is therefore also a potential threat to the integrity of the system. System components that do not connect seamlessly are a potential source of deviance and flaws.

The level of coupling has an influence on information exchange too. Tightly coupled systems can exchange information more quickly than loosely coupled systems, but when subsystems are loosely coupled, complexity as a result of interfaces can be reduced (Perrow, 1999: 89-96). Loosely coupled systems can therefore absorb shocks, failures and pressures for change without destabilisation. Tightly coupled systems can function only in one particular mode, with very precise resources in an invariable sequence and process. As a result, loosely coupled systems may be less dependent on information. Loosely coupled systems tend to have ambiguous or perhaps flexible performance standards. They can also recover from failure more easily. But effort is always required to ensure integration.

Slack is overcapacity that helps to manage and reduce deviations that could undermine performance (Galbraith, 1976: 26). In the management of complex infrastructure projects slack can be achieved in terms of time, cost, scope and quality. If workers or engineers have ample resources, and quality and scope benchmarks are not overly ambitious, they have more opportunity to cope with deviations themselves. A lack of pressure in the lower tiers of an organisation makes it easier for the people there to meet schedules. Also, more security is built in when tasks are attended to redundantly. For example, in addition to hiring professionals, a manager or sponsor might hire specialist staff to oversee the work these professionals do. This does mean, of course, that the end-result is achieved less efficiently. In the public realm, this practice may be considered an irresponsible expenditure of public money. Slack or redundancy are therefore not very common or popular measures.

Organisational coping tools

Organisational strategies can also be used to reduce the information required, first, by defining **autonomous tasks**. When creating autonomous tasks, designated working groups implement their own subsystem and have their own equipment and resources at their disposal. Task assignment then shifts from functional or input orientated to geographical or output orientated. By distinguishing the output to be achieved with a set of means, decisions can be made at a lower tier of the organisation, which brings decision-making closer to the source of information (Galbraith, 1976: 26-28, 37). Defining autonomous tasks is problematic, however, when subsystems are functionally, and hence in their designs and tasks, highly interdependent (cf. Perrow, 1999). In these cases it may lead to configuration problems and a shifting of responsibilities and liability.

Galbraith also provided some techniques for enhancing organisational abilities to process information. This enables a similar amount of information to be used more efficiently, so the quantity of information ostensibly increases. Investing in **vertical information systems** is one such strategy. It enlarges the capacity of existing communication channels and introduces new decision-making techniques. It also expands the organisation's capacity to use the information acquired during implementation (Galbraith, 1976: 40). The downside is that there is no one best way to organise these systems (Galbraith, 1977: 96-110). Moreover, even effective systems have inefficiencies, either on the input side or in the working components. Quinn's (1988: 36-38) categorisation of information processes suggests that vertical information systems are best matched to the hierarchical or internal process approach, reflecting a preference for long timelines and high certainty and the need for predictability and security. Vertical information systems tend to emphasise standardisation and perpetuation of the status quo. This is ill suited to the nature of the complex projects discussed here, as vertical information systems' usability is limited mostly to known knowns.

Another strategy would be to create **lateral relations**; that is, direct contact between departments within the same tier (Galbraith, 1976: 56-75). Thus, people working in different divisions would have direct contact with one another, rather than via a higher tier. This enhances mutual understanding and information flows. Sometimes lateral relations are accommodated by task forces or designated intermediate managers. These may lead to leadership problems, however, because if contacts no longer go through a higher tier, higher managers may lose sight of things happening within the organisation. Also, Hansen (2002) showed that whereas direct relations between divisions mitigate problems of transferring non-codified (i.e. tacit) knowledge, they were harmful when the knowledge to be transferred was codified, because the direct relations were less needed in these cases but still required maintenance costs. Lateral relations are particularly useful for understood variance that is unknown to the manager (unknown knowns), but less useful or perhaps even inefficient in dealing with other forms of uncertainty.

Among the four strategies derived by Galbraith – slack, autonomous tasks, vertical information systems and lateral relations – Galbraith stated that if none is consciously chosen, the first will automatically apply: slack in the form of diminished performance. His analysis, however, referred predominantly to single-organisation situations, which omits consideration of reliance on the professionalism of other actors (one of the coping strategies in the category "increasing the information available").

3.5.6 Limited resolution of the coping tools

Table 3.4 presents a categorisation, derived from the two previous sections, of ways to deal with uncertainty in infrastructure project organisations.

Table 3.4 Ways to deal with uncertainty in infrastructure project organisations.

Category		Coping strategies to reduce uncertainty	Limitations/downsides
Increasing the information available	**Technical**	**Models and statistics**	Largely limited to known uncertainties
		References and analogies	Largely limited to known uncertainties
		Tests	Largely limited to risk
	Organisational	**Moving up in the hierarchy**	Delays (inefficiency), intention uncertainty
		Hiring professionals	Inefficiency, intention uncertainty
Reducing the information required	**Technical**	**Quality assurance**	Limited to known standards
		Dimensioning/tolerancing	Inefficiency
		Divisibility/decomposing/ uncoupling	Compromised system integration (creating new uncertainty)
		Slack	Inefficiency
	Organisational	**Autonomous tasks**	Compromised system integration (creating new uncertainty), averting responsibility
		Vertical information systems	Limited to known standards
		Lateral relations	Decreased leadership oversight (increasing uncertainty), inefficient (except for unknown knowns)

Overall we can conclude (i) that technical measures to increase the information available are largely limited to dealing with risks and known uncertainties; (ii) that technical measures to reduce the information required are often inefficient and compromise system integration; and (iii) that organisational measures to increase the information available cause delays and additional expenses, compromise the leadership position (unity of leadership, oversight) and introduce problems of intention uncertainty. The tools to reduce the information required can only be used with known standards. Much trouble could be avoided by accepting a certain degree of inefficiency, beyond the normal inefficiencies already in place, such as contingencies. But this hardly seems satisfactory in practice. Galbraith (1977) considered attempts to improve the information available for decision-making mostly a matter of improving information processing. In the management of complex construction projects, there are a few other decision-making issues that play an important role too.

Recap
Tools currently used to deal with uncertainty have various limitations and downsides, such as inefficiency, a strong focus on knowns and known standards, threats to system integration and adverse effects of intention uncertainty (possible strategic behaviour).

3.6 The result: Decision-making with bounded rationality

Uncertainty materialises most profoundly in decision-making, because this is where managers and engineers experience the actual dilemmas associated with complexity. Apart from increasing the information available or reducing the information required, managers can also reconsider the way they make decisions. Galbraith's ideas on organisational design, discussed above, are normative and prescriptive elaborations of foundation theories by, for example, March, Simon and Cyert.[3] But due to the downsides of many technical and organisational strategies for coping with uncertainty in information and decision-making processes, it is instructive to return to those foundation theories.

March and Simon (1993) pointed out that rational decision-making is not always possible, particularly in cases of limited information. Indeed, in the academic world rational decision-making has been strongly debated and often put aside as illusory. Still, no practical alternative has yet been found, and decision-makers still try to make options and values explicit.

March (1994: 10) presented four information constraints that hamper rationalisation and cause uncertainty:

- *Problems of attention*. Not everything can be attended to at once, yet too many signals are often received. Attention is scarce and must be properly allocated.
- *Problems of memory*. People and organisations have limited capabilities to store and recall information.
- *Problems of comprehension*. Decision-makers have limited abilities of interpretation of information.
- *Problems of communication*. People have limited capacities for sharing complex and specialised information.

The clearest examples of the emergence of bounded manageability in relation to rationality limitations appear in trade-offs between four performance benchmarks: implementation time, cost, scope and quality. These benchmarks are interdependent. A change in one normally affects one or more of the others. But the effect may be ambiguous. Extending the scope of a project normally implies a rise in project cost and implementation time. If project management tries to achieve a larger scope within the same budgets and schedules, difficulties tend to arise. The chance of overrunning schedules and overspending increase and quality may suffer. This may ultimately lead to bounded manageability.

3.6.1 Attempts to rationalise decisions

Various means of rationalising decisions under uncertainty can be distinguished. Some are conscious strategies, while others develop unwittingly. This section discusses three of the most typical ones.

Simplifying the problem and satisficing

The larger the uncertainty gap, the more difficult it is to make rational decisions, as rational decision-making requires complete information about all alternatives and about the consequences of choices. March (1994: 12-14) noted some empirically established strategies aimed at modifying the problems confronting decision-makers. Managers or engineers can, for instance, edit or decompose designs or other problems. This simplifies problems before a decision is made, as some information is excluded or the amount of processing of some information is reduced. Comparable behaviour was mentioned by Simon (1956). People do not always strive for the optimal solution, but for one that is sufficient and satisfies. Simplification and satisficing are well-matched to uncertainties that are known to the manager (instability uncertainty, incompleteness uncertainty and interpretation uncertainty). The manager is aware of the uncertainties, but tries to cope with them using the information he/she does have available.

Heuristics and practical rules

Another way decision-makers reduce uncertainty, and therefore act better under bounded rationality, is by making use of their own references when approaching issues. Decision-makers can, for example, detect patterns and apply rules of appropriate behaviour to the situations they encounter, like rules-of-thumb. This is called “heuristics”, a term attributed to Herbert Simon, though “intuitive judgement” is a similar concept used by others (cf. Hogarth, 1987). In fact everyone, often unwittingly, uses heuristics to make decisions under uncertainty. It is therefore an important concept for understanding how the manageability of a project develops. Experienced actors have an advantage over novices, because they have a greater stock of patterns that they previously encountered and may recognise. Heuristics involves framing issues by applying paradigms, perspectives and beliefs that are already available. It can be used in relation to a design problem or other issue, to information that has to be collected or to aspects that need to be evaluated. Heuristics focus and direct the decision-maker’s attention (cf. Kahneman and Klein, 2009).

A comparable, but more "codifying" way of dealing with uncertainty, is by rule-making. The rules developed along the way are then applied when working with novel, and hence uncertain, technologies or designs. Wynne (1988) introduced the concept of "unruly technology" as a problem of "the absence of appropriate rules to guide fundamental engineering decisions", as Vaughan (1996: 200) paraphrases it. Although engineering behaviour is rule-following, i.e. engineers are expected to use technical standards and specifications, Wynne (1988) stated that, due to the inherent uncertainty of the situations engineers face, they in reality do not so much follow rules laid upon them by the technology but develop "practical rules" to deal with real-world situations. The consequence is that "rules" for dealing with a technology actually follow from these evolving practices:

> *"Beneath a public image of rule-following behaviour and the associated belief that accidents are due to deviation from those clear rules, experts are operating with far greater levels of ambiguity, needing to make uncertain judgements in less than clearly structured situations. The key point is that their judgements are not normally of the kind – how do we design, operate and maintain the system according to "the" rules? Practices do not follow rules; rather, rules follow evolving practices"* (Wynne, 1988: 153).

This type of response to uncertainty matches best with uncertainties unknown to the manager. The process of codifying the manager's behaviour in making decisions is not entirely conscious. The bases on which judgements are made are implicit and have been created unwittingly in the managers exchanges with and under dependence of other people and organisations.

3.6.2 Bounded rationality and bounded manageability

The rationalisation attempts mentioned above – simplification, heuristics and practical rules – are inevitable and even important to achieve at least some level of progress and continuation in processes in the face of uncertainty. But all of them can contribute to bounded manageability. Simplification has as a downside that things may be left out arbitrarily. Suboptimal decision outcomes can result if management misses out on important information, leaving crucial uncertainties intact. The downside of heuristics is that its value in decision-making is strongly defined by the very personal frames of reference of the actors involved. It makes judgements subjective and strongly based on perceptions and assumptions, such as regarding the behaviour of others, related to intention uncertainty. This could be troublesome if the decision-maker is inexperienced or strongly influenced (e.g., politically). Rule-making, as described by Wynne (1988), has as a downside that undesirable practices may develop into rules and therewith gain widespread following. These downsides could potentially develop into a situation of bounded manageability.

Law (1992, 1994) argued that information availability does not necessarily rationalise decision-making. Decision-making is also considerably influenced by the values held by an actor in a network of human actors and by non-human factors. The better the fit between an argument, or set of arguments, and the dominant social values of the group that will experience the effects of the argument, the smaller the force required to put it into practice (Parkin, 1996b: 261-262). This theory largely coincides with ideas about the analytical paradigm developed by Robert K. Merton. According to Merton, a paradigm is a systematic statement of the basic assumptions, concepts and propositions employed by a school of analysis (Allison, 1971). A paradigm shaped in a certain way, can enhance the processing of information and decision-making, providing that the paradigm does justice to the complexity of the problem. The role of a project manager in relation to the actor network being steered is another relevant factor in the processing of information in decision-making (Parkin, 1996a: 13-19).

Limitations to rationalisation attempts

Every attempt at rationalisation in situations of uncertainty has its limitations. First, interpretation uncertainty and intention uncertainty lead to bounded rationality problems, because they require the involved manager to make assessments of other actors' behaviour. If, for instance, there is a potential for strategic behaviour, even acquiring more information might not help to rationalise decisions where interaction-driven variance plays a role.

Second, heuristics are not objective. They depend heavily on the actor. Each actor has his or her own background, experiences and insights. This creates the divergences that occur in interpretations of information. It can lead to conflicts, as different managers or engineers depend on their own perspectives, beliefs and background.

Third, attempts to reduce the uncertainty gap can never be definitive. After all, if the size of the gap is unknown how can project managers or engineers be sure that their attempts fill the entire uncertainty gap? This applies particularly to cases where the competences of the project owner fall short, because parties that lack competence fail to see or understand the competence they are lacking. This phenomenon will be discussed later as the "Dunning-Kruger effect" (Dunning-Kruger, 1999). The only exception is a situation in which a manager deviates from a well-known situation (e.g., to reduce costs or to include an innovation) and has the option to return to the point of departure.

Allison (1971) and March (1994) distinguish “maximising” and “satisficing” to describe a situation in which the decision-maker tries to achieve a sufficient level of certainty. When “maximising”, one pursues the optimal solution, whereas when “satisficing” one pursues a solution that is good enough. Heuristics and framing, as well as slack, entail that the decisions eventually made aim more at “satisficing” than at maximising or optimising (March, 1994: 18-21). Furthermore, paradigms are not necessarily rational either.

The result is that in a bounded rationality situation, decision-making easily ends in poor interpretation and hence poor decisions.

3.7 Conclusions: Uncertainty and bounded manageability

3.7.1 Uncertainty as explanatory variable

The line of reasoning in this chapter can be summarised as follows:

- Due to complexity in technical and organisational systems, managers must make use of imperfect information and decision-making strategies and they face uncertainty in doing so.
- Currently-used tools for dealing with uncertainty have limited resolution.
- Acts and decisions in managing projects are made in situations of bounded rationality.
- In these situations, managers use coping strategies to steer their acts and decisions.

The chapter’s most important findings are three:

- The sensitising concept of bounded manageability was elaborated into six types of uncertainty in project management. These were categorised as uncertainties typically knowable or typically unknowable to the manager and as incognition-driven or interaction-driven uncertainties. They can be further divided into ever-present uncertainties and potentially arising uncertainties.
- Currently-used tools have limited resolution. They deal mostly with the known uncertainties implied by incognition-driven variance (instability and incompleteness uncertainties), and far less with interaction-driven variance (interpretation uncertainty and intention uncertainty). Moreover, use of the tools available tends to be inefficient. So, they do not cover all types of uncertainties, cannot render uncertainties fully understood and do not eliminate the entirety of the uncertainty.

- Coping strategies to deal with situations of bounded rationality are more like rules of thumb and usually applied unwittingly. If the frame of reference that produces these rules of thumb is poor – which is often the case in uncertain situations – bounded manageability can emerge. Even with a strong frame of reference, these coping strategies shape managers' behaviour in the face of uncertainty. They do not eliminate the uncertainty.

3.7.2 Identifying organisational uncertainty empirically

The next step in this research will be the "axial coding" (Strauss and Corbin, 1990). The occurrence of bounded manageability is empirically explored in real projects. For each occurrence of bounded manageability, the conditions and context of the occurrence, the actions and interaction strategies applied and the consequences of these actions will be described (Strauss and Corbin, 1990: 96). The findings will then be explored in relation to the theories of uncertainty elaborated in this chapter. This should, according to grounded theory, result in selective coding, with the findings converting into underlying dilemmas that explain the results of dealing with bounded manageability.

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[1] Engineers are usually most likely to indicate technical risks, but obviously risks can also originate in, for instance, economic, political or organisational aspects. To cover those kinds of risks, it might be important to include other managers in a risk survey.
[2] Jaafari (1995) supports this. See also Covello et al. (1986) and Hubbard (2009).
[3] Galbraith refers to the original editions of *Organizations* (March and Simon, 1958) and *The Theory of the Firm* (Cyert and March, 1963). Here, further references will be to later editions of those titles.

4. Researching uncertainty and bounded manageability in complex underground infrastructure projects

4.1 Introduction

This chapter takes the step from theory to empirical research. Section 1.6 already announced that a semi-grounded theory approach (Straus and Corbin, 1990) matches the purpose of this research. The empirical fields in which uncertainty and the potential for bounded manageability occur were explored in chapters 2 and 3, producing researchable aspects. This chapter starts by describing how the case research was set up. It then introduces the data gathered and how it was compiled (sections 4.2 and 4.3, respectively).

4.2 Case research

4.2.1 Empirical research

The discussion up to now has presented the level of manageability as a result of the occurrence of uncertainty in projects and the capabilities of the project organisation to deal with them. How this works in practice has to be determined. A case study approach has been chosen for this. This section will motivate this choice and will discuss the design of the empirical research.

Explorative case studies (axial coding)

To explore how bounded manageability develops in practice this research included case studies. These cases served only for the purpose of theory-building, in conformance with grounded theory. Flyvbjerg (2006) quoted Eysenck (1976: 9) on the function of case studies beyond their usual application for comparative research: “[S]ometimes we simply have to keep our eyes open and look carefully at individual cases – not in the hope of proving something, but rather in the hope of learning something.” This is the function of the case studies in this research. Their explorative nature is well suited to the grounded theory approach. The cases are therefore predominantly descriptive. They have an inductive set-up, aimed at formulating factors that determine manageability; framed only by the relevant concepts found in chapters 2 and 3. They stand at the very beginning of extended research into this topic: in the pre-statistical phase of seeking a basis for possible further analysis.

The research questions formulated in chapter 1 were:

- 1a: How does bounded manageability, as elaborated in chapters 2 and 3, emerge in practice
- 1b: Why does bounded manageability in complex underground projects, as discussed in chapters 2 and 3, emerge?".
- 2: What can be done to respond to the boundedness of manageability in these projects?

Chapters 2 and 3 approached the questions from a theoretical angle. The empirical studies were structured along the lines of the literature review, but expressly retaining the breadth required for grounded theory research. This step sought to answer the research questions from an empirical angle.

After identifying these questions, and providing no propositions are used in this semi-grounded theory research, the remaining steps to design a case study as means of empirical research are establishing the unit of analysis and the criteria for interpreting the findings (Yin, 2009: 27). The remainder of this chapter will define the unit of analysis and the interpretation for analysis.

Unit of analysis: the occurrence of uncertainty and bounded manageability in projects

The case-study chapters (5, 6, 7 and 8) discuss uncertainty and bounded manageability on the basis of the occurrence of features of complexity. They follow a common outline. First, the complexity of the case is described. To provide an idea of the project scope and the environment in which the project took place, project objectives are examined. This provides a first indication of the project's technical complexity. Then, the project organisation is described, particularly who was looked to for delivery of the intended scope. This gives an idea of the project's organisational complexity. Overall, these sections reveal the independent variables of system complexity, as discussed in Chapter 2.

Chapter 3 elaborated on how these independent variables result in uncertainty and, possibly, bounded manageability. But, the way bounded manageability influences project performance depends on how the project organisation deals with the bounded manageability. This "dealing with" will be elaborated based on choices and behaviour found in events in which (potential) bounded manageability occurred (indicated as "occurrences" in the case-study chapters).

The case-study chapters discuss the types of uncertainty that emerged through these occurrences and then identify the manageability dilemmas that emerged in these occurrences as a result of the uncertainties. Due to the grounded theory approach used, there was no preselecting of substantive criteria for the occurrences. They were sought, roughly, in three major project management aspects:

- *Front-end development*. Uncertainties in the engineering design concern ambiguities regarding the definition of the project scope and its requirements. As such, they relate to, for example, technology, innovations and dependence on contractors and suppliers for knowledge resources. All six uncertainties are applicable, but with an expected stronger presence of uncertainties resulting from aspects unknown to the manager (inscrutability uncertainty, inconceivability uncertainty and intention uncertainty).
- *Implementation*. Uncertainties in implementation, encompass the technical and operational aspects of executing the project and concern all six types of uncertainty. They could also relate to all of the distinguished interfaces, such as soil conditions, but also to social aspects in the project environment.
- *Contracting, financing and schedules*. Uncertainties can arise related to the administrative side of project management, such as funding availability and budget management in general and the allowed variability on critical paths.

Due to the lack of substantive preselection criteria, the occurrences were chosen based on two criteria that accommodated the grounded theory approach. Occurrences were included if they met either or both of two criteria:

- Occurrences had or could have had a high impact on performance of the project in terms of cost, schedules, scope delivery, quality or safety.
- Occurrences were mentioned by respondents as influential or crucial to the manageability of the project.

Analysis and deduction for selective coding

For the purpose of learning, the case studies were aimed at generating answers to the question of what the main dilemmas were in the project and how they contributed to potential bounded manageability. Chapter 9 presents the analysis, which has two main components. First, key dilemmas in management of complex underground construction projects are formulated. This is done based on how, according to the empirical study, the way organisations deal with complexity and uncertainty led to manageability or bounded manageability in practice. Managers presumably did not wittingly undermine manageability. It is therefore valuable to understand what trade-offs they had to make that influenced manageability. Second, a few ideas are presented on how these dilemmas interrelate. Third, ideas are formulated on how dilemmas can be dealt with in such a way that a project remains manageable (second research question). These ideas were derived from practices found in the cases and supported by the reference cases, where alternative organisational configurations provided pointers for different practices.

Chapter 10 presents conclusions, answering the research questions.

Exploration of references for further axial coding

Because the empirical study has no statistical value, it could, from a grounded theory point of view, be valuable to find out whether cases that feature fundamental differences in characteristics also have different manageability characteristics. Hence, differences in levels of manageability and organisational set-up were actively sought, to see if these suggest ideas for improvement. Differences in technical complexity were considered straight forward; less complex projects likely being better manageable than more complex projects. Differences in organisational features were considered of interest though, because the basic assumption underlying the research was that bounded manageability develops at the interface between technology and organisation and it is a variable that is strongly influenced by the choices made by a project owner or sponsor.

One case in which little bounded manageability occurred was studied to offer a basis for comparison (Chapter 7) to two that did experience bounded manageability (Chapters 5 and 6). In addition, chapter 8 presents and analyses reference cases that had a fundamentally different organisational set-up. This comparative step may provide insight into possible directions for better manageability practices. The intention was to provide initial ideas to answer the second research question: How can bounded manageability be dealt with in project organisations? It started from the assumption that actors, rather than technology, define manageability; so a deviating actor network might be worth looking at. Indeed, it would be interesting to learn whether conditions or circumstances can be identified that explain this minimal development of bounded manageability.

4.2.2 Data gathering and processing

The discussion in the case-study chapters is based on documentation from the projects studied, news sources which provided chronologies of events, official reports and briefings and meeting minutes (for a full overview, see Appendix III). Interviews were also conducted with people involved in management or in other capacities in project development (for an overview, see Appendix II).

Among those interviewed were members of the project organisation affiliated with the sponsor or owner, the contractor and the design engineer (depending on the organisational configuration of the concerned project). Some had combined roles. Respondents were selected based on their ability to provide information on the topics of complexity and project management. The primary focus was on the role of the sponsor as the main decision-maker and therefore the main actor subject to manageability features. Particularly in the larger projects, project management tasks were divided over several managers, either in different functions or in different phases of the project. The cases' individual complexity and manageability features suggested inclusion of respondents with diverging affiliations. Three main groups can be distinguished:

- *Functional managers*. These are people closely related to the management of the physical work and the technology and in decision-making on these aspects, either related to the sponsor or to the contractors, including engineers and design engineers.
- *General managers*. These are people involved in the general administration of budgets, time schedules, scope and quality – so not directly in technical management or the physical structure. They were concerned mostly with decision-making on managerial issues at the level of the project as a whole.
- *Observers and external stakeholders*. These are people with information about the project, but no direct responsibility in its management.

Different respondents were approached for two main purposes: in-depth information on the features of the project and reflections on strategies pursued in relation to manageability. Information from these sources drew a picture of how such things as ownership and project management were organised and how designs and engineering issues emerged.

To collect the data, semi-structured interviews were held comprised exclusively of open questions. Respondents were asked to explain the technical and organisational characteristics of their project and, in particular, highlight events and mechanisms that were influential for project manageability. One benefit of the use of semi-structured interviews was that they could be geared to the affiliation of the individual respondents. This meant that the interviews and data collected from varying sources became complementary rather than comparative. The interviews were aimed primarily at gaining insight into the projects; not at establishing the "truth" since, as noted, perceptions on matters were expected to diverge between respondents.

The benefit of this method was that respondents reflected on the project from their own perspective and position. They were better-informed on the project than the researcher. This way, questions and answers were less framed by the researcher's theoretical framework and more by the actual events. The purpose was explicitly to learn about the respondents insights, rather than to confirm or measure selected variables, in order not to exclude views that theory has not yet provided. A main downside was that some of the material was less usable, because some respondents were less adept at reflection than others. But this was balanced by the benefit that respondents who did reflect insightfully produced more valuable material than they could have in structured interviews. The interviews focused on the most complex issues that produced the largest uncertainties and bounded manageability in project preparation and implementation.

It was also necessary to rely on written data to some extent. There were topics on which respondents could not or did not want to reflect, mainly because they were sensitive or part of pending lawsuits. In those cases, data were sought in meeting minutes (and on day-to-day decisions if available) and from official investigation reports and briefings, for instance, reflecting on the project organisation or courses of action taken.

Data gathering from document research and interviews centred on the variables introduced in chapters 2 and 3. Table 4.1 provides an overview.

Table 4.1 Theoretical themes and entry points for empirical data gathering.

Chapter	Themes	Entry points for exploration and interview questions
2	Technical differentiation	Exploration of the tasks that challenged the manageability of the project most
	Technical interdependence	Functional interdependence of subsystems Main complexities in project environment
	Organisational differentiation	Number and variety of policy-making institutions
	Organisational interdependence	The role of different actors Coordination effort; dependence on specific actors and interfaces between actors (e.g. contracting relationships)
3	Uncertainty gap	Indicators of the size of the uncertainty gap (consideration of the level of ambition and the competence of the project organisation). The way in which the sponsor attempted to deal with the gap between knowledge required and knowledge available.
	Instability uncertainties	Exploration of the tasks that challenged the manageability of the project most
	Incompleteness uncertainties	Exploration of the tasks that challenged the manageability of the project most
	Inscrutability uncertainty	Assessed competence of involved actors (perception of respondents and proven competence in the field)
	Inconceivability uncertainty	Exploration of the tasks that challenged the manageability of the project most
	Interpretation uncertainty	Sponsor's processing of and decision-making on the basis of input from other actors
	Intention uncertainty	Potential for moral hazard and adverse selection (on the basis of contracting relations and perception)
	Rationalisation attempts	Simplification, heuristics and practical rules used (if any)

The author had an independent role as researcher in each case. Appendix II gives details about the interviews. All case studies were carried out specifically for this research, except the Randstad Rail case, which was commissioned by the project's sponsor, but implemented strictly independently. In agreement with the research assignment, these interviews were confidential (the commissioner had no access to transcripts or interview reports). It is for this reason that only in that case individual references in the text had to be anonymised. A list of respondents, including those of Randstad Rail, can be found in appendix II. All interviews were done individually by the author, except a few for the Randstad Rail case, which were conducted by or with a colleague. Some interviews for the Randstad Rail case were conducted by the author together with a colleague. Some respondents were involved in two cases. Interviews on both were then combined. Also, some respondents were only willing to reply to questions by email or to have the interview done by telephone. All details of the above can be found in appendix II. The interviews in the Netherlands were conducted in Dutch, those in the United States in English and those in Germany in German. The researcher got access to the cases by permission of the project's commissioners. He has been free in approaching respondents in all cases.

Considering the nature of the material, it is probably self-evident that the research was qualitative. Also, as mentioned, these analyses included considerable hindsight observation. This was not too problematic considering the research's explorative nature, particularly since the purpose was to define the key dilemmas in a value-free manner. It was, however, important to prevent hindsight bias based on project performance. The analyses never intended to state that managers could have been aware of certain indicators previous to an event in which these indicators played a role. That would also neglect the impact of luck as a factor in successful project management.

The case-study chapters discuss the outcomes of the research on the themes from Table 4.1. That means features of complexity are discussed based on the uncertainty they evoked for the project, and hence the manageability challenges.

Interpretation: causality

The empirical research links causes and consequences. Project performance represents the consequences and everything else can be considered a cause – or a cause of a cause – of the project performance. De Bruijn (2007) explored the different research methods used by investigation committees, which typically also seek causal relationships. Though not intending to do the work of an investigation committee, the distinctions found among these methods are of major importance. The first distinction is that between a causal approach and a contextual approach. In the causal-casuistic approach, the researcher departs from the consequence or outcome and tracks a path backwards in which one event explains the other. The researcher tries to find a connection between decisions or acts and consequences of these decisions or acts, or where actors have, from a normative standpoint, not adequately executed their responsibilities in the light of later events. The actor making the decision or formally responsible can then be held responsible. Forensic research is usually based on this approach. The explanation of the consequences follows directly from decisions and acts, and those people who made the decisions or committed the acts are therewith held responsible for the consequences.

The above method, however, is largely unable to explain why the actors at the beginning of the chain acted the way they did. To answer that question requires an analysis of the context in which people acted. An alternative to the casuistic approach is thus the contextual approach. Here, the researcher tries not only to explain consequences with causes, but also to sketch the context that provided the background for the cause. This enables the researcher to answer the question *why* a decision was made or an act committed, rather than just explaining who was responsible. Therefore, the contextual management situation (project organisation, available resources, interests) is considered when attending the *why* question. Understanding bounded manageability requires awareness of conditions and circumstances and their impact on actors' behaviour (see also Reason, 1997). This context, which we find at the beginning of a causal chain, often explains why the actors involved did what they did. The current research used the contextual approach, as it did not seek to assign responsibility but rather to explain the variables determining manageability. This corresponds to the grounded theory research method.

A second distinction made by De Bruijn (2007) is that between *backward mapping* and *forward mapping*. In backward mapping, the researcher follows a path from consequence to causes. In many cases, a cause is found that leads to another cause, which caused the cause. The researcher thus ends up with a chain of evidence that explains the consequence. A disadvantage of this method is that the analysis stems from the consequence. The causes are explained from the perspective of the known consequence, rather than from the trade-offs the people and organisations involved were confronted with. This may result in consequence-based bias, which is another reason why this research adopted the contextual approach. Actors' decisions and acts were considered not only in relation to the known end-result, but also in relation to the position and resources of the actor at the time the decision was made or the act committed.

Limitations

The information on manageability can be derived from accounts of actors involved. Yet, these present two problems. First, accounts may be subjective. Uncertainty and manageability are, after all, not necessarily objective; they are also perceptions. That means, for instance, that every actor involved in a project may assess its manageability differently. This depends not only on the organisation one worked for; perceptions may diverge even within a single organisation. Perceptions of manageability are based on heuristics. They do, however, provide an idea of the dilemmas faced. Since these subjective viewpoints often diverge, it is important to emphasise that the purpose of the empirical aspect of this study is to map the dilemmas that resulted from dealing with uncertainty. The empirical research thus illuminates occurrences of complexity that introduced uncertainties into a project. Some occurrences proved extremely sensitive due to pending legal cases and liability issues. On these, respondents were often unwilling to reflect back, and the researcher had to use alternative sources such as minutes of meetings, briefings by the project management and reports from official investigations.

Another problem is that the eventual success or failure of a project may have biased respondents' assessment of its manageability. It is then the project's final outcome that creates the heuristics. For this reason too, no normative assessment is possible, because in hindsight people involved in successful projects are likely to consider the manageability of their project greater. They may be less aware of the dilemmas that underlay their decisions than people who were involved in projects that experienced significant problems. Success might as well be attributed to sheer luck. Managers in some projects acknowledged the complexity of the work they did, whereas managers in other projects were unaware of the dilemmas they faced and the trade-offs they made, because the project's final outcome provided no urge for them to give their earlier deliberations a closer look in retrospect. So, assessments are strongly susceptible to the valuing of a project in hindsight.

Despite the interpretive, social constructionist approach in the current research (Habermas, 1970; Easterby-Smith et al., 2002), this study is less interested in human factors than would generally be expected in social constructionist research. This is because deductions are based as much as possible on objective descriptions of project preparation and implementation processes. This should prevent contamination as a result of personal viewpoints, and has its main value in explanation, rather than proving a hypothesis. In research such as this, it is difficult to speak of "truth", as individual viewpoints provide much of the input. In the current study, the case narratives were considered only perceptions of the truth or accounts of events. Any conclusions drawn therefore must be attributed to the researcher. Again, the focus was to define manageability dilemmas, which are in essence neutral, and not a reflection on performance.

Moreover, the respondents did not start with the same theoretical background as the researcher, which made it particularly the task of the researcher to reflect on project features. Issues that respondents may have considered normal, could still be valuable for reflection by the researcher. A tight framework would exclude from the analysis issues that were unknown to the researcher in advance but are of paramount importance in explorative research. According to Kahneman and Fredericks (2005: 274):

> *"People who make a casual intuitive judgement normally know little about how their judgement came about and know even less about its logical entailments. Attempts to reconstruct intuitive judgements by interviewing respondents […] are therefore unlikely to succeed because such probes require better introspective access and more coherent beliefs than people normally muster."*

Kahneman and Fredericks (2005: 274) suggested instead the use of a heuristic elicitation method in which one group of respondents provides judgements on a target attribute for a set of objects and another group evaluates the hypothesised heuristic attributes of those same objects. This method is not ideal for this particular study for a number of reasons. First, the same information was not available to all respondents, because they were involved in the projects from diverging affiliations. The heuristic elicitation method provides equal information to all respondents. Second, in Kahneman and Fredericks' (2005) studies in which heuristic elicitation was used, the respondents got a very clearly-defined judgement assignment, which would be difficult in explorative research such as this. In the current study, it was not necessarily obvious in advance which issues were important for the manageability of the projects. Third, the elicitation method has primarily been used to demonstrate the existence of heuristics in judgements, rather than to explain how they come about and what impact they have. It is possible that after this study's exploration, follow-up research using the heuristic elicitation method could be fruitful.

The current research focused on the complexity circumstances and the occurrences of complexity that shaped managers' heuristics. This required a restrictive use of subjective data. Where possible, subjective data was supported by other data, particularly documents (e.g., meeting minutes and official investigation reports). The interviews helped in selecting the main issues and considerations faced by project managers.

4.3 Case selection

The cases that guided this study's search for manageability patterns were chosen for their validity. That means they were not a random sample of the whole collection of underground construction projects. The purpose was to detect patterns, which could best be done by looking at projects in which certain features were very profound. This can be compared to a nurse tying off a patient's arm to accentuate the veins before inserting a hypodermic needle. Flyvbjerg (2006: 229) had the following to say about the method:

> *"When the objective is to achieve the greatest possible amount of information on a given problem or phenomenon, a representative case or a random sample may not be the most appropriate strategy. This is because the typical or average case is often not the richest in information. Atypical or extreme cases often reveal more information because they activate more actors and more basis mechanisms in the situation studied. In addition, from both an understanding-oriented and an action-oriented perspective, it is often more important to clarify the deeper causes behind a given problem and how frequently they occur. Random samples emphasizing representativeness will seldom be able to produce this kind of insight; it is more appropriate to select some few cases chosen for their validity."*

Such a case study approach is well suited to the semi-grounded theory approach applied in this research.

An information-orientated selection was made (Flyvbjerg, 2006: 230):

> *"…to maximise the utility of information from small samples and single cases. Cases [were] selected on the basis of expectations about their information content"*.

The cases were chosen to provide both variety and similarity. A certain similarity of complexity was necessary to prevent the course of one project from dominating our search for patterns and to ensure that the cases were in fact complementary. In other words, despite the aim being to assemble information rather than to compare it, the information from the different cases needed to be aligned to some extent. The variety ensured that the study produced more than one pattern of manageability. As this implies, the study results cannot be interpreted as statistically proven. Rather, as mentioned, the research was highly explorative in nature.

A number of case selection criteria were applied. The discussion below indicates whether similarity or variety was pursued with each. Chapters 5 through 8 discuss the various cases. They, too, include materials that are complementary rather than comparative.

The first prerequisite for the projects selected as case studies was that they had to be, at least partly, underground (similarity) to ensure that at least part of the system featured the expected extreme complexity. Furthermore, cases were sought that exhibited strong interfaces with a complex environment, such as a densely built-up area or unstable soil conditions (similarity). Projects in non-complex conditions might have too few technical interfaces. It should, however, be noted that, because of the uniqueness of underground construction projects, complexity is never equal in any two cases. Besides, as mentioned earlier, complexity may include hidden or unknown interactions. Also, different actors may perceive complexity differently, because each has a different level of competence in dealing with complexity. Therefore, manageability was examined not in association with the existence of complexity, but in association with the existence of uncertainty, which we defined earlier as the difference between the information required and the information available (Galbraith, 1977).

Furthermore, projects in different countries were sought (variety), to prevent bias as a consequence of possible typical practices or culture within a country. However, the countries in which projects were selected belong to the same "family" of nations (similarity). Although this was not a comparative study, it did seek to detect patterns of manageability, and if the backgrounds of the cases were too heterogeneous the patterns found might be too divergent to yield joint conclusions. Besides, the study would have little relevance if there were no opportunity for similar strategies to be applied (cf. De Jong, 1999).

Hofstede (2000) distinguished countries based on their policy culture. This concerns, for instance, power distance, masculinity/femininity, uncertainty avoidance and collectivism/individualism. Thus, Hofstede characterised most Western countries as having individualist cultures. Such countries, at the same time, have many complex underground construction projects. Besides, collectivist countries are in many cases countries where the government has substantial power in the kind of projects undertaken, which may blur manageability and the roles of different actors to a greater extent than in other types of countries. To ensure that enough organisational interfaces were found for a proper investigation, this study focused on countries with – to some extent – individualist cultures. These Western countries also tend to be characterised by a medium to small power distances.[1] This is important because in such countries, actors other than governmental institutions were expected to own some of the involved resources and be required for successful implementation. These strong dependencies add to the organisational complexity of projects. Finally, these countries do not tend to display strong differences on masculinity.

From the strong focus on uncertainty in the theoretical framework follows that a culture of uncertainty avoidance is a relevant factor as well. This urged a selection of projects encompassing countries with an uncertainty acceptance culture and those with an uncertainty avoidance culture. Here, it might be interesting to focus on differences rather than similarities. The cases chosen for this study were found in three countries: the Netherlands, the United States and Germany. These countries do not have strong differences on most aspects (similarity). Germany, however, has, according to Hofstede (2000), a stronger uncertainty avoidance culture than the other two. As uncertainty complicates manageability, this suggests the hypothesis that managers in the German projects were less confronted with manageability problems, because their culture of uncertainty avoidance prevents bounded manageability from occurring in the first place. It implies that this study includes both uncertainty acceptance and avoidance.

Chapters 5, 6 and 7 discuss the three main cases. Each case is from a different country, though all feature a public client and each has its own challenges. Bounded manageability may be particularly likely to emerge in large and complex projects if they have public clients, and a public client is the most common situation in large infrastructure projects. Chapter 8 presents a briefer discussion of several projects with different organisational configurations, to explore variances in manageability features and any insights this might provide for better manageability.

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[1] Hofstede (2000) defines power distance as the extent to which less powerful members of institutions or organisations in a country expect and accept that power is divided unevenly.

5. The Hague area public transport infrastructure projects

5.1 Introduction

The first case was found in the Netherlands, in an initiative to enhance urban transport and relieve the nuisance caused by existing transport systems in and around the city of The Hague. From the early 1990s until 2006, local and regional authorities implemented two major projects to improve the transportation networks in and around the city: the Randstad Rail light-rail project and the accompanying Souterrain project, which was built to accommodate the Randstad Rail's intersection with The Hague's busy city centre. Both projects were among the most complex in the city's history. The Souterrain project was approached as a functional part of the larger Randstad Rail scheme. The projects were, in fact, interconnected, though Randstad Rail and the Souterrain had formally separate project managements, and their sponsor and funding situations differed. The projects were, moreover, implemented sequentially. Both project organisations, however, resided under the municipal government of The Hague.

Section 5.2 describes the general background of Randstad Rail and the Souterrain, including project objectives and the set-up of the project organisations. Sections 5.3 and 5.5 examine the main occurrences of complexity in the projects. Sections 5.4 and 5.6 discuss the uncertainties that emerged in the projects related to the manageability dilemmas introduced in Chapter 3.

The data for this case study were obtained predominantly from official documents, including meeting minutes and research reports, alongside the semi-structured interviews carried out in the course of the current research. The main interview topics were configuration of the project organisation, key engineering trade-offs, the occurrence of calamities and the process following calamities to get the project back on track. The research on the Randstad Rail project was done as part of an evaluation commissioned by, but strictly independent from, the client, Stadsgewest Haaglanden (SGH). References to inputs from individual respondents in relation to that project are for that reason anonymised in this chapter. A list of respondents can be found in the appendices. The research on Randstad Rail took place after the eventual opening date. Research on the Souterrain project started when the project was being completed and was finished when it was in service.

5.2 Randstad Rail and the Souterrain project

5.2.1 Randstad Rail programme objectives

The Dutch central government and the regional authorities of the wider metropolitan areas of The Hague and Rotterdam have, since the 1980s, sought to improve public transport services in the southern part of the Randstad conurbation, in the western Netherlands. The Hague and Rotterdam are the major urban centres of this region. To better serve the area with public transport a plan emerged to connect the existing Rotterdam metro with The Hague tram network via existing heavy rail commuter lines. A major benefit of the project would be to improve the cities' accessibility from satellite towns. To this end, a new light-rail system was proposed. It would require restructuring of two existing commuter railway lines operated by the Dutch Railways (NS). Major restructuring would be required on the "Hofplein" line between Rotterdam and The Hague which serviced several satellite towns (Berkel en Rodenrijs, Pijnacker, Nootdorp and Leidschendam). And extensive work would be required on the "Zoetermeer" line, linking The Hague with the satellite town of Zoetermeer. Both lines ran separately from and were redundant to the main intercity railway connections. To connect the metro of Rotterdam to the tram network in The Hague required construction of a new metro tunnel in Rotterdam (the Statenweg Tunnel) and new tram connections in The Hague. The configuration of the lines in the centre of The Hague was such that a subsurface crossing would be required.

Originally, the local and regional authorities wanted to build a full metro system. But the investment required for this was far beyond the planned budgets. Another option was to terminate the new Randstad Rail lines at the existing heavy rail stations, requiring travellers to change to other modalities for the remainder of their trip. Local authorities opposed this option, however, stating that it afforded too little improvement over the existing situation.

The only alternative that did fit the available budgets was a somewhat fragmented system that would connect to both the metro and the tram.[1] Linking existing networks meant that the new Randstad Rail modality would have to comply with three different rail systems: tram, metro and heavy rail. Light rail would be able to do this. There had been good experiences with light rail elsewhere, for instance, in some German cities. However, its use was a relatively new idea in Dutch public transport.[2]

5.2.2 The Souterrain project objectives

With the Randstad Rail programme in mind, the Municipality of The Hague foresaw a worsening traffic situation in its city centre. A large intersection (where the Spui crosses Kalvermarkt/Grote Marktstraat) had been a problematic traffic node for some time, since trams, cars, bicycles and pedestrians crossed here in four directions. The addition of frequent Randstad Rail trains would make the situation unmanageable. Therefore, construction of a tunnel for trams was proposed in the city council of The Hague.[3] At that point, many authorities were already committed to the Randstad Rail scheme, though definitive approval and central government funding were only granted a number of years later.

The scope of the tunnel project was extended twice. It started as a basic, relatively short tram tunnel under the Spui-Kalvermarkt/Grote Marktstraat intersection. The first extension was below the Grote Marktstraat. This important shopping street was too busy to accommodate the street-level addition of Randstad Rail. Therefore, the tunnel was extended underneath the Kalvermarkt and Grote Marktstraat to a total length of 1,250 metres. It would include two stations: Spui and Grote Markt.

The second extension was the addition of a two-storey underground car park. Now that a tunnel was to be excavated anyway, an opportunity was seen for creation of additional, short-term parking in the city centre. The added cost of the car park could be earned back with the sale of an operator's concession. Also, the car park satisfied abutters, most of which were department store owners. They feared lost income as a result of the works for the tram tunnel and wanted to see this compensated by the advantages of extra parking spaces. Besides, the project could now be made part of a city development plan for reconstruction works in downtown The Hague.[4] The reconstruction programme became one of the key projects in the central government's Fourth National Spatial Plan.[5] This made it eligible for central government funding, independent of the political process involved in the building of Randstad Rail, which continued to drag on.

The additions made the system to be created more than just a tram tunnel. The car park, as added functionality, had not been part of the planned functionality of Randstad Rail, so the tram tunnel was officially named "Souterrain Kalvermarkt/Grote Marktstraat".

Due to this uncoupling and insertion of the Souterrain project into a central government urban restructuring programme, the Souterrain project was approved and built earlier than the rest of the Randstad Rail programme, which was not eligible for a grant under the same scheme. Moreover, during the 1990s, some important aspects of the Randstad Rail project had not yet been decided on. For example, it was still unclear how to connect the old heavy rail tracks with the tram and metro grids and what kind of vehicle to use. Also, the ambitions of Randstad Rail were larger than the foreseen budget that the Ministry of Transport and Water Management made available for that specific project. It was clear, however, that whichever alternative was chosen, a tunnel under the city centre would be needed, and the Souterrain would be useful in and of itself. So the Souterrain could safely be built, taking advantage of the momentum of the Fourth National Spatial Plan.

Approval for the Souterrain project came in 1993, while approval for Randstad Rail would take another eight years. Construction of the Souterrain started in 1996, well before approval was obtained for Randstad Rail. In the end, however, the Souterrain was opened only two years prior to the rest of Randstad Rail, mainly due to implementation problems.

Cutting apart Randstad Rail and Souterrain development, and incorporating the Souterrain project into the downtown restructuring programme for The Hague optimised the funding opportunities. The uncoupling improved political manageability, particularly of the Souterrain project. It also created the chance to realise the tunnel earlier than the rest of the system, providing relief for some other urban problems without dependence on the viscous political process that preceded approval of Randstad Rail. Finally, it spread the implementation works, preventing a large strain on the municipality's resources, though this was not mentioned explicitly as a motive.

5.2.3 Randstad Rail project organisation

The Haaglanden regional authority (SGH) was the client of the Randstad Rail initiative in the urban area of The Hague. SGH is a regional cooperative body that includes all the municipalities in the wider metropolitan area. SGH shared ownership of the Randstad Rail project with its counterpart in the Rotterdam area, as part of Randstad Rail was to be located within the jurisdiction of that regional authority. Legally, the division of responsibilities lay at the geographical border between the regional authorities. In practice, the Rotterdam authorities took care of some of the functional tasks in the Haaglanden region and vice versa.

Apart from the division between Rotterdam and Haaglanden, there was also a division of ownership and responsibility within the Haaglanden area. Specifically, the tram tracks in downtown The Hague fell under the responsibility of the Municipality of The Hague, whereas those outside the city centre fell under SGH's responsibility. This reflected the city's traditional responsibility for tram infrastructure. As tram tracks are physically embedded in the city's streets, the municipality considered it undesirable for another party to own the tracks.[6]

The Haaglanden regional authorities later delegated implementation of the Randstad Rail project to the Municipality of The Hague, its largest constituent. SGH founded BORR[7] as oversight committee. The municipality founded PORR[8] for the project management. The municipality thus became responsible for implementing the whole project within the Haaglanden region, including in other municipalities surrounding The Hague.[9] The Rotterdam authorities did the same for the Rotterdam part, but delegated all tasks to RET, which was to be the designated light-rail operator. In the Haaglanden region, only the acquisition of rolling stock was done by the proposed light-rail operator, HTM (The Hague's public transport company). In The Hague, a concession could not be granted to HTM immediately without public tendering, as HTM had been privatised shortly before (unlike RET). Eventually HTM did get the concession, but only after a special exemption was granted by the central government. This permission was subject to long debate and negotiations and came only a year before completion.

The reason why SGH delegated implementation of the project to the Municipality of The Hague was twofold. First, SGH lacked the engineering staff necessary for such a technically complex project. Second, it did not have the financial means to bear all the risk linked to such a project. The Municipality of The Hague did have these capacities. As it had been constructing tramways for decades, it was considered the best party for project management.[10] The project was transferred on the basis of a design-build-finance contract, including all risks and possible losses or surpluses.

One reason why the Municipality of The Hague accepted the risk was the proposed transfer to the municipality of the complete central government subsidy for the project as a lump sum. The Ministry of Transport and Water Management awarded a €413 million grant for the Haaglanden part of Randstad Rail.[11] The four Haaglanden municipalities with planned rail connections added another €33 million, for a total budget of €446 million. This did not include the Rotterdam part. The Municipality of The Hague considered the subsidy ample and hoped to be able to transfer eventual remainders to other municipal projects.

Randstad Rail was largely conceived within the municipal organisation. It was initially a project within The Hague's Urban Development Department, an administrative unit focused mainly on political processes and contacts with other governmental authorities. The project was transferred to the City Management Department after the final city council decision to move forward with implementation. The City Management Department is an engineering-orientated department.

5.2.4 Souterrain project organisation

Initiation of the Souterrain project was similar to Randstad Rail. Its preparation started within The Hague's Urban Development Department, and it moved to the City Management Department after the city council's decision on July 1st, 1993, to implement it.[12]

Costs of the Souterrain were estimated at approximately €127 million, of which €90 million would be provided by central government via the Ministry of Transport and Water Management. Until the definitive design phase was reached in 1994, the Souterrain had been a separate project within the City Management Department. After that, it was coupled with the Konings Tunnel project, which unlike the other two projects, started in the City Management Department.[13] Both projects were part of reconstruction plans for the city centre. The municipality hoped to make the management of both projects, which were considered rather comparable, as efficient as possible.

Both were to be managed by a single project organisation: the City Centre Tunnels Project Group (PTC = Projectgroeg Tunnels Centrum). Specialist tunnel engineering expertise could thus be applied to both projects, and this would be more efficient than establishing separate project organisations for each. However, this did lead to expectations about similarities between the two projects that did not materialise. For instance, the roles of the project executives and Rijkswaterstaat, the Dutch public works department, were incorrectly assumed to be analogous. These expectations were often unjust, as the project organisation configurations were different.

Rijkswaterstaat did play an important role in development of the Konings Tunnel, but it stayed much more on the background in the Souterrain project. However, the municipal managers did not fully appreciate this. They considered the engineering design reviews conducted by Rijkswaterstaat as constituting a full check, while Rijkswaterstaat was gradually assuming a more detached, background position. So despite their coupling, the projects were not fully interchangeable.[14]

Contracting

When The Hague started the Souterrain project it had never before implemented a project of such complexity.[15] In consequence, in 1992 the Urban Development Department hired a specialist consultant to serve as design engineer and project executive. The municipality selected SAT Engineering for this job. SAT was a joint venture of the engineering firms Grabowsky & Poort, D3BN and Jongen. These firms had mainly been involved in residential and office buildings, but wanted to gain a foothold in the tunnelling market in an era when Rijkswaterstaat was withdrawing more and more from the design and management of government-subsidised infrastructure projects.[16] SAT's main assets were its innovative design ideas for preventing nuisance, its sensitivity to municipal politics and its financially attractive bid, which underlined its seriousness about gaining a position in the tunnelling market, despite its atypical background and limited experience.[17]

SAT Engineering suggested several contract forms for project implementation. Considering the large number of ancillary conditions related to the project environment, it suggested first selecting a construction contractor with specific knowledge of design, implementation and unit rates. After selection, the design and specifications would then be elaborated in a construction team.[18] After the project was transferred to the City Management Department, it decided, in line with an external consultancy, to choose another contract form though.[19] The main reason stated was the greater expense associated with the originally proposed contract set-up, since it basically meant that the engineering departments of two different firms or consortiums would be involved from an early stage.[20] Another reason to reconsider the contract form was caution of such a set-up among municipal legal advisors, due to possible ambiguities regarding responsibilities and liabilities. SAT Engineering was now to be exclusively responsible for the engineering design, and the construction contractor would be hired only for physical implementation. There are diverging views on SAT's competences as a sole designer of tunnel systems. Some considered it a suitable consultant to create an innovative design,[21] while others would have preferred a more experienced design engineer/executive.[22]

The transfer of the project within the municipality created an organisational interface.[23] Such an interface can threaten continuity and the tacit knowledge acquired within a project and the policies initiated. This was in fact observed in several elements of the project. In the Souterrain project, for instance, the City Management Department was not involved in the tender for the engineering design and executive director functions, although it would be the responsible actor for project implementation. This interface complicated the management on the sponsor's side.[24] The City Development Department's choice for SAT Engineering was questioned, in hindsight (after completion of the project), by at least one PTC project manager within the City Management Department.[25] Furthermore, the City Management Department was not involved in drawing up the basic project scheme, which was expanded when the two-deck car park was added, which made the project more complex. This may explain, at least in part, why the increased complexity of the design apparently did not figure as an important issue in the decision to expand the project.

Unlike the Souterrain, the engineering bureau of the City Management Department itself designed the Konings Tunnel (the project to which the Souterrain was coupled within the

PTC organisation). In that project the department itself also hired the project executive, Articon, to oversee implementation.[26] The Ministry of Transport's engineering department in Rijkswaterstaat had a relatively strong advisory role in this project, because it was considered a stretch for the municipality's engineering capacities.

For the same reason, Rijkswaterstaat considered the design of the Souterrain too large a challenge for the municipality's engineering bureau. For the Souterrain project, it had insisted on a specialist designer.[27] Rijkswaterstaat's strong involvement in the Konings Tunnel project, albeit under different circumstances, had raised expectations within the municipal organisation about Rijkswaterstaat's depth of involvement in the Souterrain project. In that latter project, however, the Rijkswaterstaat engineering bureau was much less prominent, with its activities limited mainly to overseeing expenditure of the central government's subsidy.[28] In the aftermath of the calamity that eventually befell the project, respondents did note that they had had different expectations of the engineering bureau's involvement. Or they said they were surprised that Rijkswaterstaat had not objected to the fundamental risk (or flaw) in the grout arch design, but had gone along with the design in the end.[29]

The combination of the design engineer and executive roles in the Souterrain project, unlike the Konings Tunnel, may have given PTC unrealistic expectations of SAT's work. Each change or suggestion from the contractor that had to be calculated placed SAT's staff under pressure. PTC also thought that SAT might execute more controls on the contractor, but SAT was in it for a limited number of hours and had to reduce its effort where it could, without undermining the project.[30] Combining design and oversight in one actor also meant that the time and effort spent on these roles were interchangeable.

When the construction work was tendered, TramKom, a consortium of the construction firms Ballast Nedam, Strukton and Van Hattum & Blankevoort, bid very low and won the job. The consortium wanted the work very much.[31] The Ministry of Transport wanted to adjust its subsidy to the advantageous outcome of the tender, but PTC warned of the possibility of additional costs as a consequence of the tender result.[32]

In the following phase, some aspects of the division of responsibilities remained unclear, particularly the task of engineering and responsibility for risks. In some cases, TramKom was asked its opinion on engineering issues. Once given, a request to elaborate regularly followed. TramKom refused, since it was not the responsible design engineer, and its engineering capacity had not been commissioned by PTC or SAT. This looking in askance at TramKom may have been an excrescence of PTC's initial intention to include the construction contractor in the designing.[33]

Table 5.1 presents the tasks and actors in the Souterrain and Randstad Rail projects.

Table 5.1 Tasks and actors in the Souterrain and Randstad Rail projects.

	Souterrain	Randstad Rail
Client	Municipality of The Hague	Haaglanden regional authority (SGH), executive: BORR
Owner	Projectgroep Tunnels Centrum (PTC)	Municipality of The Hague (PORR)
Design engineer/project executive	SAT Engineering	Municipality of The Hague (PORR)
Contractor(s)	TramKom (Ballast Nedam, Van Hattum & Blankevoort)	HTM, Siemens, Alstom, WBN, BAM, etc.
Operator	HTM	HTM

5.3 Occurrences of complexity and uncertainty in the Randstad Rail project

Implementation of the Randstad Rail project was quite successful until the time came for the actual conversion works, to switch over from the old systems to the new. The early days of operation, too, were plagued with problems that revealed the highly complicated preparation and realisation trajectory that had taken place before. The conversion works could not be completed in the short time period planned. Opening was therefore delayed. Soon after opening, there were regular disruptions. In addition, there were four derailments, the fourth injuring seventeen travellers. Afterwards, the Transport Inspectorate shut the system down. It was reopened only a year later.

Many people linked the implementation problems to the chaotic conversion and testing and trial period. A huge number of works had to be done in parallel, by numerous different contractors within a very short period of time. This resulted in a scheduling and coordination effort that was hardly viable, once contingencies began to flare up on the ground. A series of manageability-related occurrences are discussed below, in which the six uncertainties discussed in Chapter 3 were manifest.

5.3.1 Occurrence I: Version control issues

In the preparation phase, the project scope changed frequently. Yet, system integrity demanded that all parties worked with the same version of the terms of reference. The first official version of the terms of reference for Randstad Rail already differed in a number of places from the grant request, based on which the Ministry of Transport provided its subsidy. Afterwards, too, the terms of reference constantly changed but were not consistently kept up to date. Managers in the project organisation developed coping behaviour to deal with this. For example, they stuck to agreements made in the project management team. They then instructed subcontractors in more detailed and elaborate specifications. There was no common document to refer to, so management was required to execute extensive control, creating incompleteness uncertainties.[34]

5.3.2 Occurrences II and III: Problematic conversion with difficulty in the test and trial period, disruptions and derailments

Occurrence II: Adverse weather conditions and request for a schedule extension

During the first phase of the conversion works, problems occurred because a 10 kilovolt power cable burst out of its sheath due to the exceptionally warm weather in July 2006. The next month was exceptionally wet, leading to various schedule-threatening setbacks, finally delaying completion.[35] These are typical examples of instability uncertainty. The conversion also included the test and trial period. The tests and trials went remarkably well, considering the numerous disruptions that had taken place in the previous period. After opening, though, the disruptions returned. The switches were the main problem.[36]

Conversion of the existing tracks, installation of new systems and test and trial runs were all scheduled to take place in a mere six-week period during summer, when traffic was light. Ultimately the installation of an electronic safety system was added to the works, and the conversion, test and trial period was extended to three months. But still, some project managers considered the period too short.[37] Relatively late, the need to replace track on the Zoetermeer line was discovered, though this had not been part of the original project scope. The time extension was usurped almost completely by its execution, and no other works could be done on that line in parallel. So effectively very little progress was made on that section in the period. Engineers therefore advised extending the conversion period again. The managers at BORR requested information on where scheduling problems were expected, but the engineers could not be that specific. Their concerns about the ability to deliver on time were based on the tacit knowledge they had developed in previous projects. BORR management rejected the request for an extension on this basis.[38] It perceived the situation differently and at some point even admonished the engineers for the extra slack they seemed to be trying to obtain (interpretation uncertainty in relation to assumed intention uncertainty). The project managers of sponsor SGH and the manager within the Municipality of The Hague had a pivotal role between decision-makers and implementers. They sought to balance project management values, but lacked the ability to make formal decisions on them.

Occurrences III: Disruptions and derailments

There were four derailments within a month of the start of Randstad Rail operation. Two occurred at almost the same place, near The Hague Central Station. One was in a bend at Ternoot, and the last was at a switch complex near Forepark Station. The last two happened within a timespan of twenty minutes. The derailment at Forepark wounded seventeen passengers, which was the reason the Transport Inspectorate halted Randstad Rail operation. This last derailment took place while the traffic-handling centre was immersed in dealing with the earlier derailment at Ternoot. During the handling of this derailment a vehicle broke down in Pijnacker and had to be returned to the railway yard in Leidschendam. One of many signalling disruptions at Forepark occurred right at that moment, so the vehicle had to make several traffic centre-controlled manoeuvres through red signals to arrive at the shunting yard. In one of these manoeuvres the train broke a switch that appeared to be in the wrong position. But according to the specifications, it needed to be able to be opened by driving through. Neither the driver nor the control centre operator noticed the failure of the switch. After the train had passed, the next train from The Hague Central Station derailed on that specific switch. Later, it turned out that the switch positioning device wasn't functioning properly, as it had not detected the failure position. The switch may have been damaged during the conversion period, as there was no full control over activities, suggesting a typical inconceivability uncertainty.[39] It took eleven months before Randstad Rail reopened.

The most persistent problems, which kept disrupting rail service, occurred in the connection between the switches and the electronic safety systems. Both used proven technologies, but had different suppliers, neither of which considered their product the cause of the difficulties. It finally emerged that the interface software between the two subsystems was new and not functioning properly. This problem was understood only in hindsight and, hence, represents an inconceivability uncertainty. This was one of the problems that kept the system out of service for almost a year after the initial opening. Most problems were resolved after an update.

5.3.3 Occurrence IV: Specification issues (super-elevation specifications and abrasive wear)

The investigation of the incidents resulted in discovery of several technical problems that had previously been unknown. The derailments near The Hague Central Station were caused by abrasive wear of the rail bars. This phenomenon had never before been seen in The Hague tram network. The derailment at Ternoot was caused by distortion of the track as a result of super-elevation of the outer rail, which is necessary to receive centripetal force. It was known beforehand that this newly renovated bend did not comply with the specifications of the new light-rail rolling stock, as the tender for rolling stock had taken place rather late. It was, however, calculated that problems could be prevented with a minimum speed of 50 kilometres per hour. This speed could in practice not always be maintained in that bend, as it transpired, due to a signal immediately beyond the corner, which was sometimes red. Managers took a calculated risk here, which essentially makes it an incompleteness uncertainty. However, as unexpected abrasive wear occurred here as well, a train derailed from almost a standstill.[40] Since the phenomenon of abrasive wear had been unknown, this particular aspect could be called an inconceivability uncertainty.

The problem recurred during the shut-down period. This time, it happened on the Zoetermeer line, which was still under construction. The construction contractor had to outline the tracks before the norm for distortion tolerance for light rail was known. It therefore used ProRail's norm for heavy rail which had previously applied to this former heavy rail section. HTM used a stricter norm for its trams, possibly for maintenance reasons. The Transport Inspectorate ultimately demanded the use of HTM's norms, meaning that the tracks as built, could not be used. The client SGH and the Transport Inspectorate got embroiled in a persistent disagreement about this, finally leading the Transport Inspectorate to accept the norms as-built, providing certain that conditions were met.[41]

5.3.4 Occurrence V: Many scope changes

Throughout the preparation process for Randstad Rail some functional requirements of the system appeared impossible to meet with existing light-rail technology. Other changes in the technical configuration of the system were thought to be needed as well. For example, The Hague tram, the Rotterdam metro and the conventional heavy railways all had different voltages, requiring "downchoppers" on the trains. At some point it was concluded that power could not be drawn from the national railway infrastructure manager ProRail, which meant that Randstad Rail would have to build its own power stations. A whole new power supply system was therefore added.

All these changes to the terms of reference could be realised within the margins of the project budget, because of the ample subsidy and favourable tender results. The lump sum character of the contract did provide an incentive for The Hague to try to fend off scope changes. However, an alderman of The Hague was both project sponsor – representing The Hague in the SGH board and drawing up plans, schedules and terms of reference for the project – and manager, as the Municipality of The Hague had taken on implementation of the project.

Scope changes were abundant. The peculiar sponsor-manager position prevented interpretation and intention uncertainty issues, but similar problems resurfaced in the relationship between the municipality and other parties. In addition, the line to Zoetermeer would need to be replaced within a couple of years for maintenance reasons. It was judged far less disruptive if this replacement could be done before operation, so it was decided to move this work forward and execute it during the conversion period – though formally this was not a scope change, because this work was not originally part of the project.

Despite the optimisations realised, the scope changes did lead to a number of managerial problems that the decision-makers did not foresee when making trade-offs in each individual case. These could, strictly speaking, have been known. The first pertained to the rolling stock, which set the technical conditions for the infrastructure and vice versa.[42] The project organisation decided to make the infrastructure leading, but in some cases this generated specifications that could not be attained with the rolling stock available on the market. Most of these changes can hence be considered a result of incompleteness uncertainty.

Second, tailoring was challenged by the fact that responsibility for both systems was split between the project organisation of the Municipality of The Hague and operator HTM. The project organisation within the municipality considered the programme too large to tender in one piece. It therefore cut the works into pieces, issuing different contracts.[43]

Third, coordination of the construction contractors for these works proved difficult. Different departments of the project organisation managed different contracts, sometimes also using different versions of the terms of reference. As a consequence, interface problems occurred between the different contractors' works.

Fourth, almost all changes meant that additional work had to be done in the short conversion period. This period was only extended once, however, from six weeks to three months. The decision for this extension was made to include an electronic safety system that could not be installed before termination of heavy rail operations. It was prior to the discovery of the need to replace the track on the Zoetermeer line though. That discovery came a year before the conversion, along with the knowledge that the work itself would take six weeks' time to complete. But it did not lead to an additional schedule extension. As a consequence, the three-month conversion period was characterised by major coordination and oversight challenges. There were so many construction firms on the tracks at the same time, that they interfered with each other's work.[44] The project management team (PORR) did not grow in step with the expanding coordination effort though. Nor did it decide on scope aspects, which were determined by the political administrators in the administrative board of the client (BORR).

The decision-makers, who were political representatives, let the optimisation of functionality and short implementation time prevail over, particularly, technical certainty and quality. They also extended the scope of the project regularly, adding for instance, an electronic safety system and a new power supply system, changing switches and replacing a considerable part of the track, while extending the conversion period only once. Operational managers mentioned the potential manageability problems this would cause. But they did not succeed in convincing the politicians to approve a time extension, as seen in occurrence II.

Gradually, differentiation grew as various systems were added, and interdependence increased as well. For instance, the signalling and newly added safety systems were highly interrelated. With this, the coordination effort of project management grew. As a result, the incompleteness uncertainties were gradually transformed into inconceivability ones.

5.3.5 Occurrence VI: Variety among and interfaces between works and actors

The Randstad Rail project had a rather complex organisational structure. This was the result of the dispersed administrative responsibilities in the southern Randstad conurbation and of ambiguous formal responsibilities and less formally confirmed competences of the different actors involved. The diversity of the project confronted the project organisation of the Municipality of The Hague with a rather difficult span of control problem. The highly varied works of the functional managers were difficult to coordinate, which jeopardised the coherence of the system.[45] This manageability problem occurred both within the project management organisation at the Municipality of The Hague and between the different actors involved in project preparation and implementation, particularly SGH, The Hague and HTM.

The Randstad Rail project exhibited high variety too. It comprised not only the construction of infrastructure but, for instance, also the acquisition of rolling stock, with the obvious need for the infrastructure and rolling stock to match. For the section between The Hague and Zoetermeer, for instance, new rolling stock with low floors (matching the platform height of The Hague's tram system) was to be bought from Alstom. For the Rotterdam-The Hague section, however, existing Bombardier trains, which were also used on the Rotterdam metro network, were to be used. One section, used by both trains, was to have platforms of two different heights.

The larger the variety and the more numerous and complex the interfaces, the larger the span of control required. The Randstad Rail project, indeed, was a remarkable assembly of interrelations and interdependencies. Many different subsystems that had to interact were managed by different actors. Different managers were responsible for the various subsystems, but there were no managers responsible for the interfaces between subsystems. Communication was often poor and different actors had diverging understandings of tasks and responsibilities.[46] Most uncertainties were of the incompleteness kind, since they could have been avoided with full knowledge of each other's systems and responsibilities.

The connectivity of rail and rolling stock proved uncertain, partly because the specifications of the rolling stock remained unknown for quite some time. It was therefore unclear how they would relate to track specifications. Acquisition of rolling stock was rather late, because there was persistent uncertainty about whether client SGH could give the operation concession to operator HTM without a public tender. It was also uncertain to what extent the existing track's deviations from the specifications of the rolling stock were troublesome. The strongly differentiated network of organisations – including the municipality, HTM, switch and switch mechanism manufacturers, rolling-stock manufacturers – in which trade-offs were made and constraints set for other parties, resulted in a whole series of incompleteness uncertainties. These were imbued with the ample tacit knowledge on each individual subsystem available within each individual actor's organisation.

Kazanjian (2000) noted specialist engineers' tendency to focus on their own specific subsystems rather than the effect of their subsystem on other subsystems. It is also much easier to specialise in a subsystem than in interfaces between subsystems. As a result, the interfaces may be left unattended. Several examples were found in Randstad Rail:

- Three different organisations were responsible for infrastructure and rolling stock, and it appears they were not always able to get the two matching (TNO, 2007). The problems with the interfaces were not limited to technical systems. Responsibility for the Randstad Rail tracks was divided between the Municipality of The Hague (for the track outside the city) and HTM (within the city). The calculated risk that HTM took at Ternoot, where the specifications of the infrastructure and rolling stock did not match, was known neither to the project organisation of the municipality nor to project client SGH.
- Regular disturbances occurred in control of the switches. Different suppliers were responsible for the switches and for traffic management. Both used proven technology. The interface between the two, however, was unproven, though neither supplier felt responsible for this.
- The heavy rail infrastructure management agency, ProRail, did not want to be involved in the application of some specific electro-technical systems and therefore ignored certain specifications in the terms of reference.[47]

Complications also occurred in dealing with the disruption and derailment events described earlier. Responsibilities for different sections of track were divided between SGH (outside the city) and the Municipality of The Hague (inside the city). The time it took to find the cause of the numerous service disruptions and derailments, and the time it took to get the system working after it had been shut down, all indicate how difficult it was for the engineers and managers to understand the interfaces and how many unknowns were involved. This is typical incompleteness uncertainty.

The differentiation and interdependence, both technical and organisational, led to interpretation uncertainty: specialists understood the system, but the managers pasting system components together did not, at least not to the same extent. This bounded rationality in trade-offs, because the unknowns allowed room for interpretation while other values, such as time, often imposed a clearer and more objective constraint. For instance, there was a fixed opening date. The latter therefore gained more prominence. This is typical interpretation uncertainty.

The above demonstrates that differentiation and interdependence were important sources of incompleteness uncertainty, which can deflect individual actors away from the common effort and motivate them to try to optimise a subsystem individually. This could lead to interaction-driven issues, hence feeding occurrences of intention and interpretation uncertainty.

5.3.6 Occurrence VII: Evasion of overarching responsibility

There were serious uncertainties in the project management's interactions with ProRail, the Ministry of Transport and HTM. This led to all kinds of strategic behaviour, such as HTM putting little effort into producing specifications for wheels and rails, because it did not know with certainty that it would get the management and operation contract for Randstad Rail. Similarly, ProRail refused to sell traction power to Randstad Rail and to pay a "new for old" maintenance fee. Much of this behaviour resulted from difficult interdependences with other markets and political issues, such as the position of conventional rail, energy and privatisation of local and regional public transport. Eventually, the evasion of overarching responsibility for the end result was predominantly a matter of intention uncertainty: the sponsor had unrealistic expectations of the extent that other actors would put effort and goodwill into pursuit of a common goal rather than letting their self-interests prevail. All this complicated the development process and forced actors to find solutions within narrowly set conditions, rather than enabling a search for the optimal solution.

5.3.7 Occurrence VIII: Problematic transfer of old systems

Various externally originating uncertainties occurred, mostly related to the fact that systems were transferred from previous owners, particularly from ProRail, the national railway infrastructure manager. This generated, for instance, the unexpected cost of a shunting yard for which a foreseen financial contribution for maintenance from ProRail did not materialise. It also meant that a terminal at The Hague Central Station was unavailable, because owner ProRail claimed the tracks for heavy rail operations. ProRail also refused to temporarily provide electricity to the Randstad Rail grid, requiring Randstad Rail to build its own power supply, further piling up the amount of work that had to be done.[48] ProRail attributed this to a new energy law prohibiting resale of energy. But others involved put it down to unwillingness, making it an intention uncertainty.[49]

Then there was the unknown status of the tracks in the Zoetermeer line, which were to be transferred from ProRail. Uncertainties about them remained even after measurements, because it was unclear what tolerance for geometrical deviation the light-rail rolling stock would allow.[50] This classifies it as incompleteness uncertainty.

5.3.8 Occurrence IX: Hiccups in drawing up of terms of reference

The complexity and novelty of Randstad Rail confounded its management. The initial goals in the terms of reference were ambitious, and could not be achieved under the existing conditions. It was difficult to adjust the terms, however, because the functional requirements of Randstad Rail had been set politically. The origin of the problem lay in the novelty of the system, combined with the limited expertise of the available managers (incompleteness and inconceivability uncertainties), the strong influence of political representatives (particularly the alderman of The Hague) in the definition of the functional requirements (with a potential for interpretation uncertainty) and the poor involvement of specific parties, such as operator HTM due to the continuing external negotiations on the possible requirement for a tender (intention uncertainty).[51]

Both technical and organisational complexity were such that uncertainties remained unresolved. Role conflicts then arose between various actors, such as HTM and The Hague’s project managers and between The Hague’s project managers and the administrative board.

HTM, the prospective operator of Randstad Rail and the most knowledgeable actor on operational and rolling-stock aspects could not be involved in drawing up the terms of reference, because that would have disqualified it from bidding on a possible tender – as such prior involvement would compromise a level playing field among bidders. SGH officially had to tender the operation concession – though negotiations with the Ministry of Transport later made private contracting possible after all.[52] This segmentation in the organisation of the project injected additional difficulties into Randstad Rail management. Such segmentation increases the chance of intention uncertainty. For example, why would HTM feel responsible for the end result if, ultimately, a competitor may be the one benefitting from the effort? This potentially led to suboptimal solutions.

5.3.9 Occurrence X: Novelty challenges safety testing

Light rail was a new transport modality in the Netherlands, so no regulations or standard operating procedures were available for the system. The Ministry of Transport could not provide Randstad Rail with a framework of reference or regulations, just a bag of money. This applied particularly to the test and trial procedures, in which incompleteness uncertainties emerged. Norms and guidelines that the Ministry of Transport had drafted for light-rail development, were established parallel to, and partly based on, the Randstad Rail project itself.

Meanwhile, the Transport Inspectorate was changing its oversight methods from norm-based visual or physical controls to procedural controls backed by safety case studies. This implied not only that no norms were available, but also that safety assessors had no reference that they could use in their work. Norms and procedures were either developed discretionarily or taken from existing, partly analogous systems (metro, tram, heavy rail), on the basis of familiarity with those systems. The trial period was set as three days' rush hour service. A brief trial period was convenient because of the early planned opening, just a few days later. The project's safety assessor and management developed their own method to evaluate the functioning of the system during the trial period.[53] This corresponds with Wynne's (1988) theory of *unruly technology*.

5.3.10 Occurrence XI: Premature reallocation of budget

As the conversion period approached, a budget surplus emerged. This was thanks to considerable windfalls during the preparation and implementation phase, as favourable market conditions led to relatively cheap contracts. This was an instability uncertainty that turned out favourably. It did, however, lead to the substantial scope changes in the preparation phase. These were optimisations from BORR's point of view, but manageability issues for the engineers. The different perspectives suggest interpretation uncertainty.

But there was more. The lump-sum character of Rijkswaterstaat's grant enabled the Municipality of The Hague to reallocate moneys to other projects. The surplus, however, included various incompleteness uncertainties, some of which were said to be more like certainties, because they were part of the scope and therefore bound to happen.[54] When, briefly before the start of the conversion period, a new mayor and aldermen entered office, the financial situation of the project was presented as advantageous. Later, when setbacks did occur (mostly instability-related), the surplus had already been reallocated. The €12 million gap then had to be filled from municipal funds. The responsible alderman stepped down, even though he had not been in charge of budget management and reallocation in the most crucial days of the preparation.[55]

5.4 Uncertainties in Randstad Rail

5.4.1 Manageability problems stemming from complexity-related uncertainties

This section will analyse for each occurrence what manageability problems emerged from the explained uncertainties and the dilemmas related to these problems.

Occurrence I: Version control issues developed as a result of the many activities that had to take place in parallel (the considerable difficulty involved meant a large *uncertainty gap*) by large number of involved parties (high *segmentation*). First, this could have been taken care of with a better management configuration from the start. It could also have been avoided with fewer actors and more slack, but that would have implied lower ambitions.

Occurrence II: The time pressure during the short conversion period eventually boiled down to a dilemma of whether or not to extend the conversion period – even before the adverse weather conditions came to pass (*dynamics*). The bar was set unrealistically high, because managers on the client's side had put substantial effort into optimising the system (*uncertainty gap*), but their optimisations and additions had led to little observable change in the scheduling of the works. The client had decision-making authority, but most information was with people on the owner staff, such as engineers and project execution managers (*value variety, information asymmetry*). In making trade-offs regarding the scheduling of the conversion works, the managers on the client's side sought to *rationalise* their decision-making by only considering objectifiable input. The alternative would have been to tone down the ambitions regarding completion date and allow for more slack, even though the actors that requested this could not provide substantiation.

Occurrence III: No explicit trade-offs were made on the disruptions and derailments, because there was no dilemma. The events' occurrence could be understood only in hindsight. Managers and engineers had not been aware of the possibility of the occurrences. In hindsight, one could say that the chance of these events might have been smaller in a less ambitious scheme; that is, a scheme in which the total system was less fragmented or the functionality of the different parts less integrated (*uncertainty gap*). But due to the particular origin of this project, that would probably have implied the project would have been impossible.

Occurrence IV: The abrasive wear issue was an inconceivability uncertainty and could not therefore have been part of earlier considerations. With regard to the incompleteness uncertainty of the super-elevation, where a calculated risk was taken, the possibility of failure could have been known (large *uncertainty gap*), but aspects had been overlooked that cannot specifically be related to manageability trade-offs.

Occurrence V: Managers on the client's side were very receptive to scope changes (*dynamics*), because in the capricious political process and with the windfalls in the construction market, further optimisation appeared possible. The changes after design finalisation suggest that the *values* of the client prevailed here, because from a project execution viewpoint, changes from that point onwards put added strain on the project. In other words, the project was optimised from a project definition angle (*uncertainty gap*), not from a project execution angle. If the project had been optimised from a project execution angle, detrimental dynamics in this phase could have been avoided.

Occurrence VI: As a consequence of the extensive interdependence with other systems, *segmentation* and *value variety* were high. This can be explained by the choice to make use of existing technical systems. Dependence on other actors created dependence on potentially *strategically* motivated input. An alternative would have been to uncouple the systems and the project as much as possible from other systems and actors. That would, however, have been in contradiction with the very origins of the project. In other words, the size of the *uncertainty gap* in this case was to some extent inevitably large.

Occurrence VII: The strong dependence on other actors (*segmentation, value variety*) introduced large-scale intention uncertainty. As above (occurrence VI), this interdependence was inevitable to some extent. The alternative, uncoupling, would have conflicted with the basic definition of the project.

Occurrence VIII: With regard to the conversion from the old systems to the new system, the situation here is identical to occurrences VI and VII.

Occurrence IX: Many uncertainties played a role in the drawing up of the terms of reference. As noted previously, the essential requirements already made for a fairly large *uncertainty gap*. The project was dependent on many actors (*segmentation*), with strongly diverging *values*. Many of them had indispensable knowledge (*information asymmetry*). SGH transferred part of its responsibility, acquisition of rolling stock, to another actor (HTM). In other areas, the project managers within the Municipality of The Hague had to make most of the decisions. Here, the municipality's desire to retain full control over tracks within the city was influential. The municipality made most of its decisions in consultation with SGH. An alternative was hardly available.

Occurrence X: In the uncertainties surrounding the safety testing, the manageability considerations of the actors involved had almost no influence. The regime was decided externally (*information asymmetry*). The only alternative would have been to use an existing transport system – so, other than light rail – to minimise the *uncertainty gap*.

Occurrence XI: The premature reallocation of budget involved other trade-offs at the political level, so these were not under the control of project managers. For the politicians the alternative would obviously have been to acknowledge the characteristics of variability (an important *value* in project execution) and refrain from the budgetary changes (*dynamics*). Instead, a larger *uncertainty gap* was created.

Table 5.2 presents an overview of the different types of uncertainties in the project and the dilemmas associated with each.

Table 5.2 Uncertainties in Randstad Rail and related manageability dilemmas

Occurrence	Description	Main uncertainties	Dilemmas in consideration
I	Version control issues	Incompleteness	Uncertainty gap, segmentation
II	Adverse weather conditions and request for schedule extension	Instability, inscrutability, interpretation, intention	Uncertainty gap, value variety, information asymmetry, dynamics, rationalisation
III	Disruptions and derailments	Inconceivability	Uncertainty gap
IV	Super-elevation and abrasive wear issues	Incompleteness, inconceivability	Uncertainty gap
V	Scope changes	Incompleteness	Uncertainty gap, value variety, dynamics
VI	Variety and interfaces works and actors	Incompleteness, interpretation	Uncertainty gap, segmentation, value variety, information asymmetry, strategic behaviour, rationalisation
VII	Evasion of overarching responsibility	Intention	Segmentation, value variety
VIII	Problems in transfer of old systems	Incompleteness, intention	Segmentation, value variety

IX	Hiccups in drawing up terms of reference	Incompleteness, inconceivability, interpretation, intention	Uncertainty gap, segmentation, value variety, information asymmetry
X	Unclear safety cases	Incompleteness	Uncertainty gap, information asymmetry
XI	Premature reallocation of budget	Instability, interpretation	Uncertainty gap, value variety, dynamics

5.4.2 Loose observations on uncertainties

Our discussion up to now of the Randstad Rail project suggests a number of loose observations on uncertainties:

- What may have been an incompleteness uncertainty for one actor could be an inconceivability uncertainty for another, depending on the actor's knowledge and familiarity with the technology.
- Interaction-related aspects also played a role in inconceivability-driven uncertainties. The windfall in the tendering and contracting, for instance (instability uncertainty), eventually contributed to bounded manageability, because the principal used it as an opportunity to extend the project scope (interpretation uncertainty). Likewise, engineers' tacit knowledge was perceived as potential intention uncertainty, because the engineers were unable to objectivise their knowledge.
- Uncertainties in external interfaces fed into internal interfaces. The dependence on specifications for the rolling stock, for instance, became an issue through uncertainty in the internal technical interface with the rail specifications.
- Likewise, uncertainties in organisational interfaces fed into uncertainties in technical interfaces. ProRail's unwillingness to temporarily provide electricity for the Randstad Rail grid meant that new technical features (power stations) had to be added to the system.

5.5 Occurrences of complexity and uncertainty in the Souterrain project

Like Randstad Rail, which first became operational two years after the Souterrain was opened, the latter was also plagued with problems during implementation. During construction, major leakages occurred in the grout arch; a physical element included in the design to stabilise tunnel walls and to keep groundwater out of the excavation during construction. This section looks at these occurrence and their background, including the decisions to include the grout arch in the design, the way it was designed and the exploration for alternative techniques after it had failed.

5.5.1 Occurrence I: Scope extension makes project more complex

External interfaces played an important role in the Souterrain project. Some crucial design decisions were made regarding the inclusion of the grout arch in the early stages of project preparation, fuelled by the interests of powerful abutters (department store owners). The biggest change was the switch from a one-storey tram tunnel to a three-storey underground structure that included, in addition to the tram tunnel at the –3 level, a two-storey car park at the –1 and –2 levels. This addition was considered necessary to gain the indispensable support of the powerful abutting real estate owners. That support was needed because the retailers in the streets above strongly opposed the lengthy construction works proposed at their front doors. They reckoned that the parking spaces provided in the car park below would increase their turnover.[56]

The project's location in the middle of the busy shopping district meant that it would affect a number of very powerful actors with, initially, no particular interest in the project. The addition of the car park was a strategic move by the municipality. It gave the department store owners an interest in the project. Meanwhile, it also considerably complicated the technical system, stretching the capabilities of the municipality's management team and increasing the uncertainty gap, making the organisation more vulnerable to instability and incompleteness uncertainties. This was, however, not a particular point of consideration at that time. To reduce nuisance in the shopping district, a top-down construction method was to be used. Diaphragm walls were to be built from street level. Once finished a new street surface/tunnel roof would be built, after which excavation would take place below the new roof. This would reduce nuisance at street level.

5.5.2 Occurrences II: Inclusion of the grout arch

The addition of the car park made the Souterrain a substantially larger underground structure with its deepest point more than 13 metres below street level. This greatly increased the influence of the groundwater level, compared to the original, relatively shallow structure. It thus introduced higher levels of instability, incompleteness and inconceivability uncertainties. The fact that the Souterrain would now be considerably deeper and the fact that the tunnel walls had to be built very close to the abutting structures meant that large sideward pressure on the tunnel walls would occur. A strut now had to be built to prevent deformation (tunnel walls bulging to the inside), which could cause subsidence near the excavation. The strut was designed with the temporary function of preventing too large deformations in the long stretch of diaphragm wall that was to be excavated, as there was no space to build thicker diaphragm walls. The strut would lose its function after completion of the lowest tunnel floor (which itself would function as a strut).

Design engineers at SAT studied various options for dealing with this difficulty. In some places, the diaphragm walls of the 13 metre deep excavation were only one and a half metres from the facades of existing structures. This posed serious deformation risks. SAT used a common framework for calculating deformation tolerance, in consultation with its geotechnical advisor Fugro.[57] In this phase, SAT and the municipal Building Inspectorate conferred regularly about the allowed deformations of soil and subsequent movement of abutting structures.

While SAT was preparing the definitive design, in 1994, the municipal Building Inspectorate expressed additional worries about the vulnerability of the project environment after geotechnical tests had been done. It demanded tighter deformation margins than SAT had been working with. The design would have to be revised.[58] At that point, SAT opted for inclusion of a grout strut, in consultation with the Ministry of Transport's engineering department.[59] A normal strut would require excavation first, which would cause an immediate hazard of leakage and subsidence. Grout is a cement-like product that can be injected into the soil using a twisting hollow lance. It then mixes with the soil and hardens to create a firm layer of interconnecting columns.[60] The use of grout would thus enable the designers to put the strut in place before excavation started.

The high groundwater level in combination with the soft soil of the site was another difficulty for underground construction. It meant there was a constant threat of leakages. The original design had therefore included a separate water seal, to be created with a horizontal gel layer deep underground, to prevent groundwater from flowing into the tunnel.

The need for the strut had a major impact on the Souterrain project. The grout layer made construction more expensive. Cost overruns were unwelcome, however. The Municipality of The Hague was short on funds, and even under a financial oversight regime by the national government.[61] Although there is no proven relation between the municipality's financial situation and specific engineering decisions, a return to the original budget was desirable. The final design was in fact a compromise between money and technology.[62] It could be considered an optimisation from an efficiency viewpoint.

One solution applied was to drop the gel layer that was initially included to keep groundwater out of the construction pit during the works. The engineers reckoned that the grout strut layer would be sufficient to prevent groundwater from flooding the excavation. To enable it to do so, it would use an arch shape with the hollow side up, to counter upward groundwater pressure.[63] The second measure was to apply grout only under the tunnel stretches, not under the stations. Application in the wider station compartments would be much more expensive, and the strut was not strictly necessary there. In those places, the engineers maintained the gel layer,[64] creating an internal physical interface between the grout and gel layers. These measures, however, increased exposure to instability, incompleteness and inconceivability uncertainties.

Grout had been used both as a strut and as water seal before, but not with both functions combined.[65] Earlier experiences with grout in the Netherlands were limited and not equivocally positive.[66] Via specialist consultant HGB, SAT had earlier on in the preparations contacted the German firm Johann Keller, which had used grout both as strut and as a water seal.[67] According to the consultant, Keller advised against the use of grout for a combined strut and water seal.[68] It did provide equipment and staff for the works on the grout arch though.[69]

There was an important additional design trade-off related to the prerequisites for the two functions of the grout arch. A strut was best placed immediately underneath the eventual excavation depth, to prevent deformation of the diaphragm walls as a result of sideward pressure from outside the excavation. For the function of groundwater seal, however, it was best placed deeper in the ground, so that there would be sufficient soil counter-pressure between the arch and the maximum excavation depth to limit possible small leaks in the arch. After all, there was sufficient experience with grouting to know that grout layers are never a hundred per cent waterproof (an incompleteness uncertainty).[70]

Coupled with the depth of the grout arch was the depth of the diaphragm walls. A high grout arch could do with shorter diaphragm walls, which was a third option for reducing costs. Besides, a high grout arch was a more secure strut than a low one, due to its smaller chance of deformation.[71] Choosing a high grout arch would, however, compromise the water sealing function.[72] The design engineer saw no other option than to install the grout arch directly beneath the deepest level of the excavation. This decision can partly be explained as a compromise between cost and robustness, particularly due to the combination with the shortened diaphragm walls and the elimination of the watertight gel layer.[73] The short diaphragm walls did mean that if leakage were to occur, the consequences would be greater, because the diaphragm walls no longer reached the deep watertight soil layers, thus allowing more groundwater to flow in.[74] In general the decision increased incompleteness uncertainty.

5.5.3 Occurrence III: Calamity

Most of the manageability issues during implementation were concentrated around one main event. On February 19th, 1998, almost two years after the start of construction, when construction contractor TramKom was excavating to the lowest level underneath the Kalvermarkt, a breach sprang in the grout arch under the excavation that would become the Souterrain. The grout arch was built as a temporary barrier against groundwater and as a temporary strut for the diaphragm walls during excavation. Huge amounts of water flooded the tunnel. The flow was temporarily stopped using technical emergency measures, but on March 8th, before a permanent solution had been found, the breach reoccurred in massive form. Some 140,000 litres per hour flowed in, carrying sand from outside the excavation into the tunnel. This caused immediate danger, because the voids created outside the pit could cause the excavation to become instable and collapse in the project environment. Part of the street caved in. The only way to prevent further damage was to flood the construction pit to provide sufficient counter-pressure to the groundwater.

No definitive answer has ever been established to the question of what caused the leak.[75] Despite some alternate views, most engineers agree on the cause. In some peat layers present in the soil where the Souterrain was being built, grout column diameters of only 1.60 metres seem to have been achieved with the injection lance used to install them, whereas 2.30 metres was expected in normal soil conditions. Small leakages in a grout layer are normal, as grout layers are not expected to be completely waterproof. But these insufficient diameters caused such large voids that “piping” could occur. In such a situation the upward pressure of the groundwater would be such that the flow of water pouring into the excavation could threaten the stability of the whole excavation. This was an inconceivability uncertainty (an unknown unknown) for PTC, but a combination of instability (variability) and incompleteness uncertainty for more informed actors, such as TramKom.

5.5.4 Occurrence V: Organisational interfaces related to the grout arch design

In 1995, the construction contract was tendered with five participant bidders. Even at that early stage, problems arose regarding the grout arch design. Sponsor PTC wanted the construction firms to design the whole grout arch, with SAT Engineering responsible for the design of the rest of the system. The assembled bidders considered this undesirable, because it would blur the tender procedure. They suggested the situation should be equal so that all participants could bid fairly.[76] Because the bidders acted collectively, bypassing their concern was difficult; after all, it nullified the replaceability of each individual potential contractor. So sponsor PTC gave in and decided that indeed SAT Engineering would provide the specifications for the size, shape and location of the grout arch.[77] This meant, however, that the sponsor became liable for these parameters. Based on the specifications provided, the contractor would then elaborate the detailed design; that is, the exact dimensions and heart-to-heart distances of the grout columns, including a considerable portion of the watertightness features.

To compensate for the risks associated with the grout arch, the design engineer was to use strict safety margins. This complicated responsibilities further though, affecting the organisational interface between sponsor and bidder/prospective contractor. From the bidders' point of view, the sponsor would now be responsible for the technical capabilities of the grout arch, with the contractor responsible for its implementation.[78] Sponsor PTC considered construction of the grout arch to be manageable as long as the contractor respected the safety margins.[79] There was a discussion with TramKom about the required heart-to-heart distances between grout columns, which the project director (SAT) had considered too large. But because these features (design and construction) were now the responsibility of the contractor, reducing this distance (and in so doing increasing the number of injections) would count as additional work with corresponding additional costs.[80] The contractor was formally responsible for successful implementation and a safe construction process. But the choice for the "common-mode" grout arch was the responsibility of the sponsor, and robustness features were defined largely by the sponsor's willingness to pay for it, though the contractor was still held responsible for delivering the defined heart-to-heart distances and further implementation.

There was an additional complication for the Municipality of The Hague in the design and tender process. Not only were the potential construction contractors reluctant to become liable for the grout arch. The consortium of insurance companies involved in the project, led by Allianz, had doubts about the grout arch design too, based on analyses done by their own geotechnical engineering consultant. The insurance consortium had hired HGB, the consultant that had earlier facilitated SAT's contacts with the specialist construction firm Johann Keller, to discuss the grout arch solution.[81] As mentioned, the people at Johann Keller had said they would not use a design with a grout arch that combined the strut and water seal functions, like that drawn for the Souterrain.[82] On the basis of the tender design, the insurance companies excluded liability for any possible damage to the grout arch from the construction all-risk insurance. Only consequential loss as a result of grout arch failure would be covered. PTC, however, had confidence in SAT's competence and thought that if SAT stood behind the design, it was trustworthy. Besides, there was in fact no way back. The tender was based on this design and it had deliberately been made as efficient as possible. Hence, the sponsor decided to carry on.[83]

Within the sponsor's organisation, there was high uncertainty regarding the grout arch . Both the construction contractor and the insurance company had an incentive to warn of the possibility of a flawed design, to limit their liability. If they expressed their worries in advance and excluded the grout arch design from their responsibilities, it would give them an avenue to dispute any liability in possible future events. PTC and the City Management Department had to consider this intention uncertainty. They, moreover, had insufficient expertise to rely on their own trade-offs in this.[84] This left room for PTC's interpretation to deviate from TramKom's (interpretation uncertainty). The only actor that they were sure had the same interests as they had was the design engineer and project executive: SAT Engineering. If all actors in the network were to be considered equally competent – and at that point PTC had no reason to think otherwise – SAT was the most trustworthy partner. PTC was confident about the design because it had been approved by the municipal Building Inspectorate, SAT Engineering and the engineering department of the Ministry of Transport.[85]

The role of the engineering department of the Ministry of Transport (Rijkswaterstaat) was somewhat ambiguous. Rijkswaterstaat was itself in the midst of a transition from a proper engineering bureau to a department concerned mainly with oversight of public expenditures in state-funded projects. The latter implied a more passive role, concerned mainly with acquisition and asset management. In the Souterrain project, the municipality of The Hague had relied relatively extensively on Rijkswaterstaat, and the latter's engineers had contributed actively to thinking on design trade-offs, particularly regarding the grout arch. However, Rijkswaterstaat did this mainly in a spirit of providing suggestions, whereas the sponsor interpreted its contributions more as committed proposals. This gap in interpretation was quite predominant. Respondents involved in the Souterrain project often defended the choice for the engineering design by mentioning the approval by Rijkswaterstaat. Although they did acknowledge the ambiguous and changing role of this agency (as acknowledged by Rijkswaterstaat itself), this did nothing to lessen the considerable trust they placed in Rijkswaterstaat as a backup. Since this is related to the sponsor's perception, it can be considered an interpretation uncertainty.

5.5.5 Occurrence V: Grout arch installation process – differentiation and the "flaw of averages"

Part of the grout arch risk was in the "flaw of averages". The grout arch sections consisted of a total of eight thousand columns that had to connect tightly. If the installation was done properly, this result would have been achieved. The repetitive character of the installation process already resulted in a higher vulnerability to instability uncertainty (variability in the works). But the fact that this activity had to be repeated eight thousand times and the fact that deviations were theoretically possible, made it likely that a flaw, leading to leakage, would occur at some point, considering the variability known to be applicable to these kinds of works. This is an “inverse law of large numbers”. The theory of large numbers expects results to level out the larger the number of occurrences. Just one deviation could be fatal in this case though. In the aftermath of the breach, this chance was statistically determined at five occurrences in the whole project.[86]

TramKom conducted a test of the grout columns before the works on the Souterrain project commenced. It was meant to show how the columns would connect to each other and what diameters were achieved with the injection lance, to reduce some of the incompleteness uncertainty. These tests determined the parameters needed for the grout arch, but they did not assess its quality as a groundwater seal. To prove this, a pump test was executed. In hindsight, however, results of this test were considered equivocal.[87] As a result, uncertainty remained about the performance that could be expected from the grout arch.

Throughout the early phases of construction, the grout arch was the trickiest element of the works. Construction contractor TramKom was supposed to continuously monitor grout column installation using a new and innovative technique, but it regularly failed to do so. The insurance company warned about this.[88] There was also some friction about the calculation of the required margins. Here again, there was no unequivocal method for measurement.[89]

After the occurrence of the calamity, a discussion of liability got underway. TramKom had committed to a contract to build a grout arch in accordance with the specifications, including the stated safety margins, provided by SAT. These specifications would result in a functioning grout arch. As the grout arch failed to do what it was designed for, the conclusion could be that TramKom had not built it correctly. There was, however, a difference between technical theory and practice. Small deviations in the soil composition could make the grout arch defect even if it was built in accordance with the specifications.

In essence, TramKom and PTC had different views on the uncertainty involved in the grout arch installation. TramKom considered possible deviance the result of variability, and hence an instability uncertainty. PTC, backed by SAT, considered the uncertainty of the incompleteness kind. The process would be controllable if a large enough safety margin was used and if TramKom was sufficiently meticulous in its effort. It has never been established whether TramKom built in compliance with the margins specified.[90] SAT Engineering was involved both as design engineer and as project executive in the construction phase of the Souterrain project. It was in it for a limited number of hours, however. Time spent on required design changes ate into the time available for monitoring the contractor's work. It therefore remained unknown to what extent TramKom indeed installed in accordance with the required margins. But since the design was sensitive to such deviations, which were partly instability uncertainties and hence hard to evade, TramKom considered the design too vulnerable in the first place. The possibility that PTC interpreted this differently indicates an interpretation uncertainty.[91]

5.5.6 Occurrence VI: New design for completion

After the breach, discussions began on how to complete the project. This process had three main phases.[92] The first phase was aimed at finding a construction method for project completion. Five options were considered:[93]

- Permanently draining the water from the excavation
- Freezing the soil to prevent groundwater from flowing into the excavation
- Underwater construction
- An additional groundwater seal
- Atmospheric overpressure to prevent groundwater from flowing into the excavation

Draining was problematic, because it might cause settlement in the project environment. Freezing was extremely expensive, and could not be considered for such a large application. Underwater construction was unworkable for the contractor, due to required demolition of the upper part of the grout arch which would be very difficult to do underwater. In addition, the limited dimensions of the tunnel meant there was insufficient space to execute such works. In June 1998, agreement was reached on the use of atmospheric overpressure technology.[94] Involved in this decision were specialists from the construction contractor TramKom, design engineers from SAT Engineering, the municipal City Management Department (of which sponsor PTC was a subsidiary), the municipal Urban Development Department, transport operator HTM, the insurance company, the municipality's consultant Gemeentewerken Rotterdam[95] and the engineering department of the Ministry of Transport and Water Management. A team of engineers from both SAT and TramKom elaborated this solution. Yet, when they presented the outcome, the costs appeared far too high for the Municipality of The Hague, meaning that the solution was politically unacceptable.[96] The project organisation did manage to restore the street surface according to plan in October 1998, which gave them a bit more time for further deliberations.

From November 1998 until February 1999 research was done on the possibility of phased excavation with draining equipment as backup[97] and cancellation of one parking deck to raise the tram tunnel in the design, so as to be less dependent on the reliability of the grout arch. The latter was rather costly, since finished work would have to be adapted and partly demolished. Moreover, the project's financial yield would be considerably diminished and its functionality reduced. The solution of phased excavation with emergency drainage as backup was unacceptable to both the Province of South Holland and the municipal Urban Development Department, since changing groundwater levels could instigate settlement in the project environment. The insurance consultant also opposed this solution, due to high risk of consequential damage.

In March 1999, SAT Engineering presented the underwater stabilisation layer as another solution. The elaboration of this solution can be considered the second phase in the process. SAT sought second opinions on this method from the engineering department of the Ministry of Transport and Water Management, geotechnical consultant GeoDelft and Gemeentewerken Rotterdam. The specifications were then transmitted to TramKom, which estimated costs and outlined some of the risks involved. TramKom was not convinced of the technical feasibility of the method. SAT and TramKom also made very different estimates of the time and costs involved in the works, particularly those related to the excavation and demolition of the grout arch. TramKom's estimates were significantly higher than SAT's. SAT estimated the costs at approximately €10.7 million to €12.7 million. A few months later SAT was still unable to convince TramKom of the validity of the underwater stabilisation layer method. Neither was SAT able to disqualify TramKom's objections.[98] They had reached another impasse.

The relationship between SAT and TramKom had deteriorated so much that sponsor PTC decided to hire an additional consultant (Toornend & Partners) to mediate in the process. After TramKom's objections to the stabilisation layer, an engineering working group was organised and met regularly. They, once again, considered all technical options, twelve in total. It was decided that if none of these was considered acceptable, the fall-back option would be to eliminate a parking deck. This would reduce the depth of the tunnel, bringing the challenge of the project better in line with the capabilities of project management.[99] This alternative did not make it though. Such a reduction in scope was unacceptable to the municipality, as it had sold the parking garage to a private operator, which stipulated the functionality as a hard performance requirement. Not delivering on this contract would pose a major financial difficulty.

After a while, two options were left: phased excavation and completion under atmospheric overpressure. TramKom and the insurance company consultant considered phased excavation risky, which meant that no unanimous verdict could be reached on the two methods. Both sides were willing, however, to be convinced on the basis of realistic arguments. Therefore, elaboration of plans for both methods began. Engineers soon discovered that phased excavation in the Kalvermarkt section was much more risky than in the Grote Marktstraat section. Therefore, the decision was made to use atmospheric overpressure there. In October 1999 planning for both the Kalvermarkt and Grote Marktstraat sections was finished. SAT, supported by the engineering bureau of the Ministry of Transport and Water Management, and TramKom drew up their estimates for the project's completion.

Concerning the Grote Marktstraat section, the insurance consultant had strong reservations about the use of any corrective solutions, such as phased excavation, rather than preventive solutions, such as atmospheric overpressure. To keep the situation under control, any eventual repairs would have to be done very quickly indeed, and this was considered a substantial risk.[100] Since atmospheric overpressure was the technique most likely to prevent any new failure, TramKom still preferred it.[101] SAT preferred phased excavation.[102]

Atmospheric overpressure technology could be applied in two ways: repairs could be commenced with atmospheric overpressure technology as a backup or using permanent atmospheric overpressure. In the former situation, excavation and repairs would take place under normal atmospheric pressure, though equipment for creating overpressure would be on hand in case of leakages. In the latter, permanent measures would have to be taken, such as counter-pressure for existing structures and decompression sluices for both workers and equipment. The latter would be considerably more expensive, and the labour conditions would be less favourable. The choice for use of overpressure as a backup was therefore logical.

The new plan foresaw completion in 2003 (according to SAT) or mid-2004 (according to TramKom) at a cost of €24 million to €30.5 million (according to SAT) or €34 million to €40.5 million (according to TramKom). The differences between the two calculations were largely due to the different execution times.[103]

A potential leakage scenario model indicated that the groundwater would carry sand within two hours. The insurance consultant accepted no longer than one hour of repair attempts. After that, overpressure was to be created. The technique was applied, yet three or four breaches appeared within just a short period.[104] TramKom considered the situation unworkable, meaning that construction would have to proceed under permanent atmospheric overpressure. At that point TramKom lost confidence in SAT's solutions. Toornend & Partners then advised drawing up a new contract on the basis of the new construction method.[105] TramKom would do both the design and construction from that point on, meaning that SAT Engineering would leave the project.

The damage and the new completion technique doubled the original costs to approximately €242 million.[106] The time it took to decide on a technique to use to complete the project and the additional implementation time for application of the technique pushed the completion date back by some four years, to October 2004.

Various uncertainties came together here. Failure involving groundwater could be both an instability uncertainty (variability in groundwater flows) and an incompleteness uncertainty (state of the soil at different locations). In considering these uncertainties, TramKom applied tacit knowledge (inscrutability uncertainty), which PTC perceived as possible strategic behaviour (intention uncertainty). An important reason for the conflict between TramKom and SAT Engineering was TramKom's doubts about SAT Engineering's interpretation of the risk (interpretation uncertainty).

5.5.7 Occurrence VII: More implementation problems

Even more leakages occurred, though not as bad as the calamity in early 1998. One of the causes was that the design had been made as efficient as possible. That meant there were many interfaces between steel sheet piling and diaphragm walls, from grout arch to gel injections, etcetera. Each of these physical interfaces developed leakages during the works. There was little experience with all these interfaces, particularly not at this scale and depth. It is debatable whether this could have been remedied with more extensive testing (which would have made it an incompleteness uncertainty) or whether it was a variability issue in the work of the constructors (which would make it an instability uncertainty). It could have been prevented with a more consistent and hence more expensive design (e.g., with diaphragm walls everywhere).[107]

Meanwhile, a new practical problem occurred. The gel injections that provided a temporary groundwater seal under the stations for the period of construction had a limited lifespan. Due to all the delays, they started to lose their effect. Water started to seep in through this layer. This water was basic and could dissolve organic material. As a consequence, the draining equipment got jammed. Filter pipes that were installed to solve the problem jammed too. This eventually threatened to lift a peat layer and crack the floor. An extensive monitoring programme had to be implemented to prevent this.[108] Since the possible occurrence of this problem was known, it was an instability uncertainty.

5.6 Uncertainties in the Souterrain project

5.6.1 Manageability problems stemming from complexity-related uncertainties

Occurrence I: The decision to add a two-deck underground car park to the design made the project more susceptible to instability and incompleteness uncertainties. But in the trade-off the political importance of the feature easily became dominant, at the cost of, for instance, implementability. This enlargement of the *uncertainty gap* stemmed from a political process involving many different actors (*segmentation*) with a strong variety and diverging or even conflicting *values*. The municipality's position was determined by its strong focus on the values of the project environment. PTC could not ignore these values, so a high-impact change to the design was made (*dynamics*). The alternative was to keep the project simple, conflicting with the large variety of values surrounding the project.

Occurrence II: The decision to add an underground car park to the project and hence enlarge the *uncertainty gap*, created crucial interdependencies with both the physical environment (soil, groundwater and abutting structures) and the social environment (actors specialised in geotechnical techniques) (*segmentation, value variety*). The decision-making process and inclusion of geotechnical specialists suggest the existence of *information asymmetry*. PTC, as the main decision-maker, addressed this by assembling information rather than, for instance, by transferring decision-making authority, and by including redundancy. It should be noted that some redundancy was expected to be provided by Rijkswaterstaat, whose role may in hindsight have been overestimated. Eventually, use of the grout arch as an engineering solution led to a dispute between PTC and TramKom on the perception of risk. In that situation, PTC worried about possible strategic behaviour because TramKom could not objectivise its concerns. PTC therefore could not *rationalise* it. PTC fended off TramKom's worries and carried on. The alternative would have been to build the tunnel differently, for instance, lower with deeper diaphragm walls, or with a gel injection layer. This would have reduced the uncertainty gap, but would have been more expensive. The potential for strategic behaviour was averted, but could alternatively have been taken into consideration. This would have required changes, however, and hence again additional costs.

Occurrence III: The calamity went counter to PTC's expectations regarding the grout arch design, judging from PTC's perception of the risk involved. It did bear out the fears of TramKom regarding this technical feature. No real trade-off was made on the event itself. The main trade-offs were in the introduction of the design feature (see occurrence II) and in the technique to be used to complete the project after the calamity (see VI below).

Occurrence IV: The different viewpoints (*segmentation*) on how to design the grout arch indicates various uncertainties. The possible deviations during construction could have been of the instability kind (variability in the work) and the incompleteness kind (unknowns regarding soil composition). Interpretation uncertainty was also at work, as the sponsor/design engineer had to provide the parameters. Intention uncertainty was in play too, as the contractor would then have to implement the specifications. As in occurrence IV, the size of the *uncertainty gap* was an issue. The sponsor's instruction to carry on with the design and use larger safety margins for the injections resulted in higher vulnerability and hence a larger uncertainty gap.

In overseeing the works, the owner was heavily dependent on provided input. Hence, *information asymmetry* was an issue. The contractors' attempts to avoid liability here can be ascribed to their differing *values*, which could be the result of *strategic behaviour*. The owner therefore looked for ways to *rationalise* choices for specifications.

Occurrence V: The trade-off in the grout arch installation process was between the larger safety margins that PTC wanted and decided to apply and an alternative technique that would probably have been more expensive and required re-engineering (*uncertainty gap, value variety, dynamics*). The main issue was that PTC was very aware of TramKom's *strategic* interest in the problem, and TramKom could not *rationalise* it objections.

Occurrence VI: The starting point for the discussions of a completion technique was how to deal with the *uncertainty gap* between the knowledge required to complete the project without further calamities and the knowledge available in the project organisation. A significant number of actors had to be involved in this discussion (particularly, PTC, the design engineer and the construction contractor), and more were added to increase the knowledge available (*segmentation*). Inevitably, *value variety* entered the picture. Accounts of the debate that took place thereafter demonstrate the *information asymmetry* between TramKom and PTC. SAT's position was somewhat less clear. Though PTC did not transfer decision-making authority, it did organise some redundancy by including additional engineering specialists. The discussions also made clear PTC's reluctance to allow too-large changes from the status quo (*dynamics*), although TramKom's position was that these were required. PTC again feared *strategic behaviour*, which was an important reason for its hesitance to adopt TramKom's position. TramKom had a hard time convincing the others, because its objections to other solutions could not be objectified (*rationalisation*). TramKom's concerns were predominantly based on its tacit knowledge on the matter. The alternative in this case would have been to dismiss TramKom, but the repercussions of that would have been too large.

Occurrence VII: Many of the implementation problems that occurred, particularly in the later phases, can be related to engineering design decisions. Many of these were trade-offs between certainty and costs (*uncertainty gap*). Cost efficiency was always decisive, but it introduced *information asymmetry* dilemmas.

These occurrences of complexity led to the uncertainties presented in Table 5.3, which also indicates the manageability dilemmas involved in each.

Table 5.3 Uncertainties in the Souterrain project and related dilemmas.

Occur-rence	Description	Main uncertainties	Dilemmas in consideration
I	Scope extension	Instability, incompleteness	Uncertainty gap, segmentation, value variety, dynamics
II	Introduction of grout arch	Instability, incompleteness, inscrutability, interpretation, intention	Uncertainty gap, segmentation, value variety, information asymmetry, rationalisation
III	Calamity (possible peat layers)	Inconceivability/instability, incompleteness	Uncertainty gap
IV	Organisational interfaces grout arch	Instability, incompleteness, interpretation, intention	Uncertainty gap, segmentation, value variety, information asymmetry, strategic behaviour, rationalisation
V	Installation process grout arch	Instability, interpretation, intention	Uncertainty gap, value variety, information asymmetry, dynamics, strategic behaviour
VI	New design for completion	Instability, incompleteness, inscrutability, interpretation, intention	Uncertainty gap, segmentation, value variety, information asymmetry, dynamics, strategic behaviour, rationalisation
VII	More implementation problems	Instability, incompleteness	Uncertainty gap, information asymmetry

5.6.2 Loose observations on uncertainties

Our discussion up to now of the Souterrain project suggests a number of loose observations on uncertainties:

- Again, an external interface (the demanding project environment) led to uncertainty in internal technical interfaces, in this case with the grout arch.
- Occurrence inscrutability uncertainty can coincide with interpretation uncertainty or intention uncertainty (depending on who the owner of the tacit knowledge is). Tacit knowledge could not be made explicit. It was therefore unobjectifiable and evoked suspicion among other actors. This was reflected in other actors' assessments of the inputs provided by the tacit knowledge owner. In the

Souterrain project, this was clearly visible in PTC's assessment of TramKom's inputs regarding the grout arch.

- Instability uncertainties can become instability certainties by repetition. If an operation is to be repeated many times, such as the installation of the grout columns, the negative variability beyond the predefined tolerance is statistically increasingly likely to occur.

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[1] Respondent anon. A, O.
[2] Existing fast trams in Amsterdam-Amstelveen and Utrecht-Nieuwegein are described by some as a kind of light rail.
[3] Resolution by city council member Bianchi in 1989.
[4] Programme "De Kern Gezond" (Healthy Core), approved by The Hague city council in 1989.
[5] It was designated as a project of supra-regional importance under the name "Den Haag Nieuw Centrum" (The Hague New Centre) (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Vierde Nota Ruimtelijke Ordening Extra, final version approved in 1992).
[6] Respondent anon. C.
[7] BORR = Bestuurlijk Overleg RandstadRail (administrative board Randstad Rail).
[8] PORR = Projectorganisatie RandstadRail (project organisation Randstad Rail).
[9] Apart from The Hague, this concerned the municipalities of Zoetermeer, Leidschendam-Voorburg and Pijnacker-Nootdorp.
[10] Respondents anon. A, B.
[11] Disposition of December 11, 2002 by the Minister of Transport and Water Management.
[12] Respondent R. van Gelder.
[13] Respondent L. Alferink.
[14] Respondents J. van Beek, C Kruyt.
[15] Respondent H. Vergouwen.
[16] Respondents S. de Ronde, L. Alferink, R. van Gelder.
[17] Respondents E. Vols, L. Alferink.
[18] In an added explanation dated June 10, 1994, on a proposal dated June 3, 1994, the working group on procurement for the Souterrain suggested this set-up to the board of the City Management Department.
[19] Respondent J. Wendrich.
[20] Respondent E. Vols.
[21] Respondents L. Alferink, C. Kruyt.
[22] Respondent R. van Gelder.
[23] Respondents R. van Gelder, L. Alferink, C. Kruyt.
[24] Respondent C. Kruyt.
[25] Respondent R. van Gelder.
[26] Respondent R. van Gelder.
[27] Respondent J. van Beek.
[28] Respondents L. Alferink, R. van Gelder.
[29] Respondents C. Kruyt, R. van Gelder, L. Alferink.
[30] Respondent C. Kruyt.
[31] Respondents J. Bol, L. Alferink.
[32] Respondent L. Alferink.
[33] Respondent J. Bol.
[34] Respondents anon. D, E.
[35] BORR minutes, July-August 2006.
[36] BORR minutes, September 2006.
[37] Respondents anon. A, F.
[38] BORR minutes, respondents anon. A, C.

[39] DeltaRail, Nader Onderzoek wisselsteller, Wissel 846, (closer research switch shift, switch 846), 20 December 2006. IVW, onderzoeksrapport, (Transport Inspectorate, research report) 24 April 2007.
[40] Respondent anon. G; DeltaRail, Nader Onderzoek wisselsteller, Wissel 846, (closer research switch shift, switch 846), 20 December 2006. IVW, onderzoeksrapport, (Transport Inspectorate, research report) 24 April 2007.
[41] Memo Asch van Wijk to SGH, 30 August 2007.
[42] Respondent anon. G.
[43] Respondent anon. C.
[44] Respondents anon. H, I.
[45] Respondents anon. A, D, F.
[46] Respondent anon. D.
[47] Respondent anon. C
[48] Respondents anon. A, C.
[49] Respondents anon. A, C.
[50] Memo Asch van Wijk to SGH, 30 August 2007.
[51] Respondents anon. A, D, J, K.
[52] Respondent anon. D
[53] Respondent anon. L.
[54] Gemeente Den Haag, Dienst Stadsbeheer, Afdeling Stedelijke Structuren, research report "Sturing en controle bij het project RandstadRail" (Steering and control in the RandstadRail project), 15 May 2007.
[55] Respondents anon. A, M, N.
[56] Haagsche Courant, various articles in the period 1990-1995.
[57] Respondents J. Wendrich, S. de Ronde.
[58] SAT Engineering v.o.f., Souterrain Grote Martstraat/Kalvermarkt, Fasedocument Definitief Ontwerp, February 25/March 29, 1994.
[59] The grout arch is included as an adjustment in the design in a progress report dated March 1995 on the tunnel projects associated with the Centre renovations.
[60] Respondents B. Horvat, F. van Tol, D. Luger, K. Brons, S. de Ronde, J. Wendrich.
[61] The municipality of The Hague had the temporary status of "article 12 municipality", named after article 12 of the Financial Relation Act. Municipalities with a structurally bad financial situation receive additional money from central government to make up deficits, but their financial management is meanwhile monitored intensively by central government.
[62] Respondent S. de Ronde.
[63] Respondent K. Brons.
[64] Respondent D. Luger.
[65] Repsondents S. de Ronde, J. Wendrich, B. Horvat, D. Luger.
[66] IFEX risk analysis, dated June 28, 1995, p. 6.
[67] Respondents K. Brons, J. Wendrich.
[68] Respondent K. Brons.
[69] Respondent J. Wendrich.
[70] Respondents F. van Tol, A. Verruijt.
[71] Respondent B. Horvat.
[72] Respondent J. Bol.
[73] Respondent C. Kruyt, K. Brons, J. Wendrich.
[74] IFEX risk analysis, dated June 28, 1995, p. 4.
[75] The independent Dutch expertise bureau (NEDEB) does not give an unambiguous cause (*Haagsche Courant*, 9-8-1998).
[76] Respondent J. Bol.
[77] Respondents J. Bol, J. Wendrich.
[78] Respondent J. Bol.
[79] In practice, this meant working with a large injection diameter of the columns, so that there would be a large overlap between two injection points.
[80] Respondent J. Wendrich.
[81] Respondent K. Brons.

[82] Respondent K. Brons.
[83] Respondents L. Alferink, C. Kruyt.
[84] Respondent C. Kruyt.
[85] Respondents (Van Beek, Alferink, Van Gelder, Bol) were unable to clarify whether the engineering department of the Ministry of Transport was aware of the changes made in the grout arch design to reduce costs. As subsidies are usually effectuated in a late stage of the preparation process, it is likely that they did have the final designs. It is, however, not clear how thoroughly engineers of this department looked at the final designs after approval of earlier drafts.
[86] Respondent K. Brons.
[87] Respondent J. Bol.
[88] Respondent K. Brons.
[89] Respondent J. Bol.
[90] Respondent K. Brons.
[91] Respondent J. Bol.
[92] Report of the process analysis by Toornend & Partners (December 1999).
[93] Toornend & Partners, Souterrain tramtunnel Den Haag; Technisch rapport december 1999. Respondent J. Bol mentions termination of the project and cancellation of one parking deck as additional solutions. They were unacceptable to the municipality though.
[94] Atmospheric overpressure can prevent groundwater from seeping into the excavation. It does require a more or less airtight compartment. Also, construction workers can work only shifts no more than five hours. They have to enter and leave the construction site through a decompression tank and are under permanent medical observation.
[95] Gemeentewerken Rotterdam is the partly privatised engineering department of the municipality of Rotterdam.
[96] Respondents J. Bol, R. van Gelder.
[97] In case of phased excavation, excavation would take place in very small parts so that eventual leakages can easily be located and fixed.
[98] Report of the process analysis by Toornend & Partners (December 1999).
[99] Respondent J. Bol.
[100] Respondent K. Brons.
[101] Respondent J. Bol.
[102] Report of the process analysis by Toornend & Partners (December 1999).
[103] Toornend & Partners, Souterrain tramtunnel Den Haag; Technisch rapport december 1999.
[104] Respondent K. Brons.
[105] Toornend & Partners, Souterrain tramtunnel Den Haag; Technisch rapport december 1999.
[106] This includes claims from third parties such as operator HTM, compensation for owners of abutting structures and temporary detours.
[107] Respondent D. Luger.
[108] Respondent D. Luger.

6. Central Artery/Tunnel Project

6.1 Introduction

The second case examined in this study was found in the United States, a country with, according to Hofstede (2000), an uncertainty avoidance culture comparable to the Netherlands, though combined with a slightly more masculine ethos. In the Commonwealth of Massachusetts, one of the most iconic underground infrastructure construction projects in the United States of all times was built: the Central Artery/Tunnel (CA/T) project – better known as the "Big Dig". The purpose of the project was to rebuild two stretches of highway largely underground. The complexity of the scheme was unprecedented in many ways, and so was the project management job.

The CA/T project was plagued by manageability problems. Throughout the extensive preparation and implementation works, costs grew massively, to almost three times the estimates at the start of construction and six times the amounts foreseen in the initial plans. In addition, after opening, technical problems emerged, both in the form of regular leakages and one acute calamity.

Like in the Randstad Rail/Souterrain programme of The Hague, the current study focused on one part in particular: the extension of Interstate 90 (I-90) under South Boston and Boston Harbor. This is the stretch where the acute incident took place. A tunnel ceiling collapsed, killing a passenger in a car. As legal investigations were still taking place, our analysis of this incident could be based only on published accounts from the managers and engineers involved.

Section 6.2 presents the general background of the project. Section 6.3 introduces the main occurrences of complexity and the resulting uncertainties. Section 6.4 presents an overview of the uncertainties found and dilemmas related to these.

Data for this chapter came not only from interviews (which took place when the tunnels were open for use and the old highway was being demolished), but also from other sources. There are a few reasons for this. At the time this study took place, the project was in a state of financial turmoil, but had not yet experienced major technical problems. The financial turmoil was a sensitive issue that was still being sorted out legally. On the technical issues, the actors involved had difficulty relating manageability issues other than the acknowledged engineering marvels required. Reflections on trade-offs surfaced only regarding the very specific and concrete event that killed the car passenger, which took place later.

Manageability issues related to the client's oversight of the main contractor were also subject to legal investigations, the latter mainly related to compensations for cost overruns. Due to the sensitivity of both issues and the legal procedures being carried out, including liability for the events, actors exercised prudence in the information they provided, particularly surrounding these aspects. Official investigations into the management of the project, as well as official statements related to both the fatal accident and project management were made public, however, and this information proved a valuable source of compensatory data. Also, the extensive reporting done by the project's management was valuable.

6.2 The Central Artery and third harbour tunnel

6.2.1 Boston's highway system objectives[1]

In the 1950s, the Commonwealth of Massachusetts built an elevated highway, part of Interstate 93 (I-93), to assure accessibility of Boston's downtown area in an era of rapidly growing vehicular traffic. The highway, regularly referred to as the "Central Artery", ran straight through the heart of the city, cutting off Boston's waterfront and the North End neighbourhood from downtown. Its construction required demolition of 36 city blocks, and was completed in 1959. Meanwhile, plans were being made for the "Inner Belt". This additional highway would allow through traffic to bypass Boston's downtown area. It would require demolition of another 3,800 homes plus numerous commercial buildings and parks. Some of those parks were part of the "Emerald Necklace", a chain of parks across the city's central districts that were considered the "green lungs" of the city.

However, with the Central Artery having been completed only shortly before, resistance to additional highway construction in Boston grew massive. In response, the governor commissioned a study group to review Boston transportation planning. This group included, among others, the state's later secretary of transportation Frederick Salvucci. The group advised against further highway construction. Indeed, in the 1970 gubernatorial elections, both candidates opposed further massive highway construction schemes in the city. The eventual winner enacted a moratorium on surface highway construction in central Boston. Thus the plans for the Inner Belt were abandoned. Instead, funding was reallocated to public transport.

Because of this, the city ended up with only its elevated highway through downtown; now used by both local and through traffic and despised by many as noisy and unsightly. With the Inner Belt cancelled, traffic pressure on the Central Artery grew far beyond its design capacity. Within ten years of completion of the Central Artery, alternatives for the highway were already being considered. The study group that had produced the Boston

Transportation Planning Review advised building a third harbour tunnel to the city's Logan Airport, located on the other side of the harbour. This would relieve pressure on the existing tunnels connecting to the Central Artery. It also advised rebuilding the Central Artery underground. As a result of political turbulence, however, the projects did not obtain approval.

Meanwhile, traffic on the Central Artery kept growing, causing more and more congestion. It was increasingly perceived as a nuisance too. Moreover, the existing elevated Central Artery had by that time been operational for more than 20 years. Within the not too distant future, the infrastructure would be due for major maintenance and refurbishment for normal lifecycle reasons. This was another incentive to consider possible alternatives.

In the early 1980s, the federal interstate programme, from which interstate highways such as the Central Artery were predominantly financed, ran to its end. The final date for submission of environmental impact statements for interstate projects was September 30th, 1983. This meant that if the Commonwealth of Massachusetts wanted to make use of a substantial (approximately 90%) federal grant, it had to submit a project proposal soon.

By that time the diaphragm wall (also "slurry wall") technique had been developed. Its use would mean that the highway could remain open during construction of an underground replacement. This created new opportunities. Receiving federal funding seemed iffy for a time, because then president Ronald Reagan had vetoed the federal transportation bill that included the funding for the CA/T project. But after Congress overrode his veto (by only one vote), the CA/T project could proceed after all.

6.2.2 The CA/T project objectives

The CA/T project consisted of a large number of subprojects to relieve traffic congestion in downtown Boston and eliminate the undesired elevated highway in the middle of the city. The project concerned a 12 kilometre stretch, with about 260 lane-kilometres. About half of the length was to be in tunnels, 3.8 kilometres on bridges and 2.2 kilometres at grade. Both of the two main stretches were part of an interstate highway: the third harbour tunnel was an extension of I-90, and the Central Artery was part of I-93.

The reconstruction of I-93 (the north-south connection through downtown Boston) had several main purposes: to relieve the nuisance of the existing elevated highway, to replace a derelict viaduct and to extend the highway from three lanes in each direction to four or five lanes in each direction. The widening of the highway, combined with a reduction in the number of on and off ramps, would increase road capacity. The system also required a new fixed link across the Charles River at the north end of the Central Artery. The particulars of this crossing were the subject of a lengthy political discussion since there was strong neighbourhood opposition to the original plans. Finally, agreement was reached on a design, though it was one which increased costs considerably.[2]

Part of the congestion of the Central Artery (I-93) was caused by the connection to East Boston and Logan Airport. This connection, under the water of Boston Harbor, was made via the existing Sumner and Callahan tunnels, starting in the North End neighbourhood, at about the halfway point of the stretch where the Central Artery runs through downtown Boston. These tunnels attracted considerable traffic to the Central Artery. Adding a third harbour tunnel connecting directly to the Massachusetts turnpike (I-90) would bypass this problematic connection.

The corridor of land freed-up from the elevated highway was to be redeveloped into parks. Also, environmental advocates demanded that the large investment in road infrastructure be compensated by further investments in parkland, mainly along the Charles River, north of downtown.[3] Moreover, the dirt excavated from the tunnels was to be used to cover the landfill at Spectacle Island in Boston Harbor. It would then be redeveloped into parkland. As such, project's impact exceeded the geographical boundaries of the I-90 and I-93 corridors.

Coupling the Central Artery and the third harbour tunnel[4]

Originally, the plans for the underground replacement of I-93 and construction of a new connection to the airport and East Boston were separate projects. The first project was particularly supported by stakeholders that had become active in the age of resistance to additional highway builds, in the late 1960s and early 1970s. The second project was mainly advocated by supporters of highway construction in general and by businesses.

Michael Dukakis became governor of Massachusetts in 1974. He was known for his dislike of highways and cars and adopted the Central Artery reconstruction project under the influence of Frederick Salvucci (former member of the study group that had reviewed Boston's transportation planning). Dukakis appointed Salvucci as secretary of transportation. He also supported the plans for a third harbour tunnel, provided that it would not surface in East Boston. This meant, in fact, that it would surface on airport property, which was controversial.

Four years later, the next governor, Edward King, also supported the plans for the third harbour tunnel. But King considered the expensive sunken Central Artery a threat to those plans, because it could absorb all the available financial resources. This seemed to be the end of those plans, but four years later, Dukakis returned as governor. He reappointed

Salvucci as secretary of transportation and relaunched the plans for the Central Artery and the tunnel.

The existence of two parallel projects had long threatened both projects, because like King, proponents of each saw the other as a potential threat to approval of their favourite. After all, both required funding from the same sources. Salvucci realised that the chances for both the Central Artery depression and the third harbour tunnel would be greatest if the two were combined. Salvucci therefore included the third harbour tunnel in the Central Artery plans. He also included the controversial additional lanes for the Central Artery (I-93), to obtain federal funding from the interstate programme.[5] Federal authorities would be unwilling, after all, to provide interstate money for a mere urban beautification project. The additional lanes made it more than that (Altshuler and Luberoff, 2003: 94-98). Combining the projects was a clever way to optimise funding. Business leaders understood that in order to get the third harbour tunnel, they would now have to endorse the Central Artery reconstruction.

The I-90 extension was a different story. This part of the project did not replace a deteriorated or nuisance-generating highway. Moreover, construction would take place mainly in South Boston, which was occupied mainly by businesses. In the neighbourhood in East Boston where the tunnel would surface, however, there was strong opposition, as the resurface location would require demolition of part of a residential area. Eventually the main protagonist of the CA/T project, Salvucci, promised not to sacrifice anyone's home for the project. The plans were altered to relocate the tunnel resurface spot on the property of Logan Airport. This plan was initially opposed not only by the Port Authority (the owner of the airport), but also by the proprietor of the Park 'n Fly parking facility, which would have to be removed. These obstacles were eventually overcome, however, and the I-90 extension through the third harbour tunnel was indeed planned to resurface on airport property. This way, the controversial I-93 depression was brought together with the less controversial I-90 extension.

6.2.3 Project organisation

In 1986, after federal funding and approval had been obtained,[6] the secretary of transportation started to compose a project organisation. The Massachusetts Department of Public Works (DPW), a department under the secretary of transportation, was formally the most logical organisation to become responsible for project implementation, on behalf of the secretary. However, this department had been considerably diminished, since the era of massive highway construction had come to an end. Whereas in the 1960s it employed 4,500 to 5,000 people, by late 1981 that number had dropped to some 2,800. The state legislature, moreover, tended to underfund DPW's operations, and it became common for it to outsource work to private firms. This made the DPW possibly less competent to do the job.[7]

Meanwhile the Massachusetts Bay Transportation Authority (MBTA), operator of the Boston subway, had developed a better reputation in managing construction projects, particularly those that included tunnelling. It had demonstrated its competence, for example, with construction of the red and orange subway lines. It had experience with the new diaphragm wall construction method from the red line extension from Harvard to Alewife.[8]

Secretary of Transportation Salvucci eventually decided to assign the project to DPW after all. He saw the CA/T project as an opportunity to rebuild the DPW and boost the morale of its engineers. A second reason was his assessment that the Federal Highway Authority (FHWA), provider of the federal government subsidy, would consider the DPW its natural partner, because highway funding is expected to go through the DPW and not through public transport authorities. Salvucci, at the same time, decided not to have the money go through DPW, while at the same time appointing MBTA to oversee the project, in order to prevent friction between the two government agencies (Luberoff, Altshuler and Baxter, 1993: 139-146). So, DPW became the sole client organisation.

In 1991, DPW was reorganised into the Massachusetts Highway Department (MHD). During this transition, ownership of the CA/T project was transferred to the Massachusetts Turnpike Authority (MTA), which would become the owner of the highways after their completion. MTA is the semi-autonomous, non-profit organisation that operates the Massachusetts Turnpike. In practice, the whole owner organisation was transferred from MHD to MTA.[9] So, it was not so much a handover of work, but a handover of project management in its entirety.

By the time construction started in the early 1990s, the cost had grown from $2.5 billion at conception in the early 1980s to $5.8 billion. Some 90% was to be funded by the FHWA, which also executed oversight of the grant expenditure.

The large project management consultant contract was awarded to a joint venture of two engineering companies: Bechtel and Parsons Brinckerhoff, Quade & Douglas (B/PB). It oversaw the detailed work done by the many design engineers and construction contractors on behalf of the client. Table 6.1 and Figure 6.1 present the project organisation and management.

Table 6.1 Project organisation of the CA/T project.

	CA/T Project
Client	Commonwealth of Massachusetts (Secretary of Transportation)
Owner	Massachusetts Highway Department (MHD)/Massachusetts Turnpike Authority (MTA)
Project executive (project management consultant, PMC)	Bechtel/Parsons Brinckerhoff (B/PB)
Design engineers	Bechtel/Parsons Brinckerhoff (general design) and several firms (detailed design)
Contractors	Dozens of separately operating construction firms
Operator	Massachusetts Turnpike Authority (MTA)

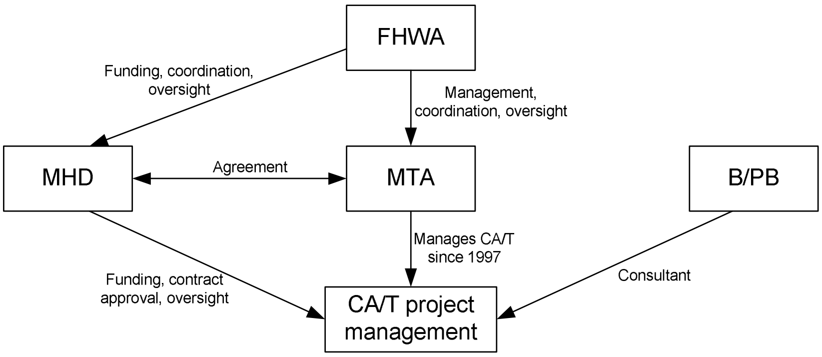

Figure 6.1 Organisational chart of the Central Artery/Tunnel project (source: project documentation).

The DPW managers of the CA/T project were placed in a different office building, away from the rest of their department, near South Station, together with the B/PB staff. The main reason for the physical separation was to prevent the CA/T project from draining all the best people and resources from the rest of the works to be done state-wide by the DPW (Luberoff, Altshuler and Baxter, 1993: 147-148). The assigned DPW and B/PB staff were to be operationally integrated. By 1991, B/PB employed 641 staff on the project (Luberoff, Altshuler and Baxter, 1993: 149-150). In the preparation phase, the DPW oversight staff consisted of eight senior managers, all of whom were assigned to both a functional task *and* a specific "geopolitical" area. Individual DPW engineers supervised each of the major project components. Due to the administrative load, DPW also funded 16 assistants from B/PB. A considerable share of the B/PB staff had been recruited particularly for this job.

Internal management restructuring

In 1994 and 1995, with the designs almost finished and construction started, CA/T management decided to have a management review carried out. It asked Peterson Consulting, Lemley & Associates and Professor Lorsch of the Harvard Business School to do the assessment. The review concerned both the B/PB part of the organisation, which had approximately 1,000 employees at that time, as well as the MHD management team of about 50. The review report mentioned areas of ineffective management, inadequate controls and a deteriorating relationship between the MHD and the B/PB joint venture. It also noted, however, that both organisations were already implementing the changes recommended in the report.

The main recommendation concerned a conversion from a functional organisational structure to an area-responsibility organisation. In the old situation functional departments, such as engineering (design), procurement, project services and construction, had area managers beneath them. The area managers presided over the various design and construction phases in a particular geographical sector of the project. According to the review, this resulted in a fragmentation of control (Hughes, 1998: 251-252). The MHD project director considered the changes an improvement, as the departments were now better able to work towards milestones, which gave them greater bonding with their assignment and incentive to perform.[10]

Transfer of ownership from MHD to the MTA

In the early phases of implementation, the secretary of transportation commissioned Lazard Frères to determine if the state could match the federal money with local funds. One of the things Lazard Frères looked at was who should be the final owner and operator of the project. This did not seem urgent, as the tunnels would not be completed for several years, but Salvucci reckoned that someone had to consider the engineering from an operations and maintenance perspective. Lazard Frères advised that these tasks would best be vested in the MTA or the Massachusetts Port Authority, or a combination of both. Furthermore, Lazard Frères advised deciding early on which organisation it would be – while the engineering was still being done. A contracted engineer, they reasoned, was unlikely to design from a maintenance perspective. But if that did not happen, there was a risk of design mistakes being embedded in the engineering and construction.

Despite this advice, the decision to assign operation and maintenance to the MTA was not made until 1997, after construction was already well underway.[11] Following this decision, the MHD remained responsible for the contracting,[12] and employees were kept on the project. Ownership, however, was transferred from MHD to MTA. Politically, too, the situation changed. Part of the costs became recoverable, as MTA's toll revenues on the turnpike could be used on the CA/T project. This enabled the state to earn back some of its investment (Haynes, 1999: 224). It also led to controversy, because revenues from turnpike users far upstate would be diverted from turnpike upkeep in those areas to the financing of an infrastructure they would not use on a regular basis.

Also, the project now resided under a board that was no longer fully government-owned, but instead was semi-autonomous. As a consequence, the state had less direct control over the project. This proved particularly problematic when controversy arose over reclaiming some of the cost overruns from B/PB, which MTA managers insisted on doing and some administrators tried to prevent.

The Integrated Project Organisation

In 1997 and 1998 the project organisation was again restructured. CA/T management was integrated into an "Integrated Project Organisation" (IPO), following the example of the Trans-Alaskan pipeline project. The IPO was composed of managers from MTA and B/PB. Its purpose was to attain a more seamless and cost-effective organisational and management structure. Another aim was to ensure a smooth transition of the infrastructure to MTA operation after completion.

Project Director Michael Lewis noted a number of efficiencies generated by formation of the IPO:[13]

- It integrated two CA/T organisations into one.
- It discontinued managerial counterparts.
- It made the new organisation flatter, with fewer management tiers.
- It emphasised seamlessness.
- It reduced administrative and technical duplication.
- It expedited decision-making and execution.
- It identified the strongest managers, and appointed them as functional leads.
- It reduced work programme overhead costs.
- It improved linkages for the transition to MTA ownership.

The US National Research Council explained that functions that had been attended to redundantly would now be assigned to only one manager – the one most qualified, regardless of his or her organisational affiliation.[14] The B/PB project manager explained that all its managers had "counterparts" in each functional area, along with a direct interface between the B/PB programme and the MTA project director. Gradually, however, MTA managers were now to acquire sole responsibility.[15]

The IPO enabled direct communication between owner and contractor and brought the owner's managers closer to the contractor's extensive specialist knowledge. The project director claimed that the new organisation would also reinforce the strategic interfaces in the MTA's roles and responsibilities for monitoring the management consultant contract.[16] In 2003, the Committee for Review of the Project Management Practices Employed on the Boston Central Artery/Tunnel Project by the National Academy of Engineering of the Transportation Research Board stated, "The Integrated Project Organisation (IPO) structure currently utilized by the MTA to direct the design and construction of the CA/T project appears to be functioning reasonably well."[17]

Beyond the improved communication and the reinforcement of strategic interfaces, however, formation of the new IPO increased the unilateral dependence of the owner on the contractor. This aspect was not mentioned as an issue of concern in presentations by project management or by the managers involved. Nor was it mentioned by the Committee for Review. It was only brought up later, when occurrences of bounded manageability were analysed by the Senate Post Audit and Oversight Committee. In 2004, this committee went so far as to attribute the problematic oversight to this dependence.[18]

6.3 Occurrences of complexity

Despite some delays and cost overruns, construction of the new Central Artery and third harbour tunnel went mostly successfully. "The project has accomplished outstanding technical achievements, the project has been sensitive to those communities affected by the construction, and has a better than average safety record."[19] Mishaps did occur, but most were incidents after completion. Yet, a particular dynamic arose within the organisation and management of the project, mostly concerning attempts to improve project manageability. This section focuses on occurrences of manageability issues related to uncertainty in project management. The discussion starts with technical issues. It then continues to organisational ones.

6.3.1 Occurrence I: High technical differentiation and various engineering marvels

The CA/T project was strongly differentiated. The project was in fact a series of self-contained subprojects highly intertwined functionally but with fairly little technical interrelation. Each had the size of otherwise full-scale projects. Thus, the project was divided into many segments with, as of 1993, 56 final design sections or packages. Every package had a prime contractor, and there were 132 prime construction contracts (Hughes, 1998: 240). B/PB's work now included general designs that had to be elaborated in detail under the different contracts. All the interfaces were managed by B/PB. Apart from the large numbers of participants, differentiation was large, because the engineering concerned not only tunnels, but also a variety of structures like a large and expensive cable-stayed bridge, large traffic nods and ventilation buildings. Each required very different technologies and construction methods. Within these subprojects, there were numerous subsystems as well. This variation placed heavy demands on the abilities of the project's management to control implementation.

In addition, standardisation was difficult. Construction methods for the various tunnels could not even be standardised. Numerous techniques were used to create the system of tunnels and adjacent structures. The tunnel under Boston Harbor was composed of 12 prefabricated tunnel sections that were then immersed. The Fort Point Channel Tunnel was built at a dry dock (a casting basin) near the work trace. When the concrete tunnel box was finished, the dock was filled with water and the tunnel box pushed to the proper location, where it was immersed. The tunnel sections underneath the South Boston railway yard were installed while the tracks remained in operation. The soil underneath the railway yard was frozen, after which the tunnel boxes were jacked to the appropriate location. The I-93 tunnel was built using diaphragm walls, built next to the existing Central Artery highway. Then, a temporary construction was built atop these new diaphragm walls. After that, the old supporting structure was removed and excavation took place between the diaphragm walls, underneath the elevated highway.[20]

The way the project was defined complicated the engineering challenges involved and heightened the social complexity. The more challenging the project, the larger the influence of uncertainties on its development and implementation.

6.3.2 Occurrences II and III: Connector tunnel ceiling collapse

On July 10th, 2006, the drop-ceiling in the I-90 connector tunnel to the Ted Williams Tunnel collapsed, crushing a car. The passenger, a 38-year-old woman, was killed. The driver miraculously could exit the car alive. A drop-ceiling is a suspended ceiling, in this case made of concrete slabs, that creates a vent canal above the highway lanes, between the inner tunnel and the outer concrete shell. This allows exhaust fumes to escape, and smoke in case of a fire in the tunnel. The drop-ceilings are attached to the outer shell. The bolts holding the suspension system in place seem to have loosened, causing the heavy concrete slabs to fall onto the road deck and the car.

Occurrence II: Design change of connector tunnel drop-ceiling

The investigation after the drop-ceiling incident found that the design for the drop-ceiling by the local engineering firm, HDR Engineering, had been modified by CA/T managers. Installation and functioning of metal slabs as originally designed had proven problematic. The same type of slabs had been used in the Ted Williams Tunnel. They were relatively light. Their installation, however, turned out to be labour intensive, and the slabs were rather expensive too. Also, they appeared insufficiently stable to withstand the stronger winds and vibrations in the connector tunnel. CA/T managers decided to install concrete slabs instead. HDR had not foreseen the possibility of changes in the design.

Due to the heavier slabs now being used, project managers called for steel beams to be installed in the outer tunnel concrete, to attach the steel hangers for the heavier slabs. The last 60 metres of the connector tunnel, however, had already been built without the steel beams, and the work could not be redone. As a result, many bolts for the drop-ceiling suspension system had to be fixed directly into the concrete there, using both bolts and epoxy (a strong industrial adhesive) in the drilled holes. According to the specifications, the epoxy-bolt fixture should be able to hold a load of at least 6,350 pounds (approximately 2,900 kg). This was more than twice the weight that would need to be supported in the connector tunnel.

Because the construction contractor nevertheless had little confidence in this design, he sought help from a consultant, which proposed an alternative solution using metal slabs. CA/T managers rejected this design though, because of a crucial design interface: the emergency fans. The high-tech fan system removes smoke from fire-involving incidents in the tunnel. The system works with powerful fans that appeared to make the drop-ceiling vibrate when operating at full power. Therefore, the consultant added concrete to the slabs to increase their weight to just over half that of full concrete slabs. This time the CA/T managers rejected the design because the savings obtained for the project were insufficient, and CA/T management had already signed contracts with a concrete supplier for the full load. Management therefore decided to use the full-load concrete slabs with epoxy for the fixtures. The engineers involved still had reservations about the safety of the system and the way it was installed.[21] The Inspector General even warned, as early as 1998, of the potentially poor robustness of the anchor bolt design.[22]

There have been debates about a decision by B/PB to reduce the number of fixtures per slab and about the weight used in the safety tests. There were no standard prescribed tests for such systems, and engineers in hindsight criticised the rigour of the tests too. B/PB increased the weight in later tests of installed bolts, but it did not rerun the tests of the bolts installed earlier. A B/PB consultant referred to this as an engineering judgement based on the belief that the weight to be held would be fairly constant. B/PB declined further comment because it was subject to a criminal probe on this.[23]

The change from metal to concrete slabs demonstrated that one small change could affect the requirements for other system units to such an extent that it was hard to be sure that all ramifications could be kept under control (an incompleteness uncertainty). The judgements made by B/PB and the various subcontractors appear to be strongly based on their tacit knowledge (inscrutability uncertainty). In the assessment by CA/T management, interpretation uncertainty played a role, as evident in the doubts raised by some engineers about the management's decisions.

The engineering trade-off suggests that the project managers (maybe unwittingly) valued theoretical specifications over practical test results, though this has not been determined indisputably. It would imply ignorance of the inherent fallibility, i.e. the numerous possible deviations that could occur, in application of the technique. There are two possible reasons for this: it may have been overlooked as a matter of importance or it may have been truly unknown that deviations could occur here. The former would make it an incompleteness uncertainty, the latter an inconceivability one. In either case, technical properties dominated the frame of reference, not the manifestation of potential uncertainties as a result of deviations from the prescribed procedures (i.e. human failure) in the installation process. In both cases the perceived objectifiability of technical specifications, which are quantitative, measurable and behave in accordance with the laws of physics, can seem a welcome resort.

Occurrence III: Installation and testing of the drop-ceiling

Use of epoxy requires a very careful work process. The hole must be drilled to exactly the proper depth, the drilled hole must be cleaned of dust before inserting the epoxy, the epoxy components must be mixed exactly right and left to harden sufficiently, to name a few particularly important steps. Memos disclosed after the incident state that pores in the concrete absorbed most of the epoxy. One noted that the holes had been drilled too deeply for the amount of epoxy inserted, leaving a void. Also, cold weather procedures were not always used when appropriate and dust was sometimes left in the holes. The contractor was asked to address these problems and eventually B/PB signed off on the contract.[24]

A 1998 report by the Inspector General of Massachusetts suggests that many bolt holes were drilled through the steel reinforcement of the concrete, which could also make the fixture less reliable. The project managers did not consult any of the designers or the section design consultant for an evaluation of the possible impact of drilling through reinforcement bars on the structural integrity of the tunnel roof.[25]

After the collapse, the MTA chairperson said that the bolts had been tested before the tunnels were opened. A new, periodic inspection was allegedly in progress when the ceiling collapsed. During installation, however, some concerns about the structural integrity of the bolts and epoxy design did arise due to some observed loosening of bolts. Project management consultant B/PB decided to proceed with the installation of the ceiling while managers discussed what to do about the loose bolts. By the time the managers had a plan, in January 2000, much of the installation work had already been done. This made retesting much more expensive and time consuming. Therefore B/PB decided to do a retest only in the high-occupancy vehicle lane. Only a few bolts in this tougher test above the high-occupancy vehicle lane failed. B/PB then did not urge further retesting of the other bolts at that time.[26]

The investigation after the collapse suggested that the epoxy, a two-component adhesive, had failed to hold the bolts in their holes in the concrete outer shell of the tunnel. An investigation of the other bolts in the tunnel turned up more than 240 loose ceiling bolt fixtures,[27] and nearly all of the 1,150 fixtures were deemed unreliable.[28] Workers nevertheless said that ample inspections had been done by B/PB employees.[29] It did happen that as early as 1999, when the bolts were installed, five of them gave way. It is not clear whether the problem at that time was addressed.[30] Also, a 1998 report by the Massachusetts Inspector General on the installation of anchor bolts in the Ted Williams Tunnel, notes that 8 out of 50 bolts failed a strength test in 1994, due to improper mixing of the epoxy. Later that year, 5 out of 58 bolts failed the tests because epoxy had not been allowed to harden enough, because not enough epoxy had been used or because the drill holes had not been properly cleaned.[31] The fact that B/PB did not change the design in this regard, which, according to the Inspector General, it had promised to do after the 1998 report, was reason for the Inspector General to criticise B/PB's combination of roles as both manager responsible for the design and engineer overseeing the quality of the project.[32]

The US Attorneys eventually dropped charges against contractor Modern Continental for poor workmanship. The National Transportation Safety Board concluded that the wrong epoxy had been used. Section designer Gannett Fleming and B/PB were said to have failed to identify the proper creep resistance in the specifications for the epoxy, and epoxy supplier Powers Fasteners "failed to provide the CA/T project with complete, accurate and detailed information about the suitability of the company's Fast Set epoxy for sustaining long-term tensile loads". They also failed to determine that an anchor displacement in 1999 was a result of creep due to the use of the Fast Set epoxy. Contractor Modern Continental and B/PB, moreover, failed to execute safety checks on the occasions of the earlier problems.[33]

The long-term characteristics were the key issue here. Apparently, the specifications were not complete. That does not, however, exclude the possibility of deficiencies in the workmanship on the ceiling. Although the epoxy had been tested and the specifications had been approved, the court concluded that the specifications were wrong and had to be changed. It also meant that supplier Power Fasteners had to settle the case with the relatives of the deceased woman. Still, as the above indicates, inspections showed that various holes had been drilled wrongly, though not all possible occurrences of fallibility, for instance, related to the work process, could be proven. The contractor successfully fended off accusations of botched work. A disputable issue is whether the design could be considered flawed since fallibility was so high, perhaps not from a legal but from an engineering view point. Even if the technical specifications were indeed flawed, the fallibility of the installation process remained high, as the analysis of the bolts that gave way has shown.[34]

Many uncertainties came together in the installation and testing of the fixtures. This points to both types of interaction-driven uncertainty: the designers were uncertain about how the managers would assess the fixture technology and about the inputs they provided throughout the design and installation process. For the managers there was intention uncertainty, regarding whether contractors and their staff would install the fixtures the right way and whether the epoxy specifications provided by the supplier were correct. From the viewpoint of the design process and the construction of the connector tunnel, however, the uncertainty can also be considered a combination of the incompleteness and the instability types. The functioning of the epoxy in the particular circumstances of the attached load and the conditions of usage would be better known if a full lifespan test could have been conducted. This may not have been practicable. However, it has been debated whether the testing done was sufficient. With regard to the installation process, if every single act in the installation of the fixtures could be controlled and validated, flaws could have been prevented or detected early. This was not practical, indicating incompleteness uncertainties. The variability in the installation process is an instability uncertainty. In combination with the abovementioned incompleteness uncertainty, it can be fatal as the case shows. The outcome of the court case, which noted concerns about B/PB's work but focused strongly on the specifications of the epoxy, may conceal a "Gettier problem" (Gettier, 1963), in which justified true belief is undermined. The premise that A causes B, in which the assessor is justified in believing the causal relation, may be false, because A and B may coincidently concur. The fact that the epoxy specifications did not seem reliable for the application at hand did not mean that the highly fallible job of installing the fixtures was done exactly right. Deviations may have contributed more to the mishaps than the flawed specifications. This means that one uncertainty does not exclude another.

The trade-offs in the ceiling design of the I-90 connector tunnel reveal the risk of engineering decisions affecting a large number of subsystems. As in the grout arch columns of the Souterrain project, installation of each individual fixture might seem controllable, but with very many possible deviations, the chance that one fixture is fundamentally flawed was considerable. This again indicates a problematic aspect of instability uncertainty: just one flaw can make an entire system unreliable. Rather than the expected average performance of each fixture, the “outliers” are the relevant performances. These are unexpected in each individual event, but statistically likely when executing the same work repeatedly. Like in the Souterrain project, it is an inverse “law of large numbers” (see Chapter 5).

6.3.3 Occurrences IV and V: Design and performance of the I-93 tunnels

Occurrence IV: Leaks on I-93

In the later phases of construction and in the first month of operation, water regularly flowed into the I-93 tunnels. An investigation showed 102 defective or leaking diaphragm wall panels. Two required major repairs, 33 required moderate repairs, and 67 needed patching. These figures applied to an 80% complete check of the 1,937 diaphragm wall panels. The remainder still had to be inspected at the time of the report’s release. State investigators found that an external concrete supplier had delivered low-quality concrete, which led to legal prosecution.[35] As a result of salt corrosion, too, there was a threat of severe damage to the structures, and engineers foresaw that pumps would wear out much earlier than planned.

But on September 15th, 2004, there was an acute incident. A large breach occurred in a diaphragm wall panel of the I-93 tunnel, spilling large amounts of water onto the tunnel roadway. This leak was the result of an error at a place where two construction contracts met. The construction contractor failed to remove an “end stop” and clear away dirt and debris trapped by overflow concrete in its section of the wall. Specifically, a report on the construction pointed to contractor Modern Continental as failing to remove the temporary steel endplate left by the contractor of another diaphragm wall panel, as well as the residual concrete around that plate. As it concerned the interface of two different work packages, different firms were responsible for either side. This allowed water through the wall.

B/PB, responsible for interfaces, distinguished this from other leaks and accepted liability for it, though it claimed compensation from the contractors.[36] This occurrence had some characteristics of an instability uncertainty, since the risk that some works would have partly masked flaws was identifiable in advance. It could also be perceived as an incompleteness uncertainty in the sense that, had control mechanisms not been restricted, the deviations could have been discovered. The faulty works and the crucial position of the walls and ceiling in the functioning of the whole system rendered it a particularly nasty deviation. Other flaws were found in the construction of the panel too that were not particularly related to interfaces, such as the inclusion of debris, the use of only one tremie pipe (resulting in uneven distribution of the concrete), reduction of the size of the reinforcing cage when an obstruction was met in the trench, shifting of the bottom of the reinforcing cage when concrete was pouredand patching of an inclusion rather than repairing it.[37] These are deviations from the expected and can be categorised as the intention uncertainty that comes with the practical limitations of control mechanisms.

A second kind of leak had also occurred regularly at the roof-wall joints of the I-93 tunnels. These leaks were innumerable because as soon as one was sealed with grout, new ones sprung or old ones re-emerged. There were hundreds of leaks at the same time. This was perceived to be a structural problem that, unless a way was found to seal them permanently, could lead to higher maintenance costs. The leaks, mainly the result of a problematic connection between the tunnel walls and ceiling, started during construction in the 1990s. Though the cause was not definitively established, there were suspicions of poor construction, including use of improper equipment and inadequate surface preparation before applying a waterproofing membrane. Also, the selection and installation of waterproofing systems was problematic. A waterproofing task force was set up in March 1997. A July 31st, 1997, report attributed 95% of the waterproofing problems to unsatisfactory quality control of the construction contractors.[38]

In 2000, a task force composed of engineers from B/PB, MTA and FHWA concluded that the leaks were related to the tunnels still being partially open, as the amount of leaking water could be related to the amount of precipitation. In December 2001, however, a draft report on cost overruns written by a consultant[39] concluded that the original design of the waterproofing above the roof girders in one section of the I-93 tunnels provided insufficient protection against water inflow.[40] A comparable problem occurred at Fort Point Channel (I-90), where steel sheets were supposed to be tightly interlocked but instead were overlapped. This deviance was documented by B/PB’s field engineer, but it was not corrected. Neither was it mentioned to the owner.[41]

The leakage problems revealed two kinds of problematic interfaces. First were the technical interfaces between the diaphragm wall panels and between the walls and roof sections. Second were the interfaces between the contract areas. These created uncertainties that were difficult to resolve, because they largely concerned work executed by hired contractors. Even though the project management consultant, B/PB, was responsible for oversight, it was difficult or even impossible to implement one hundred percent control. Hence, incompleteness and intention uncertainty in the executed works remained.

Occurrence V: Diaphragm walls without tunnel box

The leakages described above can also be related to the engineering design. Diaphragm walls are usually used as temporary structural element to keep excavations free of groundwater. They were, however, used as a permanent structural element in the I-93 tunnel of the CA/T project. There was little choice in the matter because the path underneath the existing Central Artery left no space for an inner concrete tunnel box in combination with the additional highway lanes. A reduction of highway lanes was unacceptable, as it would reduce the functionality so much so that the improvement over the old, congested highway would be minimal. Widening the path at surface level would require right-of-way or real estate acquisition expanding costs and implementation times unacceptably. The only option was to leave the inner tunnel box out of the design.[42]

The design without inner tunnel box resulted in other difficulties related to construction of the tunnel roof. A connection between a 40 metre deep wall and a 30 metre wide roof was bound to crack under varying weather conditions. This was thought to be the cause of the numerous leaks that occurred after completion, described above.[43] The design also increased the technical challenge because it raised the dependence on external interfaces. It also increased the information required and the chance of important aspects remaining unknown.

In the balance between costs, implementation time, scope and quality, the design can be seen as a sacrifice of robustness; i.e. quality. But there had been experiences with the technique, mainly in other countries. This meant that within the framework of realistic options (that did not include a tunnel box) the chosen design was considered the most robust option. Risks related to this engineering decision were considered manageable. Although the Central Artery was designed “conservatively”, implying that in the engineering design, no risks were taken,[44] one could argue that “conservatively with no tunnel box” as reference point is something different than “conservatively including a tunnel box”. By using this design the project management exposed itself to more instability, incompleteness and inconceivability uncertainties.

6.3.4 Occurrence VI: Cost growth at the outset – mitigation and compensation

The CA/T project had strong involvement of external actors. Some, such as the Artery Business Committee, provided contributions and acted as a countervailing force.[45] There was also strong involvement of external actors, or interest groups, that sought to optimise the project for the communities that would be affected. In doing so, however, they contributed considerably to the complexity of the preparation process. The project became much more expensive than originally budgeted, partly due to large-scale mitigation and compensation measures included early on.

The first cost estimates for the project, some $2.5 billion, were made in the early 1980s and used for approval of federal funding. The designs at that time were preliminary, and had a limited level of detail. Many engineering features remained unresolved. The designs were further elaborated from 1985 onwards. This went in parallel with a steady increase in the estimated cost. Investments were required in parklands to compensate for the infrastructure outlay. Also, other extensive mitigation measures were approved and there was autonomous growth of the project due to more detailed insights. More labour was required for filing the final environmental impact statement and carrying out design studies on some of the most controversial parts of the scheme, such as the Charles River crossing (Luberoff, Altshuler and Baxter, 1993: 152). Many of the mitigation claims likely included intention uncertainty. They were, for instance, submitted for political reasons, to funnel some of the federal money to goals other than just highway development.[46]

The Charles River crossing elicited major controversy. It was planned at the north end of the Central Artery, where the highway entered the town of Cambridge. Apart from crossing the river, a connection had to be made with a local road that ran along the river. There was no space for a connector however. A protracted design effort finally produced "Scheme Z".[47] This design evoked fierce opposition though. When, after the 1991 gubernatorial election, a new governor (Bill Weld) and a new secretary of transportation (Richard Taylor, with James Kerasiotes as the commissioner of public works) came into office, Scheme Z was discarded in favour of an elegant bridge designed by Swiss architect Christian Menn. The bridge, however, was an estimated $1.3 billion more expensive.

Even within project teams there was sometimes tension between those who wanted to spend resources to resolve the design problems and those who preferred to focus on the most pressing political issues (Luberoff, Altshuler and Baxter, 1993: 154). The preparation phase resulted in an estimated 1,500 separate mitigation agreements directly related to the complex project environment. Ten times the budgeted number of consulting hours was spent. This accounted for at least one third of the project's total cost at that time, which grew to $5.2 billion by 1991 ($6.4 billion in 2002 prices) (Altshuler and Luberoff, 2003: 104-105).[48]

Design changes made by the state in negotiations with local constituents caused increased expenditures. A total of 1,100 mitigation commitments were included (Hughes, 1998: 222).[49] The state wanted to be responsive to local concerns, though B/PB was experiencing the pressure this placed on time and budget (interpretation uncertainty). The state's position as client could have been weakened by the emerging informal ties between B/PB and FHWA, because they bypassed the client (Altshuler, Luberoff and Baxter, 1993: 157). These contacts did not necessarily disadvantage the state's managers, but they did implicitly reduce their ability to control the process, indicating intention uncertainty (in the agent's attitude).

Second opinion committee and "owner's engineers"

According to the initial plans, DPW would provide designs to a 10% level of detail. In the late 1980s, this task was transferred to B/PB and extended to 25% to 30%. This increased the value of B/PB's contracts from $88 million annually to $158 million. Its staff grew to some 1,000 employees in the early 1990s, compared to some 60 employees at DPW.[50]

Salvucci was aware of the powerful position that B/PB had obtained in relation to the modest expertise in the client organisation. He was also aware that the joint venture did not have the same interests as the Commonwealth of Massachusetts. With his undersecretary, Matthew Coogan, he therefore raised a "second opinion committee", composed of the head of construction and engineering of MBTA (the public transport authority), the chief engineer of the Massachusetts Port Authority and the former top construction engineer of MBTA, who had since moved to the MTA.[51] This committee had a strong engineering base and was to serve as a counterweight to the joint venture. Another important role for the committee was to oversee the interfaces between B/PB as the initial designer and the section designers, who were hired to complete the designs in detail.[52] The second opinion committee later disbanded, however, as the persons appointed could no longer execute their duties.[53] The new administration under Governor Weld chose not to restore the committee by appointing new members.[54]

The Weld administration instead introduced a privatisation philosophy. To avoid the waste and inefficiency of overlapping bureaucracies, the role of B/PB was strengthened, while many DPW engineers left public service.[55] The privatisation was indeed ostensibly more efficient, but it was impossible to foresee all the possible consequences of this trade-off in manageability. These consequences may have included oversight capabilities, cost control and limitation of possible strategic behaviour by the client. In the end, the costs of the consequences may well have been higher than the efficiency savings. The possibility of defective oversight was noted by the Inspector General in 1991 (see further below). But this resulted in no changes of political views. After the ceiling-collapse incident, Inspector General Gregory Sullivan stated that he thought "Massachusetts should never again embark upon a major public works project without the help of an objective, independent 'owner's engineer' whose solitary task is to ride herd over designers, managers, and contractors".[56]

6.3.5 Occurrences VII, VIII and IX: Cost escalation during implementation

Occurrence VII: Loss of control over the budget

The CA/T project became infamous for its large cost overruns. The first cost increases, as we read, occurred in the preparation phase. But throughout implementation, too, cost manageability remained problematic. This section gives a short chronology of the uncontrollable escalation.

Between 1991 and 1993, cost estimates rose from $5.2 billion to $7.7 billion,[57] with the new design for the Charles River crossing being one of the causes. As the new bridge required a new environmental impact statement, works could not start before 1994. The overall completion date for the project was pushed back to 2004.[58]

In February 2000, even more bad news on finances was made public. CA/T officials announced a $1.4 billion cost overrun. A financial review executed later raised that figure to $2.5 billion. According to some officials, the overrun actually came to light in a "bottom-to-top" review of costs in late 1999. The information then, however, appears to have been kept from investors in state bonds in December 1999. The state treasurer forced disclosure two months later.[59]

Although the CA/T project was funded from the interstate programme, which provided a fixed grant covering some 90% of the total cost, federal government capped its contribution at almost $8.6 billion, after indications that CA/T management had misrepresented the project costs by not including a $1.4 billion cost increase in the 1997 and 1998 finance plans.[60] The remainder had to be paid by the Commonwealth of Massachusetts, constituting a substantial drain on the state's funds. This removed cost control incentives for the FHWA, which allegedly became an advocate of expensive add-ons.[61]

B/PB had already informed CA/T officials back in 1994 that the project cost was likely to amount to $13.8 billion, rather than the then-estimated $7.7 billion. Earlier that year, a draft report by B/PB's CA/T senior management review team mentioned a likely figure of $12.3 billion, with completion in 2007.[62] Shortly after B/PB managers had informed the governor, CA/T officials asked B/PB to replace the project manager. The secretary of transportation stated in December 1994, "we need a manager who exhibits a can-do attitude, both publicly and privately".[63] Those involved had different views on the reason for the manager's dismissal, varying from the manager not being sufficiently committed to presenting lower cost figures[64] or to holding down costs,[65] to the project entering a new phase with, particularly, construction activities that required a hands-on construction manager.[66] The Inspector General's investigation suggested that the CA/T management reduced the $13.8 billion figure to approximately $8 billion using more than two hundred accounting assumptions, exclusions and deductions. According to the Inspector General's report, FHWA officials were fully informed of this and disapproved of only a fraction of these measures.[67] A year earlier, the federal task force on the project had slightly different views about this and stated that project management had failed to disclose all information on its finances.[68] The total costs grew to some $14.6 billion before the project was completed in 2005.

The cost increases were to considerable extent (55%) due to inflation.[69] Mitigation measures caused 15% of the overruns. Other contributors were the expanded scope (8%), accounting changes (7%), traffic measures (5%), schedule maintenance (3%), contingencies for unknowns (2%) and other (5%).[70] The origins of the cost overruns suggest both instability uncertainties, such as the schedule maintenance, contingencies and other variability issues, and incompleteness uncertainties, such as the expanded scope and traffic measures. The chronology indicates that there may also have been interaction-driven uncertainties, related to the oversight by FHWA and the way B/PB's cost estimates were dealt with (interpretation uncertainty), alongside the possible intentions B/PB may have had in providing these figures (intention uncertainty).

Occurrence VIII: Claims and changes
Dealing with requests for changes in a contract or claims for additional costs from contractors was one of the largest management efforts. Frequent causes were site conditions differing from expectations, design adjustments and scope adjustments. These reflected both instability and incompleteness uncertainties. Project managers estimated that payments for claims and changes totalled $1.6 billion. There were more than 11,000 modifications. These represented some 20% of the total construction commitment, indicating the difficulties in managing issues arising due to incomplete designs, scheduling conflicts and contract interfaces (Table 6.2).

Table 6.2 Claims and changes as a management effort as of November 2001 (Central Artery/Tunnel Project, Construction Claims and Changes, presentation November 2001).

Type of modification	Percentage of occurrence	Percentage of costs of claims and changes
Design	35	16
Schedule adjustments	3	9
Scope modification	6	20
Diverging site conditions	21	22
Third party	9	5
Other	26	28

There were considerable costs due to scope modifications and diverging site conditions. Scope modifications were relatively benign, as they increase the functional value of the project.[71] Diverging site conditions, however, indicate that the specifications did not match reality. An often-mentioned cause was that the project took place in landfill area in downtown Boston, where relics of over two centuries of city life were found. The Office of the Inspector General, however, criticised the extensive use of the categorisation “diverging site conditions”: “[T]he Office has identified cases in which the attribution of cost overruns to ‘differing site conditions’ has been used by B/PB as a cover story for its failure to perform its contractual obligation to fully assess site conditions during the design stage”.[72] This suggests that differing site conditions were not an instability uncertainty but in fact in many cases an incompleteness uncertainty, indicating misuse of the categorisation as an easy cover for other construction or management difficulties. B/PB denied this. It must, by the way, be noted that claims came not only from within B/PB, but also from other contractors and subcontractors.

Each divergence meant a contract change was required, to be filed with the project management. With claims from dozens of contract areas, it was difficult for the managers to keep up with the input and retain control of the project. As the claims piled up, the owner decided to transfer authority for the assessment of smaller claims to lower management tiers.[73] This made the process better manageable, but meant that top management lost sight of a part of the process, eventually resulting in a surprise overrun upon a wholesale recalculation.

Occurrence IX: Cost increases under the IPO

The IPO was an attempt to stem the negative effects of the owner’s lack of expertise and to retain some control over B/PB. But B/PB employees became more or less MTA staff rather than consultants.[74] The lack of a countervailing force within the integrated organisation may have led to “groupthink” (see Janis, 1972; Janis and Mann, 1977). This might have neutralised critical views on the direction the project was heading. The Senate Committee on Post Audit and Oversight of the Commonwealth of Massachusetts was critical of the project’s organisational structure. The committee stated, “The benefits of IPOs have been realised primarily in the private sector and never on a public project that rivalled the CA/T Project in scope or cost.” And, “Public projects require a higher level of accountability, and certain safeguards are necessary to ensure efficient and responsible state government.”[75] Furthermore, the committee was critical that no long-term plan or analysis was ever pursued of the legal, financial or contractual obligations and consequences of an IPO related to the CA/T project. As a result, there was limited cost recovery and accountability.

B/PB employees basically acted as state officials under the IPO. The state has therefore been able to recover almost none of the costs incurred for, among other things, processing the numerous claims and changes, which may (or may not) be attributable to flaws in the work of B/PB.[76] Also, the Inspector General had concerns, stating, “the resulting scheme has the potential to be an accountability nightmare… [and] intertwining the CA/T oversight function with [the] private management function is an invitation to fraud, waste and abuse”, to which the Senate Committee agreed.[77]

The "merge" between public and private managers created shared responsibilities. It would normally also create equal incentives. But since information was more amply available within B/PB than within the owner organisation, decisions were only de facto made by the owner. In practice, they were made by the joint venture. The owner's managers also had trouble assessing whether their contractor was doing a good job. The lack of checks and balances, or an "arm's length" distance, meant there was no opportunity to properly control decisions, as the Inspector General also stated.[78] So, in addition to groupthink, a principal-agent problem (intention uncertainty) occurred.[79] Besides, B/PB still had a private stake in the project. This made reclaiming additional costs from B/PB more difficult. After all, where did the MTA stop and B/PB start? So in practice, the IPO dealt mostly with interpretation uncertainties (i.e. lack of assessment by state officials). But this could not neutralise the intention uncertainties within the project organisation. According to the Senate Committee these may even have worsened.

Moreover, once the IPO was in place, the weird situation occurred that B/PB became responsible for identifying the causes of project overruns and delays associated with its own work. Before November 2004, B/PB accepted no liability for any substantial cost overruns related to its own work.[80] A report issued in December 2003 by the Inspector General concerning cost recovery for the "Big Dig" stated the following:

> *"B/PB's role in the cost recovery process is like a fox guarding the hen house. B/PB's extensive role in preliminary design and final design management should preclude any role in a program – such as cost recovery program – that purports to examine problems that may have been caused by B/PB's own work. B/PB controls the data."*[81]

The IPO even created a scheme in which an MTA director was reporting to both the MTA and B/PB, which created "divided loyalties and conflicting interests".[82] According to the Senate Committee, the warnings and recommendations remained largely unaddressed.

The Inspector General of the US Department of Transportation provided lessons for future oversight in a statement. He said that at a state level: "[T]he Central Artery Project's problematic history presents many lessons in how not to manage a public works megaproject." On the IPO, he had the following to say:

> *"In 1998, the Authority [MTA, ML] combined some of its employees with Bechtel/Parsons employees in an Integrated Project Organization. This was intended to make management more efficient, but it hindered the Authority's ability to oversee Bechtel/Parsons, because the Authority and Bechtel/Parsons had effectively become partners in the Project."*

The Inspector General assumed that this partnership situation was at least partly to blame for the fact that MTA had been unable to recover any of the $1.9 billion paid to B/PB at the time of the report, despite the B/PB's acknowledged liability in some of the cases.[83] Interweaving owners and contractors can thus be considered a risky enterprise, as accountability becomes problematic. This is not just because within one organisation it can become less clear who was responsible for what, but also because the owner commits to the acts of the contractor and vice versa.

6.3.6 Occurrence X: The powerful position of the project management consultant

Secretary of Transportation Salvucci sought to compensate for DPW's lack of competence by hiring private firms for design and management. The secretary hired the joint venture B/PB to draw up the preliminary plans for the project. Later, the joint venture was also awarded the contract to manage project implementation, as a project management consultant (although some engineering tasks were also included in the contract). B/PB thus became responsible for managing the design, project planning and related operations. Eventually, B/PB oversaw 38 different section design consultants and 142 construction contracts.[84] The companies Bechtel and Parsons Brinckerhoff had most demonstrable experience in working with diaphragm walls. This was a crucial structural element. It allowed the project to keep the old highway open during the works. When the two teamed up for the tender, they were practically unsurpassable.[85] MHD/MTA selected subcontractors and formally held the contracts.[86]

Undersecretary of Transportation Coogan decided to create a small cadre of DPW managers to supervise the B/PB joint venture team, though keeping the internal staff as small and non-bureaucratic as possible. This freed the consultant to be innovative and efficient. The government managers would focus on issues of policy and constituency building. Technical and management decisions were left to B/PB. This did lead to some ambiguous leadership issues however (Altshuler and Luberoff, 2003: 149). They indicate both interpretation uncertainty (B/PB depended on decisions made by a small cadre of DPW staff who essentially had a different task focus) and intention uncertainty (DPW depended on B/PB to carry out a potentially innovative engineering design that it probably had limited understanding of).

B/PB's increasingly dominant position within the project, which now included a design job and direct contacts with the FHWA, were a source of concern for the Massachusetts Inspector General.[87] Early in 1990, the Inspector General criticised the "increasingly apparent vulnerabilities of the Department's [DPW, ML] long-term dependence on a consultant to manage the $4.43 billion" CA/T project.[88] DPW had negotiated a series of contracts with B/PB, rather than tendering each new contract. The Inspector General considered B/PB a kind of monopolist. Due to its past in the project, and hence unique knowledge, it was difficult for the DPW to hire another consultant for each new contract. This lack of a level playing field weakened DPW's position in relation to B/PB. In fact, its position became weaker with each new contract. For example, the number and values of services grew rapidly in preparation of the supplementary environmental impact statement and in some special design studies (Luberoff, Altshuler and Baxter, 1993: 158). The Inspector General noted in this regard, "[T]he Department is demonstrating an inability to control the contract, and by implication, the consultant."[89] This was again symptomatic of intention uncertainty. Some general controversy about the large-scale hiring of consultants arose as well, because the consultant's employees got higher paycheques than the civil servants (Luberoff, Altshuler and Baxter, 1993: 159-160).

The practical impossibility of hiring other firms for the project management job, once contracts had to be renewed, was one problem. Another was the difficulty Inspector General Sullivan noted with the combination of roles that B/PB acquired. B/PB was hired in the first place to compensate for the owner's lack of engineering expertise, and therefore more or less became the owner's engineer. As B/PB also became responsible for the design, and developed the design in part itself, it was in fact checking its own work.[90] This created substantial intention uncertainty.

So, the project organisation incorporated a strong mutual dependency between, most particularly, the owner organisation of MHD/MTA and the management consultant and super-contractor B/PB. MHD/MTA was heavily dependent on the expertise of B/PB, and B/PB depended on the decision-making competence of MHD and later MTA. A few things made this dependency particularly troublesome for MHD/MTA. First, it was difficult for MHD/MTA managers to oversee all aspects of the project, particularly complex engineering issues. Second, B/PB was not tied to the fate of the project, and the budgetary consequences, after completion. This does not mean that B/PB was not committed to budgetary discipline – there are indications that B/PB was actually more realistic about cost estimates than MHD/MTA.[91] But it does mean that the project was a way for B/PB to make money, considering that it was a joint venture of private companies. There was no incentive for them to reduce their own fees. There were even allegations that B/PB benefited from poor works, as they were also paid for the rectification. Irrespective of whether they misused this situation (there is no indisputable proof of such), the incentive situation was unfavourable. Former secretary of transportation Kerasiotes countered this, pointing out that the reputation of the two joint venture companies was at stake.[92]

Meanwhile, owner MHD/MTA depended on the secretary of transportation and the political processes in Massachusetts in general. This created incentives to play down and cover up cost overruns and hold on fiercely but unrealistically to budgets. In doing so, MHD/MTA clashed with the contractor B/PB, which stood at the other end of the spectrum. It even led to insinuations that the dismissal of the contractor's project manager was encouraged, as the project manager was loath to go along with the unrealistic cost assumptions.[93]

6.3.7 Occurrence XI: Design interface issues

CA/T managers divided their job into four phases: conceptual design, preliminary design, final design and construction. The conceptual design phase took place from 1985 to 1990, the preliminary design was mostly done from 1990 to 1993, and the final design overlapped with the preliminary design phase, lasting from 1990 to 1997. After that, most activities concerned construction (Hughes, 1998: 240-241).[94]

There was a fundamental problem with the design work. DPW had planned for B/PB to carry the design to 10% completion and have separate engineering firms carry out the further detailed elaboration, with B/PB reviews at 25%, 60%, 90% and 100% completion.[95] As the works fell behind schedule, B/PB successfully suggested continuing the designing while DPW advertised, negotiated and executed contracts, to save time. Federal grant provider FHWA even insisted that B/PB complete 15% to 40% of the design, so that all alternative studies would be finished before section designers started work. This introduced segmentation into the design process. On average, B/PB would now produce up to a 25% level of detail. B/PB engineer Lancelotti said that 25% to 30% would have been better to properly cover all the numerous interfaces in the designs and the need for consistency.

Once a contracted engineer came on board, it would pick up on B/PB's work and complete it. In practice, however, these engineers were reluctant to take over work begun by another firm and put their name on it. Not only were they unsatisfied by the large amount of design work B/PB kept for itself, they were also reluctant to take on possible liability for designs that were basically drawn by someone else. They typically went back and started from scratch (Luberoff, Altshuler and Baxter, 1993: 156).[96] This is a symptom of interpretation uncertainty occurring in the tension between work done by the principal (B/PB in this case) and work left to the agents (section designers).

6.3.8 Occurrences XII and XIII: Oversight

Occurrence XII: The client's oversight of the project management consultant

Towards the final stages of implementation, management controversy arose over the monitorability of the project, particularly related to all the quality problems mentioned above (though at this point the ceiling collapse had not yet occurred). In 2004, the Senate

Post Audit and Oversight Committee concluded that oversight problems on the project had resulted in substandard work. One of the main oversight problems was the "less than arm's length" relationship between the hierarchy overseeing the project and the contractors.

There were, in fact, various critical oversight problems. It should be noted that these were difficult to determine objectively, as client- and contractor-affiliated actors had strongly diverging perceptions on the issue. The analysis here is based mainly on reports by state and federal inspectors and independent oversight institutions.

As early as 1991, the Office of the Inspector General of Massachusetts raised the issue of defective oversight: "The [management] Plan does not provide the [Highway] Department with adequate means to hold B/PB accountable for managing the project in a cost-conscious and responsible manner… Virtually all administrative control and oversight appears to be vested in B/PB".[97] In May 2000 the Inspector General wrote the following:

> *"The Commonwealth's excessively broad project management contract with Bechtel/Parsons Brinckerhoff has impeded effective cost control and oversight, undermined public accountability on the CA/T Project, and eroded the Commonwealth's contracting leverage… By contracting with B/PB to perform the full range of project management services and to oversee its own work, the Commonwealth has weakened its capacity to exert effective control over the cost and quality of the services B/PB provides… Moreover, the structure of the contractual arrangement, under which B/PB is paid principally on a cost-plus-fixed-fee basis, fails to create the necessary incentives or to hold B/PB accountable for meeting CA/T Project budget and schedule goals. Most of B/PB's compensation is not tied to deliverables or other measurable performance standards; indeed, project delays and construction contract changes serve to increase B/PB's compensation… The Commonwealth's near total dependence on B/PB has eroded its negotiating leverage to the detriment of public interest. I [the Inspector General, ML] have repeatedly recommended that the Commonwealth's contractual arrangement with B/PB be reconfigured. CA/T Project officials have declined to do so precisely because they depend so heavily on B/PB's expertise. As a result, the problems caused by this contractual arrangement have been perpetuated and exacerbated."*[98]

In the aftermath of the financial turmoil (see occurrences VII, VIII and IX), B/PB was accused of benefiting from the extensive delays and overruns, an allegation that was backed by the Office of the Inspector General; as can be seen in the above quote. B/PB received a guaranteed profit of $122 million. This did not include overhead, which brought the cost even higher.[99] In accordance with the contract, B/PB was paid more when it was putting in more hours or when delays occurred; an adverse incentive from the client's point of view. This touches upon an intention uncertainty.

As early as during the Weld governorship (1991–1997), doubts were raised about the potentially problematic effects of the privatisation scheme on the project, and not only by the Inspector General. Former secretary of transportation Salvucci and former chairperson of the Massachusetts Port Authority Weinberg said the fact that Bechtel was overseeing its own designs was undesirable. According to Salvucci, the balance with the owner's expertise was lost. Secretary of Transportation Kerasiotes, however, countered this, stating that the check and balance in this situation lay in Bechtel's reputation. Being one of the world's largest construction firms was incentive enough to do a good job. This was in line with the strong privatisation culture endorsed by Weld's administration. Bechtel officials said it was common practice for managers to oversee their own designs in civil engineering works.[100] The client left itself vulnerable to intention uncertainty.

In 2003, controversy mounted after *The Boston Globe* published an exposé on the Central Artery cost overruns. Some had occurred, it concluded, as a result of "incomplete and error-filled designs".[101] *The Globe* mentioned several examples in which contractors could not carry out their assigned works due to flawed designs from B/PB. The B/PB project manager denied the allegations and stated that B/PB had done an admirable job. Perceptions differ on who was right. B/PB published an official response in which it countered each allegation.[102] The Massachusetts Inspector General backed *The Globe*'s conclusions, however,[103] which suggests that intention uncertainty did indeed have adverse effects.

One issue concerned the finding that construction on many major contracts was started with incomplete and inaccurate designs, causing costly delays. B/PB responded that three designs were still pending at the time bids were first advertised, and this was so as not to miss a window of opportunity of federal funding.[104] As perceptions differed between the main contractor and subcontractors, no conclusive answer can be given to the question of whether the designs were indeed incomplete and inaccurate and, if this was the case, what the reason for the incompleteness and inaccuracy was. It may, after all, be related to the open terms of reference used, which are not unusual in complex projects. The terms of references were not mentioned in the conclusions of either B/PB or the Inspector General. Neither did any of the involved actors indicate that the nature of the works indeed required an "open", adjustable design, which would probably be the case if they had specified many incompleteness uncertainties.

Contractors did complain about the designs. Contractor J. Cashman said that a precise design was required for the work, while B/PB offered only an open design (an interpretation uncertainty). Cashman's contract was expanded by 60%, due to later adjustments.[105] On the other hand, former MTA board member Levy hinted that the contractors were keen on change orders (an intention uncertainty issue). This may have been to compensate for the low bids. Modern Continental, the contractor that was awarded most of the CA/T works, for instance, almost went bankrupt, despite the large amount of work. In the wake of the CA/T completion it merged with J. Cashman, another large CA/T contractor.[106]

Occurrence XIII: Federal oversight of expenditure

The project was funded from the federal interstate programme. This meant that FHWA, the grant provider, exerted oversight of expenditures. In practice, this oversight was executed by the local Massachusetts branch of the FHWA. FHWA had formal relationships only with the Massachusetts DPW, not with the project management consultant B/PB. During the project, weekly “core meetings” were attended by representatives of both FHWA and B/PB. Most major design decisions were made at these meetings. The Inspector General of the US Department of Transportation noted that such a relationship was undesirable as it impeded proper oversight.[107]

The FHWA assumed a different role than that expected by some other government institutions, criticism from the Inspector General indicates. Whereas the FHWA was expected to execute vigilant control and oversight over expenditures of federal money, its employees were in fact embedded in the project organisation. They worked mainly at project headquarters, rather than on site. They were criticised as having moved too close to their inspectees. This reveals a dilemma of overseers: the tension between interpretation uncertainties and intention uncertainties. If they move too close to their inspectees, they are less able to retain an autonomous position. If they keep too large a distance, they may lose touch with primary sources of information, undermining their ability to assess the strategic values and interests of the inspectees.[108]

The FHWA has traditionally provided little oversight of the money it provides to states and municipalities. In the opinion of the Inspector General this contributed to the budget problems experienced in the CA/T project. In part due to these problems, the FHWA began developing new policies, procedures and practices to improve its oversight. The additional oversight, applied in new major projects, includes for instance, assessing management risks, reviewing financial management processes and spot-checking sample payments on highway projects.[109] The suggestion was also made that the FHWA should take a more independent and less supportive role. The Inspector General of the federal Department of Transportation even noted that the same day MTA disclosed its $1.4 billion cost overrun, FHWA had just earlier approved the project’s financial plan.[110]

6.4 Uncertainty in the CA/T project

6.4.1 Manageability problems stemming from complexity-related uncertainties

Occurrence I: The huge challenge resulting from the way the project was defined rendered the *uncertainty gap* large, because a difficult and complex project is especially likely to experience a large influence of instability, incompleteness and possibly even inconceivability uncertainties. This did indeed occur, as we know in hindsight. The strong degree of differentiation implied a high level of *segmentation*: there were many contract areas and the design work was split up. The involvement of many interest groups suggested a large *variety in values*. Moreover, the substantial technical challenge of the project implied that the Commonwealth of Massachusetts, as project client, would experience difficulty managing the project, due to *information asymmetry*. This would eventually lead to a situation in which many *dynamics*, associated in large part with the involvement of many interest groups, came together with the potential for *strategic behaviour*, due to the contractors' powerful information position.

Occurrence II: It remains uncertain whether the tunnel roof collapse was a result of incompleteness or inconceivability uncertainty. Much of the input provided seems to be based on tacit engineering knowledge and managers' interpretations. Decisions made on this basis were characterised by interpretation uncertainties. The challenging design caused an *uncertainty gap*, and there was a divergence in viewpoints between the different actors related to the *segmentation* of the actors and the *variety of values* between them. Client-affiliated actors, for example, considered the changing of existing contracts to be more problematic than the contractors did. The former argued that design changes were only justified if they brought substantial added value to the project, in this case particularly in the emergence of positive *dynamics*. Different viewpoints also reflect an asymmetry in information. Information was more amply available to engineers, and less to client-affiliated managers. Engineers eventually decided on the basis of information that was perceived as *rational* (specifications).

Occurrence III: Many uncertainties and dilemmas came together in the installation and testing of the drop-ceiling. The bounded manageability started here with the choice of a technology that left a knowledge void. Managers from the owner organisation had even less direct knowledge about the technology and progress in the installation process than the engineers and construction workers (*information asymmetry*). Eventually, managers relied on the most neutral information of all: the specifications of the epoxy in combination with the calculated ceiling load, instead of the tacit knowledge-based judgement of engineers (*uncertainty gap, rationalisation*).

Occurrence IV: The occurrence of leaks could be attributable to the decision not to include a tunnel box (occurrence V), but it also had much to do with the work process of the responsible contractors. Obviously the failure rate was linked to the larger *uncertainty gap* this created. The issue of interface management, a responsibility of B/PB, was a direct result of *segmentation*; that is, the decision to cut the work into sections. The use of poor-quality concrete can probably be explained by the interest of the supplier to gain the highest possible profit, which is a value in conflict with the owner's (*value variety*), leading to *strategic behaviour*. But it is also a manageability issue that can hardly be related to the management responsibilities of the owner.

Occurrence V: The uncertainties related to the diaphragm walls and ceiling originated in the design decision to build the tunnel with bare diaphragm walls. This created a larger *uncertainty gap*, since engineers could be less sure about the reliability of the design in practice.

Occurrence VI: The cost increases at the front-end of the project can be partly explained by uncertainties in the political process and partly by mitigation and compensation requests from interest groups. The need for community support and the client's commitment to sparing the environment gave these groups *strategic* power at the front-end of the process, and even during implementation, through the oversight committee. Some intention uncertainty issues were involved too, because ways were found to funnel federal money to other projects. These political processes forced the client to make the project larger, more complex and, hence, even more challenging, and it resulted in various design changes, the most prominent of which was the Charles River crossing (*dynamics*).

Occurrence VII: The cost escalation that resulted from instability and incompleteness uncertainties was loosely related to interaction-driven uncertainties. Many of the cost increases arose from *dynamics* in the development and construction process and had their origin in the very challenging project definition (*uncertainty gap*): an extensive, partly underground highway scheme in the downtown area of a large US city.

Occurrence VIII: The owner was aware that the contractors had a strategic interest in expanding the value of their contracts (intention uncertainty), to the detriment of the owner's interests (*value variety*). This meant that every claim for contract adjustments (*dynamics*) had to be assessed to determine whether it was valid (*strategic behaviour, rationalisation*). The workload this created was such that it was transferred down the hierarchy. This enabled potentially better assessments, but implied a loss of direct control.

Occurrence IX: The IPO was an attempt to deal with the deficiencies of the owner, hence reducing the potentially adverse effects of interpretation uncertainty *(information asymmetry*). In practice, it increased intention uncertainty, because the difference between the *values* of the owner and B/PB still existed, as did the incentive for *strategic behaviour*. Meanwhile, the owner's capability to oversee B/PB and effectuate countermeasures was reduced.

Occurrence X: The decision to divide responsibilities between the owner and B/PB, each with a different focus, implied acceptance of *segmentation* between the different focal points over two actors with diverging *values*. The consequence was partly a separation of information and decision-making (for decisions made by the owner) and partly a transfer of decision-making authority on engineering issues to B/PB (*information asymmetry*).

Occurrence XI: The uncertainty that developed regarding responsibility for the designs eventually led to manageability issues, due to the *segmentation* that was introduced. The alternative here would have been to integrate the design work into design contracts. But segmentation was propagated to enable a complete analysis of alternatives (and hence to make better decisions on the engineering design).

Occurrence XII: Integration of overseers and inspectees into one entity enabled overseers to better assess the performance of the project. But separation of these roles would have retained an "arm's length" distance between overseers and inspectees. This would perhaps have helped prevent poor performance or strategic behaviour from remaining undetected or going unpenalised. In addition, there was a dilemma with regard to the *information asymmetry* that occurred between the owner and the project management consultant. The Inspector General was critical about the power B/PB received from the client. The authority the client transferred to its main consultant, however, was a means for it to deal with its own deficiencies, as in occurrence IX.

Occurrence XIII: The dilemma in federal oversight of expenditures is comparable to the dilemma posed by integration of the overseer and inspectee in occurrence XII.

These occurrences of complexity led to the uncertainties presented in Table 6.3, which also indicates the manageability dilemmas involved in each.

Table 6.3 Uncertainties in the CA/T project and related dilemmas.

Occur-rence	Description	Main uncertainties	Dilemmas in consideration
I	High technical differentiation	Instability, incompleteness, inconceivability	Uncertainty gap, segmentation, value variety, information asymmetry, dynamics, strategic behaviour

II	Design change of drop-ceiling	Incompleteness, inscrutability, inconceivability, interpretation	Uncertainty gap, segmentation, value variety, dynamics, rationalisation
III	Installation of drop-ceiling	Instability, incompleteness, inscrutability, interpretation, intention	Uncertainty gap, information asymmetry, rationalisation
IV	Leaks on I-93	Instability, incompleteness, intention	Uncertainty gap, segmentation, value variety, strategic behaviour
V	Diaphragm wall design	Instability, incompleteness, inconceivability	Uncertainty gap
VI	Cost growth at front-end	Interpretation, intention	Uncertainty gap, dynamics, strategic behaviour
VII	Loss of control over budget	Instability, incompleteness, interpretation, intention	Uncertainty gap, dynamics
VIII	Claims and changes	Instability, intention	Value variety, dynamics, strategic behaviour, rationalisation
IX	Cost growth under IPO	Interpretation, intention	Value variety, information asymmetry, strategic behaviour
X	Powerful position of project management consultant	Interpretation, intention	Segmentation, information asymmetry, value variety
XI	Design interface	Interpretation	Segmentation
XII	Oversight of PMC	Interpretation, intention	Segmentation, information asymmetry, strategic behaviour
XIII	Federal oversight	Interpretation, intention	Segmentation, information asymmetry, strategic behaviour

6.4.2 Loose observations

Our discussion up to now of the CA/T project suggests a number of loose observations on uncertainties:

- Principals tended to be more occupied with intention uncertainties and agents with incompleteness uncertainties. To each applied that their main concern got priority.
- Many risks concerned both instability and incompleteness uncertainties: incompleteness in that there was limited knowledge on probabilities and impacts, and instability in that uncertainties remained. They may, for instance, have had a 10% probability of occurrence. But whether now was the one occurrence in ten in which the risk did come to pass could not be known.

- Performance was adversely affected by a combination of instability and incompleteness uncertainties. Incompleteness uncertainty may have made people less aware of the variability (instability uncertainty) that occurred in the work done. It could also have made the instability uncertainty less well understood.

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[1] Hughes, 1998.
[2] Hughes, 1998: 197-200; 223-235.
[3] Ibid.: 215-220; Respondent F. Yalouris.
[4] Hughes, 1998; Altshuler and Luberoff, 2003.
[5] The federal interstate programme provided 90% funding for interstate highway projects.
[6] Funding from the interstate programme was obtained for the largest part of the project; particularly those parts related to the highway trajectory, including the tunnels and main connectors.
[7] Interview with F. Salvucci in "Big Dig Revisited" that appeared in "Commonwealth" (fall 2006)
[8] Respondents F. Salvucci, R. Weinberg, interview with F. Salvucci in "Big Dig Revisited" that appeared in "Commonwealth" (Fall 2006).
[9] Respondent R. Weinberg, interview with F. Salvucci in "Big Dig Revisited" that appeared in "Commonwealth" (fall 2006).
[10] Personal communication with P. Zuk, project director until 1996.
[11] Interview with F. Salvucci in "Big Dig Revisited" that appeared in "Commonwealth" (fall 2006); "Reconstructing a tragedy", by F. Salvucci in *The Boston Globe*, July 21, 2006.
[12] B/PB's explanation of the project organisation dated June 25, 2006.
[13] M. Lewis, presentation "Owner oversight and Integrated Project Organization (IPO)" National Academy Briefing, November 2001.
[14] National Research Council, Transportation Research Board of the National Academies, Completing the Big Dig; Managing the final stages of Boston's Central Artery/Tunnel Project, The National Academies Press, Washington DC, 2003, p. 31.
[15] Statement of M. Wiley, programme manager Bechtel/Parsons Brinckerhoff joint venture before The Senate Commerce, Science and Transportation Committee, United States Senate, Washington DC, May 3, 2000, p. 3
[16] M. Lewis, presentation "Owner oversight and Integrated Project Organization (IPO)" National Academy Briefing, November 2001.
[17] National Research Council, Transportation Research Board of the National Academies, Completing the Big Dig; Managing the final stages of Boston's Central Artery/Tunnel Project, The National Academies Press, Washington DC, 2003.
[18] Commonwealth of Massachusetts, Senate Committee on Post Audit and Oversight, Road blocks to cost recovery; Key findings and recommendations on the Big Dig cost recovery process, December 2004.
[19] The National Academies, "Completing the Big Dig, Managing the final stages of Boston's Central Artery/Tunnel Project, 2003. This publication was released prior to the ceiling collapse event.
[20] Respondent M. Bertoulin.
[21] *The Boston Globe* articles "Big Dig engineers debated need for heavy panels", by S. Allen, July 13, 2006 and "Original plan had lighter tunnel ceiling; Switched to save time and money" by S. Allen, J. Saltzman, D. Slack, July 23, 2006, in which J. Montgomery of Environmental Interiors and James Bruno of contractor Modern Continental are quoted.
[22] Office of the Inspector General of Massachusetts, "A Review of the Central Artery/Tunnel Project's Use of Anchor Bolts on the C05B1 Tunnel Finishes Contract", December 1998.
[23] *The Boston Globe* articles "No evidence of bolt retests for much of tunnel ceiling; Tougher exams ordered in '99", by S.Allen and S.P. Murphy, July 26, 2006; "Designer proposed more bolts in Big Dig; Managers cut numbers in half" by S. Allen and S.P. Murphy, September 17, 2006.
[24] *The Boston Globe* article "Probe looks at possible problems with handling epoxy" by S. Allen and S. Murphy, July 14, 2006.
[25] Commonwealth of Massachusetts, Office of the Inspector General, A Review of the Central Artery/Tunnel Project's Use of Anchor Bolts on the C05B1 Tunnel Finishes Contract, December 1998: 18-19.

[26] *The Boston Globe* article "Big Dig officials chose not to retest; Only bolts over HOV lane were eyed after failures" by S. Allen and S. Murphy, August 20, 2006, in which is referred to a January 14, 2000 memo from R. Steffy (B/PB's resident engineer of the site).
[27] *The Boston Globe* article "Many more flaws detected; Romney to take over probe; Loose ceiling fixtures number in hundreds", July 14, 2006.
[28] Comment of governor M. Romney, referred to in Boston Globe article "Workers doubted ceiling method; Firm prevailed on fasteners despite tests" by S. Murphy and R. Mishra, July 18, 2006.
[29] *The Boston Globe* article "Original plan had lighter tunnel ceiling; Switched to save time and money" by S. Allen, J. Saltzman, D. Slack, July 23, 2006.
[30] *The Boston Globe* article, "Reilly: Anchor bolts failed 1999 field study", by A. Ryan, July 12, 2006.
[31] Commonwealth of Massachusetts, Office of the Inspector General, A review of the Central Artery/Tunnel Project's use of anchor bolts on the C05B1 tunnel finishes contract, December 1998.
[32] Inspector General G. Sullivan in the Boston Globe "A fatal lesson", July 20, 2006.
[33] National Transportation Safety Board, "Safety Board determines cause of Boston's Big Dig tunnel ceiling collapse last year", Washington DC, July 10, 2007.
[34] *The Boston Globe* articles "Three bolts had no glue, Reilly says", by S.P. Murphy, July 16, 2006; "Three more loose bolts in tunnel; Lanes closed; connector shut indefinitely", by R. Mishra and S.P. Murphy, July 25, 2006.
[35] US Department of Transportation, Federal Highway Administration, "Tunnel Leak Assessment Boston Central Artery", Interim Report, March 23, 2005; Statement of Inspector General Kenneth M. Mead of the US Department of Transportation before the Committee of Government Reform of the US House of Representatives, "Impact of Water Leaks on the Central Artery/Tunnel Project and Remaining Risks", April 22, 2005.
[36] Statement by John MacDonald, chairman, board of control, Bechtel/Parsons Brinckerhoff before the Massachusetts State Legislature Joint Transportation Committee, December 2, 2004.
[37] Ibid.
[38] *The Boston Globe* article "Artery errors cost more than $ 1b" by R. Lewis and S. Murphy, February 9, 2003.
[39] Deloitte & Touche, Central Artery/Tunnel Project Review and Assessment of C15A2 Global Contract Modification, December 2001.
[40] Ibid.
[41] *The Boston Globe* article "Artery errors cost more than $ 1b" by R. Lewis and S. Murphy, February 9, 2003.
[42] *The Boston Globe* article: "Big Dig began with a critical decision; Novel technique may be behind troubles", by R. Lewis, December 19, 2004.
[43] *The Boston Globe* articles "Artery Tunnel springs leak. Traffic snarled; Big Dig closes lanes, seeks cause, aims for full reopening", by D. Abel and M. Daniel, September 16, 2004; "Big Dig found riddled with leaks; Engineers say fixes could take decade", by S. Murphy and R. Lewis, November 10, 2004.
[44] Respondent J.J. Wright.
[45] The Artery Business Committee was a non-profit and non-governmental membership organisation founded by Boston's business community, in cooperation with the City of Boston and the CA/T Project organisation. Its purpose was to address business's concerns about the impact of the works on the city and particularly the accessibility of the city during the works. It had three main goals: protecting downtown Boston from negative impacts of construction, ensuring that the finished project would adequately serve the downtown area and ensuring that political and legal controversies did not threaten the project. That last was done by helping state officials secure public funds needed to build the project and by aiding efforts to ensure that the project was neither stopped, nor significantly delayed by political or legal controversies. Its activities concerned monitoring of construction mitigation, traffic management, construction means and methods, construction management, utility relocation and highway architecture. In 2006, after completion of the project, the Artery Business Committee and its abbreviation ABC were transformed into "A Better City", continuing its works for the whole downtown and Back Bay area and extending its dedication to transport and land development (Respondent T. Nally; Luberoff, D., Civic leadership and the Big Dig, working paper 11, Rappaport Institute for Greater Boston, Taubman Center for State and Local Government, John F. Kennedy School of Government, Harvard University, May 3, 2004).
[46] Respondent D. Luberoff, Hughes, 1998.
[47] Called "Scheme Z" because it was the 26th alternative.

[48] The CA/T project was developed over more than twenty years. Therefore, inflation became a more relevant factor than in many other projects. In this chapter constant prices are given in some cases to provide a proper image of the cost development of the project. The amounts are based on Table 4-3 in Altshuler and Luberoff, 1993: 116. They use 2002 as index year.

[49] Hughes' indication of the number of mitigation measures differs from Altshuler and Luberoff's (2003: 104-105).

[50] *The Boston Globe* article "Project poses a test for privatization; Critics see conflict in Bechtel's overseeing its own artery/tunnel design work", by C. Sennott, September 12, 1994.

[51] As mentioned, Salvucci had more confidence in the specialist expertise of MBTA and the Port Authority, but had considered them not the proper constituents for a highway project. By appointing them in the second opinion committee, he could mobilise this expertise despite the absence of MBTA's or the Port Authority's involvement.

[52] Massachusetts law does not allow one private organisation to hold many key tasks in construction projects.

[53] One of them died and one left his position.

[54] Respondents F. Salvucci, R. Weinberg, interview with F. Salvucci in "Big Dig Revisited that appeared in "Commonwealth" (fall 2006).

[55] "Reconstructing a tragedy", by F. Salvucci in *The Boston Globe*, July 21, 2006.

[56] Statement of Inspector General of Massachusetts Gregory W. Sullivan in *The Boston Globe*, July 20, 2006.

[57] Some $6.4 to $9 billion in 2002 prices, which is an important reference for later cost overruns that were disclosed around that time.

[58] *The Boston Globe* article, "Reconstructing a tragedy", by F. Salvucci, July 21, 2006.

[59] Commonwealth of Massachusetts, Office of the Inspector General, A history of Central Artery/Tunnel project finances 1994-2001; Report to the Treasurer of the Commonwealth, March 2001: 20-21.

[60] Statement of the Inspector General of the US Department of Transportation before the Committee of Government Reform of the US House of Representatives, "Impact of Water Leaks on the Central Artery/Tunnel Project and Remaining Risks", April 22, 2005.

[61] *The Boston Globe* article, "Reconstructing a tragedy", by F. Salvucci, July 21, 2006.

[62] Commonwealth of Massachusetts, Office of the Inspector General, A history of Central Artery/Tunnel project finances 1994-2001; Report to the Treasurer of the Commonwealth, March 2001: 23-24.

[63] Ibid.: 18.

[64] This appears to be the view of the Inspector General, based on the response of the manager in question.

[65] Other state officials were quoted in *The Boston Globe* article "Artery project official ousted", by Th. Palmer Jr. (November 22, 1994).

[66] Project director P. Zuk, quoted in *The Boston Globe* article "Artery project official ousted", by Th. Palmer Jr. (November 22, 1994).

[67] Commonwealth of Massachusetts, Office of the Inspector General, A history of Central Artery/Tunnel project finances 1994-2001; Report to the Treasurer of the Commonwealth, March 2001: 19-20 and appendix 1.

[68] Federal Task Force on the Boston Central Artery/Tunnel Project, Review of Project Oversight and Costs, April 11, 2000.

[69] Applicants for interstate funding were not obliged to include inflation in their estimates.

[70] Project documentation from the CA/T project management and National Research Council, Transportation Research Board of the National Academies, Completing the Big Dig; Managing the final stages of Boston's Central Artery/Tunnel Project, The National Academies Press, Washington DC, 2003.

[71] Respondent F. Salvucci.

[72] Commonwealth of Massachusetts, Office of the Inspector General, "Analysis of Bechtel/Parsons Brinckerhoff's Reply to *The Boston Globe* Investigative News Series Concerning the Big Dig", February 2003, p. 2 and 6.

[73] Central Artery/Tunnel Project, Construction Claims and Changes, presentation November 2001.

[74] National Research Council, Transportation Research Board of the National Academies, Completing the Big Dig; Managing the final stages of Boston's Central Artery/Tunnel Project, The National Academies Press, Washington DC, 2003, p. 31.

[75] Commonwealth of Massachusetts, Senate Committee on Post Audit and Oversight, Road blocks to cost recovery; Key findings and recommendations on the Big Dig cost recovery process, December 2004.

[76] Commonwealth of Massachusetts, Senate Committee on Post Audit and Oversight, Road blocks to cost recovery; Key findings and recommendations on the Big Dig cost recovery process, December 2004.
[77] Letter from Inspector General Cerasoli to MTA chairman Andrew Natsios, May 3, 2000; Commonwealth of Massachusetts, Senate Committee on Post Audit and Oversight, Road blocks to cost recovery; Key findings and recommendations on the Big Dig cost recovery process, December 2004.
[78] Office of the Inspector General of the Commonwealth of Massachusetts, Analysis of Bechtel/Parsons Brinckerhoff's reply to the *The Boston Globe* investigative news series concerning the Big Dig, February 2003.
[79] Respondent F. Moavenzadeh.
[80] Ibid.
[81] Commonwealth of Massachusetts, Office of the Inspector General, "Analysis of Bechtel/Parsons Brinckerhoff's Reply to *The Boston Globe* Investigative News Series Concerning the Big Dig", February 2003.
[82] Letter from Inspector General Cerasoli to MTA chairman Andrew Natsios, May 3, 2000; Commonwealth of Massachusetts, Senate Committee on Post Audit and Oversight, Road blocks to cost recovery; Key findings and recommendations on the Big Dig cost recovery process, December 2004.
[83] Statement of the Inspector General of the US Department of Transportation before the Committee of Government Reform of the US House of Representatives, "Impact of Water Leaks on the Central Artery/Tunnel Project and Remaining Risks, April 22, 2005, p. 13.
[84] Press announcement "Bechtel and Parsons Brinckerhoff reach settlement on Big Dig", by Bechtel, San Francisco, January 23, 2008.
[85] Respondent F. Salvucci.
[86] Press announcement "Bechtel and Parsons Brinckerhoff reach settlement on Big Dig", by Bechtel, San Francisco, January 23, 2008.
[87] The Inspector-General of the Commonwealth of Massachusetts is a government official assigned to prevent and detect fraud, waste and abuse in the expenditure of public funds. The main objective is to prevent these symptoms before they happen. The office was established in 1981 after a major construction procurement scandal (from: mission and history of the Office of the inspector-general; www.mass.gow.ig).
[88] Letter from the Inspector-General to the commissioner of the DPW.
[89] Letter from the Inspector-General to the commissioner of the DPW.
[90] G. Sullivan, Inspector General of the Commonwealth of Massachusetts in *The Boston Globe* "A fatal lesson", July 20, 2006.
[91] Office of the Inspector General R.A. Cerasoli, A history of Central Artery/Tunnel Project finances 1994-2001; Report to the treasurer of the Commonwealth, Commonwealth of Massachusetts, march 2001, pp. 4-5.
[92] *The Boston Globe* article "Project poses a test for privatization; Critics see conflict in Bechtel's overseeing its own artery/tunnel design work", by C. Sennott, September 12, 1994.
[93] Ibid.
[94] Respondent M. Bertoulin.
[95] Massachusetts law did not allow one firm to manage the project and produce the whole design.
[96] *The Boston Globe* article "Project poses a test for privatization; Critics see conflict in Bechtel's overseeing its own artery/tunnel design work", by C. Sennott, September 12, 1994.
[97] Excerpt from a 1991 report by the Commonwealth of Massachusetts Office of the Inspector General, referred to in Commonwealth of Massachusetts, Office of the Inspector General, "Analysis of Bechtel/Parsons Brinckerhoff's Reply to *The Boston Globe* Investigative News Series Concerning the Big Dig", February 2003, p. 21.
[98] Excerpt from a 2001 letter by the Commonwealth of Massachusetts Office of the Inspector General, referred to in Commonwealth of Massachusetts, Office of the Inspector General, "Analysis of Bechtel/Parsons Brinckerhoff's Reply to *The Boston Globe* Investigative News Series Concerning the Big Dig", February 2003, p. 21.
[99] Commonwealth of Massachusetts, Office of the Inspector General, "Analysis of Bechtel/Parsons Brinckerhoff's Reply to *The Boston Globe*'s Investigative News Series Concerning the Big Dig", February 2003, p. 20.
[100] *The Boston Globe* article "Project poses a test for privatization; Critics see conflict in Bechtel's overseeing its own artery/tunnel design work", by C. Sennott, September 12, 1994. The Souterrain initially had a similar oversight situation, with SAT Engineering overseeing the construction of its own engineering designs.

[101] The news series ran in three parts in *The Boston Globe*: Artery errors cost more than $1b (9 February 2003), State's cost-recovery efforts have been nearly a lost cause (10 February 2003), Lobbying translates into clout (11 February 2003).

[102] *The Boston Globe*'s Big Dig: A Disservice to the Truth; A Reply from Bechtel/Parsons Brinckerhoff, 20 February 2003.

[103] Office of the Inspector General, Commonwealth of Massachusetts, Analysis of Bechtel/Parsons Brinckerhoff's Reply to *The Boston Globe* Investigative News Series Concerning the Big Dig, February 2003.

[104] Bechtel/Parsons Brinckerhoff, Key facts about cost, scope, schedule and management, 20 February 2003 and Bechtel/Parsons Brinckerhoff, *The Boston Globe*'s Big Dig: A disservice to the truth; A reply from Bechtel/Parsons Brinckerhoff, 20 February 2003.

[105] *The Boston Globe* article: "Artery errors cost more than $1b", by R. Lewis and S. Murphy, February 9, 2003.

[106] *The Boston Globe* article, "Problems not new for the project's largest contractor, by C. Rowland, July 14, 2006.

[107] Statement of the Inspector General of the US Department of Transportation before the Committee of Government Reform of the US House of Representatives, "Impact of Water Leaks on the Central Artery/Tunnel Project and Remaining Risks", April 22, 2005

[108] Federal Task Force on the Boston Central Artery Tunnel Project, Review of Project Oversight & Costs, March 31, 2000.

[109] Financial Integrity Review and Evaluation Program, initiated February 28, 2005; Statement of the Inspector General of the US Department of Transportation before the Committee of Government Reform of the US House of Representatives, "Impact of Water Leaks on the Central Artery/Tunnel Project and Remaining Risks, April 22, 2005.

[110] Statement of the Inspector General of the US Department of Transportation before the Committee of Government Reform of the US House of Representatives, "Impact of Water Leaks on the Central Artery/Tunnel Project and Remaining Risks", April 22, 2005; the Inspector general refers to: US Department of Transportation, Office of Inspector General, Report Number TR-2000-050, Current Cost and Funding of the Central Artery/Ted Williams Tunnel Project, February 10, 2000.

7. Dortmund Stadtbahn

7.1 Introduction

The third case studied is situated in Germany. With its large number of medium-large and major cities, post-war Germany has seen a considerable number of underground construction projects, predominantly for transport purposes. Germany is a particularly interesting location for study because Hofstede (2000) positioned this country further towards the uncertainty-avoidance end of the cultural spectrum than the Netherlands and the United States. Compared to other Western countries, Germany, has relatively strong public-sector roles, with extended and amply staffed owner organisations that keep tight control over project implementation. The Dortmund Stadtbahn was a project with such an owner organisation. It serves to demonstrate some of the particularities of this kind of owner organisation and its effects on manageability.

The City of Dortmund has been developing a Stadtbahn network for several decades. The city has a strong owner organisation and is part of a larger urban region (the Ruhr area), which gives a broader context to its public transport plans. This diverges from the previous cases, which also had public owners/sponsors, but struggled with the unfamiliarity of this role.

Another important difference with the previous cases is that the project did not experience the kinds of mishaps that characterised the projects in the previous two chapters. On one hand this is good. Looking exclusively at projects with a calamitous history would overly narrow the overall study's focus. Moreover, a project that has been generally manageable may produce insights on success factors. It does have a downside however. The actors involved had limited experience with manageability issues. Yet, actors often become aware of these issues when the course of events deviates from expectations. The actors involved may see such deviations as abnormalities, though practice suggest there is a high likelihood of occurrence. If they do not arise, manageability is not considered to have been a problem, though success may well have been the result of luck. This impedes research on manageability. It reminds us that manageability is in fact something that can only be determined by falsification, not by verification. This chapter therefore focuses in particular on the effects of a strong owner organisation. Interviews took place during construction of the East-West section, with the main structure finished.

Like the previous two case-study chapters, this chapter starts with an introduction to the project, which had three levels of aggregation. The first was the larger urban rail network of the Rhine-Ruhr area and Dortmund in particular. The second was the East-West Tunnel, which is the specific subject of study. The third level of aggregation is one particular part of the system, construction site S10, which represented the final construction phase of this tunnel. Section 7.2 introduces the project and its organisation. Section 7.3 looks at the occurrences of complexity in the project. Section 7.4 reviews the main uncertainties and related manageability dilemmas.

7.2 Dortmund Stadtbahn and construction site S10

7.2.1 Rhine-Ruhr area transport objectives

In the era of reconstruction after World War II, the need for good transport in urban areas became a high priority in Germany. Apart from a countrywide network of highways and railways, the major cities developed urban rail networks. In addition to metros (U-bahn), many agglomerations built regional rail networks (S-bahn) as well. The two types of networks are complementary and usually connected to each other at main stations.

Post-war, urban traffic intensified in the industrialised Ruhr cities. These grew massively, eventually providing a home to some five million inhabitants. The combination of street trams and the growing number of cars created a threat of congestion. In the 1960s, the Ruhr cities of Bochum, Castrop-Rauxel, Dortmund, Duisburg, Essen, Gelsenkirchen, Herne, Mühlheim an der Ruhr, Oberhausen, Recklinghausen and Wattenscheid founded an organisation to develop a new local transport network in their agglomeration: the *Stadtbahngesellschaft Ruhr.*[1] This was in line with the *Bundesland's* objective to improve local public transport.[2]

The aim was to develop a network of about 300 kilometres of *Stadtbahn*, a sort of metro system that should, by and large, replace the existing street trams.[3] In many cases this would be done underground in inner city areas, to avoid further congestion. In more peripheral parts of the cities, the lines would run at street level, though overpass and underpass crossings were to be pursued as much as possible. The plans were largely drawn up in the 1960s, when the coal industry went into a deep crisis. Construction of such a network had as a valuable side-effect that it could re-employ many of the people who had lost their jobs in the mining and steel industry (Dittrich and Sieberg, 1989: 774-777).

The major cities of the Ruhr area lie in an east-west line, from Dortmund to Duisburg. Most Stadtbahn lines were initially planned in a north-south direction, because most east-west connections would be provided by the higher profile S-bahn lines, which used conventional heavy rail technology. The cities themselves were predominantly responsible for the actual construction of the Stadtbahn lines and for the funding required for them.

Whereas the street trams used 1 metre gauge, it was decided that the new Stadtbahn lines in the Ruhr area would use the standard European 1.435 metre gauge, as conventional heavy rail and metro. The original plan was to create a full metro network, but the planners soon realised that the budgets available would not be sufficient for that. In the meantime, funding from the federal state and the *Bundesland* North Rhineland-Westphalia was reduced. Therefore, the new Stadtbahn lines were in some cases provisionally linked to the existing street tram lines, in most cases with the use of a third rail to overcome the gauge difference. Platforms, which were standard metro height, would then be raised to connect to the higher Stadtbahn floors.

In the cities of Bochum, Gelsenkirchen and Duisburg, Stadtbahn construction never progressed further than one tunnel. The Essen-Mülheim an der Ruhr conurbation completed three lines, including a street tram tunnel. Düsseldorf, which joined in later and is not located in the core Ruhr area, completed and operates two tunnels. Dortmund built three tunnels. The third was completed in late 2007 with the delivery of the S10 stretch.

7.2.2 The Dortmund Stadtbahn programme objectives

The U-bahn system in Dortmund (approximately 600,000 inhabitants) is, for the time being, composed of eight lines that cross the city centre via three tunnels. The East-West Tunnel was the third U-bahn tunnel built in Dortmund.

The project began in 1969 when, in the framework of the *Stadtbahngesellschaft Ruhr*, the City of Dortmund decided to upgrade the street tram network to a U-bahn network. Tree tunnels, some 20.5 kilometres in total length, were planned to enable the city to eliminate the tram traffic in the city centre. One tunnel would accommodate two U-bahn lines (U42 and U46) and another four lines (U41, U45, U47 and U49). The third tunnel would accommodate lines U43 and U44. The whole programme cost about €1.25 billion (Niewerth, 1971; Dittrich and Sieberg, 1989; Sieberg and Overkamp, 1992); Schliessler and Peter, 2004).

The three tunnels were designed to cross at three stations, creating a triangle in the city centre (Figure 7.1). The two “older” lines (U42/U46 and U41/U45/U47/U49) would cross at Stadtgarten Station. Kampstrasse Station would accommodate the crossing of lines U41/U45/U47/U49 with tram lines 403 and 404 and the new East-West Tunnel. At Reinoldikirche Station, lines U42/U46 would cross tram lines 403 and 404 and the new East-West Tunnel. A three-storey underground station was therefore needed at Kampstrasse and a two-storey underground station at Reinoldikirche.

Initially, the completion date did not seem very ambitious. However, during implementation, the decision was made to switch from high-floor to low-floor rolling stock. The switch to these new vehicles was to take effect in 2008. Therefore, the main structures of the new tunnel had to be completed by late 2007.[4] Completion before the 2006 football world cup in Germany, which had the Dortmund Westfalen stadium as one of its venues, was considered appealing, but this target was abandoned early on. It was not really necessary because transport links to the stadium were already provided by a different line. The tunnels were, fully furbished, eventually opened on April 26th, 2008. Since the opening, the Dortmund city centre has been free of street-level tram tracks.[5]

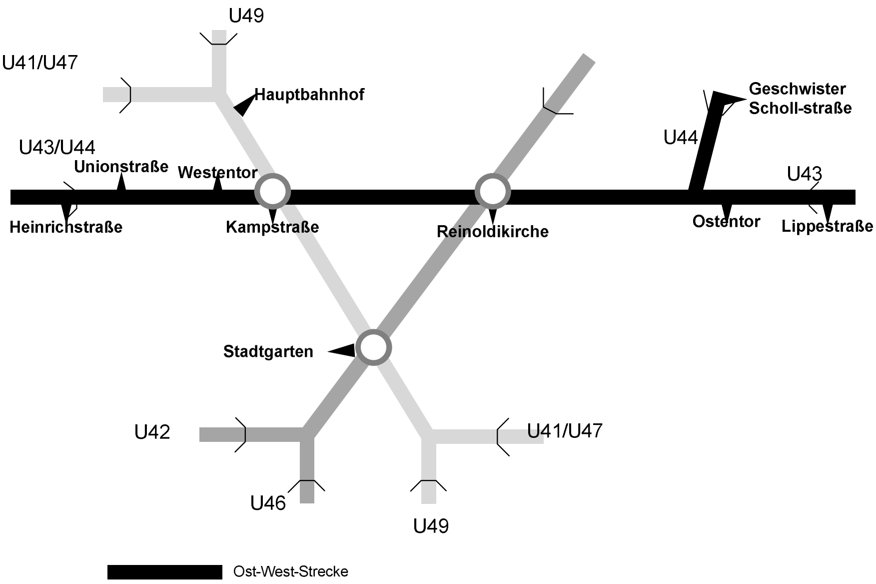

Figure 7.1 Schematic outline of the Dortmund Stadtbahn in the city centre (own illustration).

7.2.3 The East-West Tunnel project

The East-West Tunnel was to accommodate the old tram lines 403 and 404, which would be converted to U-bahn lines 43 and 44. In the original plans, tram line 404 was eliminated and replaced by bus service. This was considered possible due to the closure of the steel works at Westfalenhütte, which had been serviced by line 404. The city council was prompted to reconsider the decision, however, as strong opposition arose in the city district of Borsigplatz, which was serviced by the line. Because the line used much of the same route through the city centre as line 403, it was decided that it would have to go underground as well. Line 404, however, bent to the north, towards Borsigplatz/Westfalenhütte, before the tunnel under the old tram 403 route resurfaced.

As a result, an underground branch from Reinoldikirche Station to the north was needed. This branch would start at Reinoldikirche Station, between two separate tubes accommodating the east-west line (under tram line 403). It would resurface in the Weissenburgerstrasse (Figure 7.2).[6]

The whole tunnel was to be 2,335 metres (3 kilometres including on and off ramps). It would run underneath the Kampstrasse and Brüderweg and under parts of the Rheinische Strasse and Hamburger Strasse in the centre of Dortmund, including seven stations, five of which would be completely underground. Before the works on the eastern part (site S10) began, the structural works for the rest of the tunnel were completed.

The total cost of the East-West Tunnel was approximately €200 million. But it is hard to give an exact figure for the whole tunnel, because the first sections were part of construction works for an earlier project. The inner construction (e.g., rails, wiring and traffic systems) of the finished sections were postponed to coincide with completion of the last tunnel section.

Construction site S10

The eastern section of the tunnel is the part built most recently. This part extends eastwards from the underground Reinoldikirche Station, including the branch to the north (to Borsigplatz/Westfalenhütte). It has two one-track tubes for line 43, running underneath the Brüderweg and the Hamburger Strasse and one underground station: Ostentor (construction site S10.1). It also has one two-track tube for line 44, starting at Reinoldikirche Station between the two one-track tubes, going down and then bending to the north towards Borsigplatz, passing under the northern one-track tube and rising back to street level, resurfacing at the Geschwister-Scholl-Strasse Station (construction site S10.2) (see figures 7.1 and 7.2). The length of the straight part (the single-track tubes of line 43) is approximately 1,340 metres, of which 960 metres is fully underground.

The Dortmund city council made the final decision to implement the project in August 1999. Main construction works started in 2002. Prior to that, preparation activities, such as tendering and relocation of utility lines and street surface reconstruction took place. Building started in December 2002 and was finished in late 2007. The S10 part of the East-West Tunnel cost about €62 million.

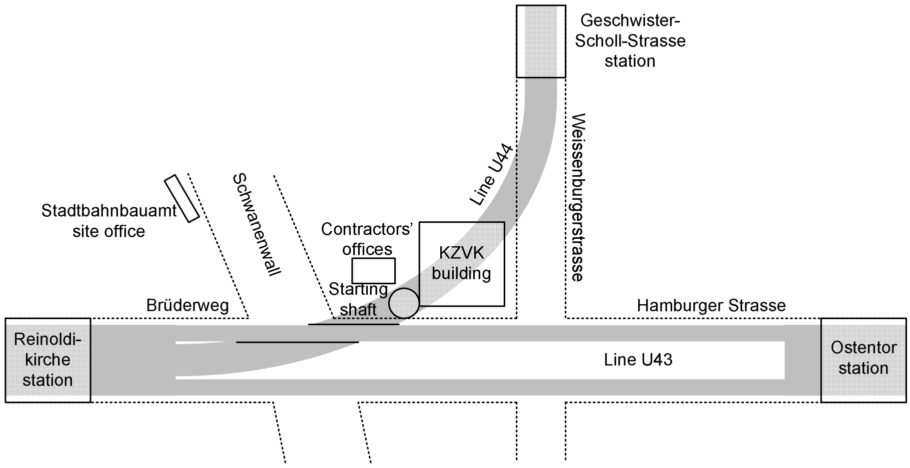

Figure 7.2 Schematic overview of construction site S10 with the U44 tunnel passing under one of the U43 tunnels and under the Kirchlichen Zusatzversorgungskasse (KZVK) building. The boundary between construction sites S10.1 and S10.2 lies between the starting shaft and the KZVK building (own illustration).

7.2.4 Project organisation

The Stadtbahnbauamt of the Municipality of Dortmund designed and managed the project, supported by, in particular, engineering consultant Ingenieursbüro Maidl + Maidl (IMM) for technical and contract specifications. The section from Reinoldikirche to Lippestrasse (construction site S10.1) was built by Wayss & Freytag and Oevermann GmbH & Co. The branch to Borsigplatz (construction site S10.2) was built by the firms Wiemer + Trachte and Alpine Bau Deutschland.

Owner

The tram and Stadtbahn systems in Dortmund are operated by Dortmunder Stadtwerke, a city administrative department. Dortmunder Stadtwerke participates in a regional transportation alliance, the Verkehrsverbund Rhein-Ruhr (VRR). Although the City of Dortmund executed the project, some 90% of the funding came from the *Bundesland* North Rhineland-Westphalia and the federal government. For typical local public transport projects, 60% of the finance is provided by the federal government and 30% by the *Bundesland*. The remainder and all related costs are provided by the local authorities.

The Dortmund Stadtbahnbauamt supervised implementation (sponsor), while additionally IMM played a monitoring role on the tunnelling technique. The Stadtbahnbauamt had a staff of some 80 civil servants, predominantly engineers. Specialities within the bureau ranged from installation technology to contract management. The Dortmund Stadtbahnbauamt thus had extensive expertise available within its own organisation, which limited uncertainty. The main design calculations were done by tunnelling consultant IMM. So, despite the ample availability of engineering staff and expertise, the Stadtbahnbauamt hired an external specialist to draw up the engineering design.

Contractors

IMM drew up the basic reference design. This design was used for tendering and procurement. The terms of reference had to be elaborated into designs with a very high level of detail. Little could be left open because, unlike for instance, normal railway tunnels, U-bahn tunnels include stations. It is particularly the stations that make the works special and require detailed elaboration. Moreover, in the organisational set-up used in the S10 project, the sponsor and its consultant IMM were responsible for the object planning and the contractors were responsible for implementation planning. The contractors needed as much information as possible to be able to make a good and reliable bid. Another reason was that a cost reimbursement contract was used. In such a contract, the bidder accounts for the different kinds and volumes of material and multiplies them by prices per unit. For reliable calculations, bidders need to know the plan in detail.[7]

Wayss & Freytag and Oevermann won the contract for construction of the originally planned works. When the project was extended with the additional branch to the northeast, this subproject was tendered separately as S10.2 (the east-west stretch became S10.1). If this scope extension had been known prior to the tender procedure, it would have been included in one contract. The sponsor now had to trade off whether it was more efficient to add the whole branch as additional work to the existing contract with Wayss & Freytag and Oevermann, or make a new contract. The part between Reinoldikirche Station and the starting shaft at the corner of the Schwanenwall and the Hamburger Strasse had to be included in the original contract as additional work, because otherwise the contract areas would interfere too much. The part from the starting shaft to the resurfacing in the Weissenburgerstrasse could be tendered separately though. The sponsor had calculated that a separate tender would probably be less costly than a sizable change of the original contract with Wayss & Freytag and Oevermann.

The tender for S10.2 was not won by those two contractors, despite their efficiency advantages of having staff and equipment on the site already and the ability to make use of the same starting shaft. Wiemer + Trachte were awarded this part of the work. Therefore, the construction site came to consist of two separate parts, each with its own entrances and construction site offices. The boundary between the two construction sites ran through the tunnel bending off to the Geschwister-Scholl-Strasse Station on the Weissenburgerstrasse, just northeast of the main starting shaft of Wayss & Freytag.[8]

The use of the starting shaft by a contractor other than the one who built it would be problematic though. This may mean that the winning bid was under market price, which could be an incentive to seek avenues to impose additional costs, for which the owner has to be alert.[9] An advantage of having Wiemer + Trachte on the job, in this respect, was that works could take place in parallel. For efficiency reasons, Wayss & Freytag had not proposed this in its bid. Wiemer + Trachte and Alpine Bau Deutschland built their own temporary office sheds in the Weissenburgerstrasse.[10]

The Stadtbahnbauamt preferred small over large consortiums bidding for the project because it had bad experiences with a large consortium in an earlier project. The main problems were coordination between the involved firms and the limited competition at the tendering phase. That latter probably drove up the price of the works. It was possible to award the S10 section to a relatively small consortium because the East-West Tunnel was being built in phases, leaving S10 as a relatively small and manageable section and an attractive contract in a competitive market.[11]

Table 7.1 Project organisation of the East-West Stadtbahn Tunnel Dortmund.

	East-West Stadtbahn Tunnel Dortmund
Client	City of Dortmund
Owner	Stadtbahnbauamt, City of Dortmund
Design engineer	Ingenieursbüro Maidl + Maidl (reference design)
Contractors	Wayss & Freytag, Oevermann (site S10.1) Wiemer + Trachte, Alpine Bau Deutschland (site S10.2)
Operator	Dortmund Stadtwerke

7.3 Occurrences of complexity

The Dortmund East-West Stadtbahn Tunnel had a number complexity features. But it also had the benefit of favourable soil conditions. This made some ostensibly risky aspects more manageable. Implementation was largely successful with only a few setbacks.

7.3.1 Occurrence I: Differentiation – phased construction in manageable chunks

The whole East-West Tunnel was implemented in three phases, though functionally the project was hardly divisible. This meant that a considerable part of the tunnel was already available, when the S10 project was being built. Compatibility of all the parts was crucial, however, for the infrastructure to become operable. The whole East-West Tunnel could function properly only if it included an entrance and an exit to the surface. For this reason, existing Stadtbahn service ran at street level until the whole tunnel was finished. Since the completed parts were finished only structurally and lying idle, maintenance costs for these were not yet a major issue.[12]

Construction of the first two tunnel tubes required construction pits in the city centre, to build Kampstrasse and Reinoldikirche stations. It was therefore deemed easiest to do the work for the East-West Tunnel in those places at the same time, so no new construction pits would be necessary later on. This was an advantage of the early knowledge provided by the comprehensive programme (Sieberg and Overkamp, 1992). The two remaining stretches, at either end of the tunnel, were built subsequently. The design features of the different sections show little variety though. All parts of the tunnel were built using the New Austrian Tunnelling Method (NATM), and outlays for the work were largely uniform.

The whole stretch consisted of ten specification areas. Since street tram service could be continued during the works, there was no immediate need to hurry. The phased construction had an important consequence, with both an advantage and a disadvantage characteristic of the incompleteness uncertainty inherent in this type of scheme. The structural works in the first two phases of the East-West Tunnel included high platforms (90 cm) to accommodate standard Stadtbahn rolling stock. The conversion from street tram to U-bahn would then have required raising the platforms at the tram stops outside the tunnel, as these were still designed for street trams. Over the years, however, low-floor rolling stock (35 cm thresholds) was developed, providing easy access to the platforms at tram height. With the acquisition of low-floor rolling stock, the sponsor could avoid the need to raise the numerous platforms outside the tunnel. It did require lowering of the already built platforms in the underground Kampstrasse and Reinoldikirche stations. Particularly in the Reinoldikirche Station this caused some difficulties because the station, located near the monumental church of the same name, was a very complex building, and important structural elements had been integrated into the platform.[13]

The whole network of three tunnels was built in eleven parts. This had the advantage that workload could be spread out over a longer period, to optimise the activities of the city's Stadtbahn construction department. The project owner could thus optimise mobilisation of means, both financial and other, and management staff.[14] So, the projects were made to match the organisation rather than the other way around. But they also had to match the money flow from the federal government and the *Bundesland*, minimise traffic nuisance and enable acquisition of parcels. Moreover, construction sites that encompassed a station plus some 700 metres of tunnel were reckoned to be optimallysized work packages for the capacity of construction firms to obtain high construction performance.[15] Optimisation of the size of the projects diminished the uncertainty gap, as it mitigated overall exposure to instability and incompleteness uncertainties. Variability was expected to be less in smaller-sized projects, and the available knowledge was expected to better match the knowledge requirements.

7.3.2 Occurrence II: Redesign after addition of the branch to Borsigplatz

A year after the start of the tendering procedure for the S10 site, the scope was expanded considerably, with the addition of the branch bending to the north, towards Borsigplatz/Westfalenhütte. The decision to include this stretch was purely political and hence an interpretation uncertainty. It was to accommodate Borsigplatz residents, who had protested against cancellation of tram service to their neighbourhood.[16] The change was technically possible because originally a small, underground shunting area had been planned between the two one-track tubes. The shunting area was now replaced with a curving underpass starting between the east-west running tracks, to and from Reinoldikirche Station (see Figure 7.2).[17]

Discussions on the inclusion of this branch spanned some ten years. Then, once the decision was made (initial disapproval), it was changed later on. Time was then needed to complete the planning process anew, due to procedures concerning abutters. By the time the decision was changed, the plans for the east-west tracks could no longer be modified. They had to be implemented according to schedule, because the planning decision had restricted time validity. The works had to start within the designated timeframe. If there had not originally been a shunting yard between the two tubes, the change of plans would have been impossible.[18]

The later addition of the branch to Borsigplatz/Westfalenhütte complicated construction of the S10 project in Dortmund. It created physical interfaces and couplings between the different tubes and between the tube to the northeast and the Kirchlichen Zusatzversorgungskasse (KZVK) building, which it had to pass under. The only way to uncouple these structures, and thereby prevent the technical interfaces, would have been to build them deeper. But that would have resulted in steeper gradients.

7.3.3 Occurrence III: The New Austrian Tunnelling Method

The S10 project was built with the use of the sprayed concrete lining method, also known as the New Austrian Tunnelling Method (NATM).[19] NATM makes use of the deformation of the soil surrounding an excavated tube to temporarily support the tunnel itself. Directly after excavation, sprayed concrete stabilises the surrounding soil, aided by lattice girders.

Afterwards, the final shell is built with cast-in-place concrete. NATM has been applied safely and successfully in stable soil, and it was used for most of the tunnel works for the Dortmund Stadtbahn. Only the oldest tunnel stretches were not built with NATM, because the method was still rather new and not yet fully proven back then. In weak soil it would be a relatively risky method, since it is based on an extremely tight coupling with – and even makes use of – the soil structure.

NATM is considered a very useful method in stable soil with no substantial groundwater threat. The method is relatively cheap, and work and nuisance on the surface are limited, for instance, compared to “cut-and-cover” or bored tunnels. In case of cut-and-cover, the street would have to be excavated and restored, and it would be very difficult or impossible to pass under a building. For boring, a larger starting shaft would be needed. NATM also allows varying tunnel configurations, enabling designers to optimise the efficiency of their design for the chosen purposes. It was thus the most favourable option. The requirement for stable soil conditions did make an NATM tunnel more vulnerable to local differences in soil structure. Yet, if these were known, designers and builders could take them into account. Thorough research on the soil in the tunnel trajectory was therefore important to minimise incompleteness uncertainty.[20]

In certain places, very wide diameter surfaces (180 m^2) had to be excavated at a relatively shallow depth (5 m). A way had to be found to ensure that this could be done safely, since the tunnelling method used depended very much on the stability of the soil, and shallow depths reduce the stability of the excavated tube. This problem was solved by excavation in lateral phases. First only a part of the diameter surface was excavated and later the rest. This way, a temporary wall provided strength to the excavation until the whole width could be furnished with a concrete shell (Schliessler and Peter, 2004).[21]

Since NATM is only suitable for very stable soils, it is not the most robust tunnelling technique. It is an efficient choice, however, though with greater exposure to instability and incompleteness uncertainties than other techniques. This aspect was one of the main definers of the uncertainty gap in this project.

The funding providers (the government of North-Rhineland-Westphalia and the federal government) were not active endorsers of development and application of innovations, preferring to avoid uncertainties instead. Where innovative technologies have been used in the past, their use was typically initiated by a contractor or, sometimes, a university. Examples in S10 construction were self-compacting concrete[22] and steel fibre concrete,[23] which were applied in some places to support the normal concrete lining. If suggested by contractors, they themselves were typically the ones who bore liability. They may do so because they think they can benefit from the application, for example, by making their work more efficient. Or they may want to apply the technology to make it more proven. In such cases it may be worth the investment in additional risk responsibility. The contractor in this project wanted to use water-resistant concrete instead of watertight foil at the stations. The Stadtbahnbauamt accepted this under the condition that the water-tightness specifications were met and the technique did not cost the owner more.[24] These are examples of incompleteness uncertainties.

7.3.4 Occurrences IV and V: East-west tube and KZVK building underpasses

The S10 site of the East-West Tunnel included two locations where a tunnel tube had to make a tricky underpass of other structures: another tube and an office building.

Occurrence IV: East-west tube underpass

The added branch to Borsigplatz/Westfalenhütte passed under the northern tube of the East-West Tunnel at a distance of less than one metre, creating high exposure to instability and incompleteness uncertainties. This required precision regarding the tunnel profiles and the limits of deformation, as the shotcrete impact zone of both tubes would partly overlap. Three main technical mitigation measures were taken to ward off technical problems. First, the inner shell of the northern tube of the east-west stretch was built after the curving branch's underpass. This way, damage to the definitive tunnel wall as a result of the possible slight settlement could be prevented. Second, the curving tunnel stretch was built to completion very quickly. Third, both tubes got extra-strong rebar structures (Schliessler and Peter, 2004).[25]

Occurrence V: KZVK building underpass

The risky underpass of the KZVK building ultimately caused no serious problems. Additional mitigation measures (tests, stabilising slabs, use of a specific composition of shotcrete and compensation grouting) worked sufficiently. Settlement of the building was intensively monitored. When the negative effects turned out to be very minor, the engineers even decided to eliminate some of the additional measures.[26]

The pragmatic attitude of the project organisation was quite evident in the engineering of the underpass construction process. The actors involved in the trade-off – most prominently the Stadtbahnbauamt and IMM – accepted their limited abilities to assess whether the normal engineering features that were part of the design were sufficient to safely pass under the building, and hence the incompleteness uncertainty. Rather than relying on standards, the actors decided to avert any risk of collapse resulting from this uncertainty, insofar as possible. They felt that the risk could be brought to acceptable levels with the use of local measures, though it was not certain that these measures would ultimately be adequate. Hence, the managers decided to proceed slowly and prudently to be able to react to any irregularities that might arise. This shows sensitivity to unexpected events.

It could not, nevertheless, be ruled out that a calamity would occur, making the situation considerably less manageable. Two observations are relevant in this respect. First, the focus was not limited to technical risks, despite them being the sole deviations that would have been quantifiable. Second, and related to the first, the actors not only took risks in consideration. They also acknowledged that they could not know everything (incompleteness uncertainty). They therefore decided to reduce the uncertainty gap by minimising the challenge and including more robustness.

It was the inclusion of the branch to Borsigplatz/Westfalenhütte that required the underpass of the KZVK building. This was a direct consequence of the politically driven decision not to cancel the Stadtbahn connections to Dortmund's northeast. It complicated the project somewhat, because it was risky, increasing the project's exposure to instability and incompleteness uncertainties. Since the tunnel was not built very deeply underground, it would pass under the building just one metre removed from the elevator shaft. To accomplish this, the engineers kept local steel-slab stabilisers at hand and left open the option of changing the amount and composition of the shotcrete they were using. They also applied smaller deformation allowance margins and proceeded extra carefully. The engineering design was further based on existing standard engineering calculations. This way, engineers considered the risks manageable.[27]

7.3.5 Occurrences VI and VII: Dealing with weak spots and occurrence of minor leakages

Occurrence VI: Weak spots

In the work procedure used, a standard engineering design was first made for the whole system. The designers then detected weak spots in the tunnel path, based on geotechnical information. This information was sufficiently available due to earlier works and soil tests carried out for the project. Prior to excavation, additional tests were done at the potentially weak spots. This information was used to make adjustments where necessary, such as modifying the concrete composition or constructing a thicker outer shell at designated locations. Subsequently, the construction was monitored extensively to detect any irregularities. Quick measures were kept available during the construction process. These were mostly measures that did not require very radical changes. An advantage of NATM is that the composition and amount of concrete can be adjusted rather easily to the circumstances.[28] The approach aimed at reducing vulnerability to the inevitability of instability uncertainty. Its use demonstrates the engineers' confidence that they could deal with the incompleteness uncertainties.

In general, the geological conditions in the centre of Dortmund were favourable for tunnelling. The soil consisted mainly of marlstone, which allows deformation with shotcrete for NATM application. The trajectory did have a weak spot under the Brüderweg though, where coarse silt was expected. This was precisely the place where four tracks were to run in parallel in one tube. Moreover, the largest tunnel tube diameter (180 m^2) had to be achieved at only five metres below the street surface. For optimal stability, the shells of the two outer tubes were first realised. After that, the walls of these tunnels could provide stability for the wide inner section that would contain two tracks without an inner support structure (Schliessler and Peter, 2004). Here, relying on prudence instead of major front-end adjustments caused slightly higher exposure to instability and incompleteness uncertainties.

Occurrence VII: Minor leakages

The Stadtbahnbauamt's knowledge base benefited from the fact that the department had been involved in construction of Stadtbahn tunnels since the early 1970s. Staff of the Stadtbahnbauamt were kept on after each project for the next one to be implemented. As such, it developed a considerable body of tacit knowledge. Dortmund's soil varies from south to north. Towards the north, the soil becomes weaker and, particularly, moister. Over the years, this knowledge has led to adjustments of engineering designs to local circumstances. Continuity and acquired knowledge reduced incompleteness uncertainties.

In the early phases of implementation, the project did face some leakages. These occurred during excavation of the starting shaft to the lowest level of the underpass to Borsigplatz/Westfalenhütte and while making the connection to this additional branch. The amount of the leakage, at maximum, some 17 litres per second, was considerably larger than expected, but it did not cause insurmountable problems. The issue was largely resolved by drainage and the use of a covering foil. The additional costs were covered by a contractual contingency post. Although the breach occurred in the tendering phase of the additional branch to the northeast, the proposed system and technologies were not questioned, despite the fact that some additional drainage from the starting shaft had to be commissioned (Schliessler and Peter, 2004).[29] The possibility of leakages was a generally known risk, part of the instability uncertainty in the project.

7.3.7 Occurrence VIII: Interdependencies – rolling stock

Due to the phased implementation, construction of the whole tunnel was overtaken by developments in rolling-stock design. The introduction of low-floor trams enabled elimination of the earlier-planned reconstruction of the platforms of the existing tram stops outside the tunnel. It did require reconstruction of the new and not yet used platform inside the tunnel, which had already been built at standard metro height. This was in accordance with specifications used for the other trains in the network.[30] The decision to acquire low-floor trams was also the cause of fixation of the completion date. Earlier, slight adjustments of schedules were not catastrophic since the existing surface tram lines would remain open until tunnel completion. At this stage (with the tunnel structure finished) the risks of delays were reduced and so an efficiency–risk trade-off was made, resulting in the choice for efficiency.[31] This exogenous development can be categorised as an incompleteness uncertainty.

7.3.8 Occurrence IX: Oversight

The project was managed from the Stadtbahnbauamt's head office and on-site by a unit located near the temporary offices of the construction contractors. The sponsor's on-site management resided strictly separately from the contractor's management, in temporary offices located across a large street. The main contact between owner and contractor took place via engineers of the city's Stadtbahnbauamt. They oversaw the contractors' works and conferred with them about progress, checks, possible deviations and unexpected events. Three Stadtbahnbauamt engineers were continuously present on the construction site. This gave the owner its own pairs of eyes on the day-to-day works. It minimised the intention uncertainty (potential strategic behaviour of contractors) and gave the owner's managers more opportunity to assess occurrences of instability uncertainty during implementation. At no point was integration of owner and contractor staff pursued. There were even formal rules preventing integration between the two, in order for the sponsor to be able to carry out its control task.[32]

Although acting strictly separately, the actors in the S10 project in Dortmund did not function fully autonomously. IMM, the Stadtbahnbauamt and the external overseers were in constant contact regarding the details of the project. Information was processed via the Stadtbahnbauamt overseers. This way, the Stadtbahnbauamt not only had first-hand insight into the project, but it could also control the implementation hands-on. This set-up meant that communication between the different actors could remain limited. There were few uncertainties that required extensive deliberation. The reference design was the main source of information linking the designer and the contractor, and normal construction reports were the main source of information between the contractors and the owner. Further day-to-day contacts and lateral relations were confined to the Stadtbahnbauamt representatives on-site.

With this, the Dortmund Stadtbahnbauamt used a very efficient enterprise mode of project management, exercised with strong leadership, in pursuance of harmony and a stable coalition. The project faced very few deviations from the reference designs and plans, which would typically reflect instability uncertainties. The results might have been different if such deviations had occurred or if uncertainties had been larger. It is conceivable that in such cases the mutual contacts and negotiations would have had to be more extensive.

In addition to the sponsor's own oversight, there was an independent tunnelling supervisor who checked the engineering designs. There was also an independent soil testing engineer who checked the soil conditions on-site on behalf of the Stadtbahnbauamt. With their independent positions, these engineers could check all those responsible for works in the project.[33]

In the development of local public transportation, Germany's higher government tiers check particularly the feasibility of projects using a standard cost-benefit analysis and the quality of the local government's proposal. For the latter, higher government evaluates the design in relation to current technical requirements. Oversight by this government tier focuses on financial management, and not on engineering issues.[34] Projects financed by higher government tiers must be elaborated in a standard fashion (sober and efficient). Changes to project plans and designs must be submitted to the higher government level. It decides whether the changes are eligible for additional funding or not. In general, rising costs for labour and materials, for instance, are eligible for additional funding.[35]

The Stadtbahnbauamt made its project organisation rather redundant on technical expertise. Despite being staffed by some 80 engineers, most with considerable experience in tunnel construction, the Stadtbahnbauamt hired IMM as a specialist tunnelling consultant. While the Stadtbahnbauamt set the terms of reference and was executive director of the project, IMM drew up the reference design and acted as tunnelling overseer. An important feature here is that the Stadtbahnbauamt was able to be the project owner and executive. Such an actor usually stands somewhat above all the other actors and therefore requires some authority other than the authority derived just from representing the client. Together, IMM and the Stadtbahnbauamt provided a sufficient counterweight to the practical knowledge of the contractors, which could have evoked intention uncertainty. The risk of such an organisational set-up is that an engineering conflict might arise that affects the relationship between the owner and contractors. IMM could be a buffer in such a case though.

Designer and consultant IMM was specialised in tunnelling and had extensive expertise in this field of infrastructure development. Due to the Stadtbahnbauamt's extensive engineering staff, there was hardly an expertise gap between the sponsor and its contractors. This made the Stadtbahnbauamt a very certain sponsor and limited its dependence on the contractors. Involvement of these specialist actors also reduced incompleteness uncertainties, because of the substantial engineering knowledge available.

7.3.9 Occurrence X: Design engineer-contractor dialogue

The Dortmund Stadtbahn construction was contracted in a traditional sponsor-contractor set-up. The engineering design was separated from the construction job, with the former carried out by IMM. Still, the tendering of the S10 section was done a bit differently than usual in Germany. After IMM produced the reference design, the potential bidders entered into a question-and-answer process with IMM, instead of submitting anonymous proposals. This enabled the bidders to mobilise their know-how to produce the best bid, both financially and design-wise, potentially reducing incompleteness uncertainties and making use of the possible tacit knowledge of contractors. There were ten to twelve meetings with all potential bidders. It took nine months for IMM to check all the bids. Due to the novelty, the construction firms were somewhat hesitant to provide all their knowledge and ideas, as these were their most important strategic assets. They were afraid that they might be pinched by other bidders or the design engineer. They were not used to this kind of openness and trust. IMM also supported the Stadtbahnbauamt in its assessment of the bids.[36]

7.3.10 Occurrence XI: Insurance

An interesting feature of this case is the fact that the Dortmund Stadtbahnbauamt and the contractors purchased joint insurance for the project. The main benefit of this was to prevent possible shifts of blame from one party to the other, reducing interaction-driven uncertainties. This went well until the terrorist attacks of September 11th, 2001, after which the liquidity of financial institutions worsened and insurance companies became unwilling to insure the riskiest part of the works: the underpass of the KZVK building. In the end, the job had to be done without insurance. The Stadtbahnbauamt considered this acceptable since the expected risks were considered manageable. The additional robustness measures (modified shotcrete composition, extended deformation and use of stabilising slabs and lances) cost approximately €200,000, which could be fully compensated with the money that would otherwise have been spent on insurance.

Due to an intensive programme of settlement monitoring, deformation was found to be limited and some compensation measures could even be abandoned, making the implementation even more efficient. Some of the measures were retained, however, as a back-up in case larger deviance than expected occurred.[37]

7.4 Uncertainty in the Dortmund Stadtbahn development

7.4.1 Manageability problems stemming from complexity-related uncertainties

Occurrence I: Since the size of the chunks of work were well-matched with the capacity and capabilities of the owner organisation, the *uncertainty gap* between the information required and the information available was fairly small. This did mean that the work became more *segmented*, both technically and organisationally. The owner did succeed in minimising the *information asymmetry* between its own organisation and the contractors, hence, keeping the essential decision-making to itself. The exposure to *dynamics* resulting from the longer overall implementation process, such as development of low-floor rolling stock, was a downside, but a minor one. It was an opportunity that could have been ignored.

Occurrence II: The political decision to add the branch to Borsigplatz considerably increased the challenge of the work (*uncertainty gap, dynamics*). It added the need for the two risky underpasses to the project. It also caused organisational *segmentation* due to the decision to organise a separate tender for this branch, which was won by a different contractor consortium than the one awarded the original contract.

Occurrence III: The choice for NATM determined to a large extent the size of the gap between the information required and the information available. The sponsor had ample knowledge of the soil structure and experience with application of shotcrete. It was confident that it could handle the higher risk associated with this technique. So, the choice for NATM set a larger *uncertainty gap*. It also implied a greater dependence on input from contractors. The amount and composition of the shotcrete used could be adjusted to found circumstances, which implied a slightly greater chance of an emerging requirement for changes (*dynamics*). Here the *diverging values* of the owner and contractors started to play a role. Contractors could take advantage of their knowledge from the field.

Occurrence IV: The East-West Tunnel underpass was an element involving serious instability and incompleteness uncertainties, such as the variability in the reach of the shotcrete lining and the fact that the exact soil composition at every single spot was unknown. These resulted from the gap created by the political decision to include the additional branch, which made the design more complex (*uncertainty gap*). The increased challenge raised other dilemmas as well. The need for contractors to deliver high-quality work increased, so *information asymmetry* became an issue. The ad hoc approach to deviations, moreover, required a relatively high reliance on the tacit knowledge of the engineers involved. Although very competent, the Stadtbahnbauamt depended on contractors to provide information from the field. The strategy chosen was to count on redundancy by supplying their own overseers. This enabled *rationalisation* on the basis of judgement, rather than just theoretical knowledge on soil composition and stabilisation.

Occurrence V: The underpass of the building posed largely the same uncertainty dilemma as the tunnel underpass (occurrence IV).

Occurrence VI: In relation to the use of NATM (occurrence III), the likelihood that *modifications* during implementation would be required was potentially high, because shotcrete is more greatly affected by weak spots than other tunnelling techniques. Therefore the same *information asymmetry* and possible emergent necessities for changes were in play. *Strategic behaviour* may have played a role in change requests.

Occurrence VII: The minor leakages that occurred were mostly a matter of variability in soil conditions. In some weak spots, they occurred. At others they did not. Other than requiring patching or repair (*dynamics*), they presented few other dilemmas.

Occurrence VIII: The dilemmas with regard to the rolling stock were a paradoxical consequence of the policy to cut tunnel construction into pieces, thus reducing the *uncertainty gap*. This created dependencies with exogenous processes and increased the impact of emerging, unforeseen (and hence inconceivability) developments, such as the introduction of the low-floor vehicles (*dynamics*).

Occurrence IX: The growth of the scope of the project brought with it more contractors and interfaces, and so, overall, a larger *segmentation* of the project organisation. The prowess of the Stadtbahnbauamt as sponsor organisation limited interpretation uncertainty in the management of the project, because overall the *information asymmetry* between the sponsor and the contractors was relatively small. As a result, opportunity for *strategic behaviour* and need for *rationalisation* were fairly small as well.

Occurrence X: With the initiation of a dialogue between the design engineer and the contractor, the sponsor hoped to optimise information-sharing, including tacit knowledge, and the design. This reduced, in particular, incompleteness uncertainties and the typical *information asymmetry* between owner and contractors. The discomfort of bidders with this model was related to their awareness of the strategic value of their knowledge, hence they were unwilling to share it with the whole world (*information asymmetry*).

Occurrence XI: The owner attempted to reduce the *value divide* between their own organisation and the contractor by using joint insurance to eliminate interpretation and intention uncertainty. As such, the owner hoped that contractors' evasion of liability for strategic reasons could be prevented. Viewed from another angle, this was a sign to the contractor that the owner's interest was to avoid conflict (e.g. due to *strategic behaviour*). Insurance companies, however, did not wholly cooperate with this scheme.

These occurrences of complexity led to the uncertainties presented in Table 7.2, which also indicates the manageability dilemmas involved in each.

Table 7.2 Uncertainties in the Dortmund East-West Stadtbahn project and related dilemmas.

Occur-rence	Description	Main uncertainties	Dilemmas in consideration
I	Phased construction	Instability, incompleteness	Uncertainty gap, segmentation, information asymmetry, dynamics
II	Addition of the branch to Borsigplatz	Interpretation	Uncertainty gap, segmentation, dynamics
III	NATM	Instability, incompleteness	Uncertainty gap, dynamics, value variety
IV	Underpass of northern east-west tube	Instability, incompleteness, inscrutability	Uncertainty gap, information asymmetry, rationalisation
V	KZVK building underpass	Incompleteness, inscrutability	Uncertainty gap, information asymmetry, rationalisation
VI	Weak spots	Instability, incompleteness	Uncertainty gap, information asymmetry, strategic behaviour
VII	Minor leakages	Instability	Dynamics
VIII	Rolling stock	Incompleteness, inconceivability	Uncertainty gap, dynamics
IX	Oversight	Interpretation, intention	Segmentation, information asymmetry, strategic behaviour, rationalisation
X	Design engineer–contractor dialogue	Incompleteness, inscrutability	Value variety, information asymmetry
XI	Insurance	Interpretation, intention	Value variety, strategic behaviour

7.4.2 Loose observations on uncertainties

Our discussion up to now of the Dortmund East-West Stadtbahn project suggests a number of loose observations on uncertainties:

- The substantively strong sponsor role mitigated intention uncertainty, but it did not necessarily mitigate interpretation uncertainty, due to the separated decision-making and implementation tasks within the client organisation.
- Reduction of other instability and incompleteness uncertainties likely occurred, as good assessments could be made thanks to ample knowledge and experience, which minimised surprises.

[1] In 1972, the cities of Düsseldorf and Hattingen joined in. The Gesellschaft was than renamed *Stadtbahngesellschaft Rhein-Ruhr*. In 1981, the City of Witten joined. In 1982, Recklinghausen left the Gesellschaft.

[2] Entwicklungsprogramm Ruhr 1968, Landesregierung Nordrhein-Westfalen.

[3] *Stadtbahn* is the name given to a modality that functions as a metro, but replaces street trams. Unlike street trams, they run mostly separate from other traffic.

[4] Respondent A. Fischer.

[5] www.stadtbahnbauamt.dortmund.de (August 30, 2008).

[6] Respondents B. Herrmann, R. Porwoll, W. Voss, H. Sieberg.

[7] Respondent H. Mämpel, H. Sieberg, W. Voss.

[8] Respondents W. Voss, B. Sauerländer, A. Fischer.

[9] Respondent H. Mämpel.

[10] Respondents A. Fischer B. Herrmann, R. Porwoll, B. Sauerländer, H. Sieberg, W. Voss.

[11] Respondent A. Fischer.

[12] Respondents B. Herrmann, A. Fischer, H. Sieberg.

[13] Respondents B. Herrmann, H. Sieberg, project documentation.

[14] Respondent H. Sieberg.

[15] Niewerth, F., Stadtbahn in Dortmund, Sonderdruck, Unser Betrieb

[16] As mentioned, due to the closure of the Westfalenhütte steel works, the city council considered the tram connection obsolete. But there was fierce opposition from the Borsigplatz district. This was a working class neighbourhood with many supporters of football club Borussia Dortmund. They used the tram and Stadtbahn to travel to the stadium in the southern part of the city on match days.

[17] Respondent R. Porwoll.

[18] Respondent H. Mämpel.

[19] Ostentor Station is an exception. This station in the S10 construction section was built in an open pit.

[20] Respondents W. Voss, B. Sauerländer, B. Herrmann; site visit with A. Schmitz and B. Schaeffer.

[21] Respondent C. Peter.

[22] Self-compacting concrete has a thin composition based on polycarboxilate. Its main advantages are time and labour savings. The technology came from Japan. When applied in Dortmund, it was rather new in Europe and had not yet been officially proven in Germany.

[23] Steel fibre concrete has many superior properties to normal concrete, but takes more time to dry.

[24] Respondent A. Fischer.

[25] Respondent C. Peter.

[26] Respondent H. Mämpel.

[27] Respondents C. Peter, W. Voss.

[28] Respondents Voss, Sauerländer, Peter.

[29] Respondents C. Peter, B. Sauerländer.

[30] Respondent A. Fischer.

[31] Respondent B. Herrmann.

[32] Respondent A. Fischer.

[33] Respondent W. Voss.

[34] Respondent C. Genick.

[35] Respondent A. Fischer.

[36] Respondent H. Mämpel.

[37] Respondents H. Sieberg, H. Mämpel.

8. Reference projects

8.1 Introduction

The previous chapters focused on large and complex projects. These projects experienced dilemmas that may or may not be typical in projects with high complexity. To assess the extent that complexity explains the dilemmas, we now turn to three smaller and less complex projects from the same institutional environments. The rationale for this addition lies in the explorative nature of the semi-grounded theory approach taken in this study. Three projects from the same three countries as the larger cases were chosen, but with a lower level of complexity.

The type of project addressed in this study – underground infrastructure construction – appears to be a kind of undertaking that offers substantial opportunity for alternate organisational configurations, with greater or lesser involvement of non-public actors. Considering that in all of the manageability dilemmas discussed in the previous chapters, every possible course of action had its downsides, it may be useful to determine if different levels of complexity, offering opportunity for different organisational set-ups, can offer the prospect of greater manageability. For instance, a particular form of project management may present fewer dilemmas of a certain nature. Or a particular management set-up may present dilemmas in which the preferred decision or action is more obvious, because it has fewer downsides. If managers in such projects were better able to deal with manageability issues, this would provide insights for improving projects with greater complexity.

The first example here is a railway tunnel in the Dutch town of Rijswijk, part of The Hague agglomeration. This project, built in the vicinity of the projects discussed in Chapter 5, was a slightly less complex than the Souterrain. But it nonetheless posed technical challenges. Unlike the Souterrain, it was owned by a central government agent instead of local or regional authorities, but it was championed and partly funded by the local authorities. Also, the project took place in an era of stronger central government involvement.

The second example, the Post Office Square reconstruction in the City of Boston, was initiated and owned by abutters – private companies – rather than public authorities, and it projected a secure return on investment. This, apart from the project's smaller size, made the undertaking less complex than, for instance, the CA/T project in its vicinity. Certainly, there were fewer interdependencies with actors with diverging interests.

The third example is the Herren Tunnel in the German City of Lübeck. This was conceived as a public project, replacing a bascule bridge by a tunnel. But the whole project – including design, construction, financing and operation – was outsourced and privatised.

This chapter follows the outlines of earlier the chapters. It first describes the projects and their project organisations. Then, the main occurrences of complexity in the projects are introduced. Afterwards, the relationship between project organisational set-up and manageability features is analysed.

8.2 Rijswijk Verdiept

The Rijswijk Verdiept project had two features that make it an interesting additional study object. First of all, the project was managed by a state-owned enterprise with a strong engineering background. Second, there was a kind of dual commissionership. The Rijswijk Verdiept project was partly a railway tunnel and partly a city renovation project, so it was co-funded by the national government and municipality. Thus, two civil authorities with partly conflicting interests oversaw the project and managed to balance each other's values. This study was conducted a few years after completion.

8.2.1 Rijswijk Verdiept objectives

During the 1980s, the Dutch central government approved the "Rail 21" programme. The programme contained plans for expanding the capacity of the country's main railway connections. On these lines, the number of tracks would be doubled from two to four. This led to allocation problems, however, in one of the most intensively used rail connections in the Netherlands: the section between the cities of The Hague and Rotterdam. The two main bottlenecks were the towns of Rijswijk and Delft. Authorities in Rijswijk had planned for a possible railway expansion for many years. When the town of Rijswijk grew across the railway track, enough space was reserved for four tracks, though only two were actually present at that time. The crossing of the Generaal Spoorlaan (street) by viaduct was also built for four tracks. When the Rail 21 programme was approved, the infrastructure management division of the Dutch Railways (NS) first concentrated on the Rijswijk bottleneck rather than Delft, because the expansion in Delft was expected to be much more difficult and expensive. Unlike Rijswijk, Delft had not reserved space to accommodate four tracks. Also, the Rijswijk section included two level crossings that the NS and local authorities wanted to eliminate. Expansion of the Rijswijk section would solve the most urgent capacity problems and give the NS time to seek an affordable solution for Delft.[1]

Although there was sufficient space along the tracks in Rijswijk, the NS did have to find an alternative for a level crossing of the Churchilllaan (street). Due to the large number of trains, the crossing was closed for a considerable part of the day, hampering traffic in town. With intensive use of four tracks, there would be little time to open the barriers. The NS infrastructure management division drew up plans to move the Rijswijk railway station slightly towards The Hague and then elevate the Churchilllaan to cross over the railway. The Municipality of Rijswijk opposed this solution, however, because of the large ramps that would be required and the fact that noise nuisance for abutters would not be resolved and in fact would even increase. The municipality then began a study of alternatives. Underground, at-grade and elevated were the options considered.[2] It also hired a process consultant. One of the results was a feasibility study of an underground solution, executed by engineering consultant and NS subsidiary Articon. This solution was estimated to be €112 million to €135 million more expensive than an at-grade solution. The municipality did not have that kind of money. It took the study to another consultant, Gemeentewerken Rotterdam, and showed it to a group of civil engineering professors affiliated with that bureau. They came up with an alternative engineering solution, “the polder construction method”, which would require only half of the additional costs calculated by Articon.

Despite the relatively low additional costs, the NS did not want to venture into a risky technology. Considering the higher interdependences associated with underground construction, it assessed the innovative design as such. Indeed, the independent geotechnical engineers involved considered the polder construction method more risky than traditional tunnelling techniques, though all the engineers involved considered the risk acceptable.[3] The NS and the Ministry of Transport and Water Management eventually agreed to the solution on the condition that the local authorities would cover part of the costs.

The basic structure of the tunnel would cost approximately €61 million. That was €15 million more than an at-grade solution. The NS and the Municipality of Rijswijk agreed that Rijswijk would contribute some €10.5 million to the basic tunnel structure. Central government would invest €4.5 million to close the gap. All kinds of financial acrobatics were performed to make the tunnel possible. The Ministry of Economic Affairs gave the Municipality of Rijswijk a value-added tax (VAT) exemption on its contribution to the tunnel, and the NS allowed the municipality to develop the land on top of the trajectory for its own benefit.[4]

8.2.2 Project organisation

In the main trade-offs on the project, particularly the polder construction design, several actors were involved. First there was the sponsor, NS Rail Infra Management, supported by its in-house design engineer, Articon. There was also the Ministry of Transport and Water Management, which provided the subsidy. There was the Municipality of Rijswijk, supported by consultant Gemeentewerken Rotterdam. There were three additional consultants as well: TNO, for risk analysis; Fugro; and Grondmechanica Delft,[5] the latter two both geotechnical engineering consultants. In practice, most discussions on the design were between Articon and Gemeentewerken Rotterdam, the main engineers of the most important actors.[6]

Some organisational features made this project a bit different from the projects in The Hague region described in Chapter 5. This project took place from 1992 until 1996. That meant it was implemented prior to the privatisation of the NS and before the nature of the ministry's involvement in large infrastructure projects changed. In those days, the large NS organisation had most activities in-house. It had a subsidiary engineering and architecture company (Articon). It also had a construction firm (Strukton), specialised in railway infrastructure. As such, the NS as the client of the project maintained ties with all aspects of the project. This minimised divergences of interests and values particularly in the implementation phase. With its subsidiary Articon as designer and project executive, NS Rail Infra Management basically managed the project itself. Whereas the decision-making phase for the Souterrain was relatively easier, the managers of that project did experience difficulties in, for instance, the handover from the engineering design to construction phase.

In the designing and in project execution all contractors were related to the NS itself. The NS assigned Articon to produce an engineering design and to execute the project. Articon provided the design to construction consortium KSBN, made up of Strukton and Ballast Nedam.

The decision-making process was characterised by strong interdependence between NS Rail Infra Management and the Municipality of Rijswijk. NS Rail Infra Management, as project sponsor, needed the municipality for a smooth process, and the municipality needed the project sponsor to get the tunnel it desired. The municipality had ample non-financial resources to contribute, such as planning and building permits and local support. Although in theory central government could force the municipality to cooperate, there were plenty of means for Rijswijk to hamper the project to such an extent that NS Rail Infra Management could no longer meet its schedules, which were linked to an upcoming modification in railway timetables. Although the municipality's ambitious desires hampered decision-making, they did provoke an optimisation of functionality. They also presented challenges, however, in terms of technology. Something similar happened in The Hague's Souterrain project, where abutters were pleased with the addition of a car park, though this resulted in a deeper excavation that eventually threatened to undermine the project. In Rijswijk, however, the outcome was positive.

8.2.3 Occurrences of complexity

Occurrence I: Polder construction

The proposed "polder construction" method entailed excavation of a trench which was separated from its surroundings by diaphragm walls and sealed off below using an existing impermeable clay stratum typical in Rijswijk. The excavation was kept dry by permanent drainage. The main cost reduction was in the exclusion of an inner concrete tunnel box. This kind of tunnel would be more expensive in maintenance though, because permanent drainage would be required. Direct interdependencies with the soil remained after completion. For more security, longer tunnel sections were used as an additional robustness measure.[7]

The depressed section had a total length of 1,500 metres of which 550 metres lay in the covered section. Other parts were the ramps on both sides. The tunnel was 40 metres wide in the new railway station, which was located in the covered part. The diaphragm walls went 21 metres deep. In the polder section (the covered part) the groundwater was drained between the diaphragm walls to 7.50 metres below sea level. The total cost of the project was approximately €87 million.[8]

Not including an inner tunnel box meant that existing construction methods could not be used to build the tunnel roof. In earlier construction using the polder technique this had not been necessary, because those applications were for structures such as underground car parks. In this project, therefore, the construction firms developed a new method in which machinery could step forward through the tunnel path without a floor being installed earlier. This innovation was a requirement that followed directly from the decision to use the cheaper design solution. It made various technical interfaces more crucial, however. Most importantly, the lack of a tunnel floor required a construction method for the pillars that was comparable to the diaphragm walls; that is, excavating and stabilising a preconfigured casting hole that is then filled with concrete. These "slurry pillars", moreover, had to be dimensioned to allow possible future buildings on top of the tunnel.[9]

The uncertainty lay not only in the technical challenge, but also in schedules. The lack of experience with the technique meant there was no proven reference for the time required per section to be installed.[10] For the diaphragm walls, Articon had better references. It had been involved in the construction of an underground car park in Utrecht, which was built using a comparable method. It could transpose that knowledge to Rijswijk.[11]

Construction was mostly successful. The tunnel was delivered exactly on time, on May 29th, 1996, though this did require some overtime at night and in weekends. The total structure was completed in 1997. Since then, there have been some minor problems with leakages. Diaphragm walls always leak to some extent, and without an inner tunnel box that water can flow directly into the tunnel. The amounts in this case, however, were larger than expected. This has not presented large problems for operation. It only means that more drainage water has to be handled by the Province of South Holland. It did, however, cause a nasty smell in the tunnel and station for some time, and the moisture has turned the walls green.

Occurrence II: Some overdimensioning

Apart from the "underdesigning" in the form of the polder construction method, which eliminated the need for an inner tunnel box, the project also included some overdimensioning. In some places, robustness was increased to compensate for the less robust, riskier design. For example, longer tunnel panels were used and the slurry pillars were overdimensioned. Another important motive for building more robust pillars was to enable later construction on top of the tunnel. This functionality was required for the municipality to earn back some of its investment, although only a relatively small portion of the roof surface has indeed been built on. For this same purpose, the diaphragm walls included a specific type of joint between wall panels to prevent deformation. And because engineers expected a sand enclosure at the tunnel entrance on the Delft end, the polder construction there was made a bit shorter, with the open box of the entrance extended to cover that spot.[12]

Occurrence III: Phased construction

One of the main technical complexities was the requirement to keep the railway tracks in operation during the works. To this end, a relatively complex phased construction process was developed in which two depressed tracks were constructed on either side of the existing tracks. Once completed, traffic was diverted to the new depressed tracks and the old tracks would be demolished and rebuilt at the same depressed level. The separate trenches could then be connected by demolishing the temporary walls between. The phased construction of different sections of the tunnel went well. The important rail connection between The Hague and Rotterdam remained in operation during the works. The newly developed construction method to install the roof panels was successful and sometimes even more progress was made than scheduled.

Occurrence IV: A fixed completion date

The NS had tight time schedules, from the very start in the preparation phase. Keeping to the schedule was an important incentive for the NS to be receptive to opposing views, as long as this implied progress. The NS was slated to start operating with new rail timetables on May 29th, 1996, at 5.00 AM. Those timetables assumed availability of four tracks in Rijswijk. The Municipality of Rijswijk threatened to hamper progress if its problems with an at-grade crossing were not resolved. Since disputes on this issue could lead to time-consuming litigation, the NS had to consider underground solutions. The time benchmark was therefore an important condition for ensuring progress.

In the decision-making process, the NS gave its project managers at NS Rail Infra Management and Articon a kind of mandate: they had six years to come up with a solution for the Rijswijk crossing, respecting the boundary conditions and including a construction period of four years. This incentivised them to focus on the tunnel solution, because they realised that an at-grade design would collide endlessly with the interests of the municipality. This led to acceptance of the polder system, even though the ministry stipulated that the municipality would have to contribute financially to realise the tunnel.

8.2.4 Uncertainty and manageability dilemmas in Rijswijk Verdiept

Occurrence I: The polder construction was a riskier version of the design and hence increased instability and incompleteness uncertainties (*uncertainty gap*). The required stepwise construction method was subject to the typical instability uncertainty of variability. The dilemma here was whether the organisation could handle this uncertainty. The assessments were made by actors with more knowledge on the matter than the sponsor had (*information asymmetry*). Although it was *rationalised* by analogies to earlier applications, use of the technology for a tunnel was new and hence the confidence was partly based on engineers' tacit knowledge. The matter was therefore mainly whether the trust in the engineers (considering possible *value variety*) and the rationalisation attempts were sufficient to proceed.

Occurrence II: Overdimensioning compensated for the greater incompleteness uncertainty that came with the polder construction technique. The main dilemma here was whether it compensated sufficiently for the additional uncertainty and, hence, reduced the size of the *uncertainty gap* enough. Apart from an engineering issue, the overdimensioning was a political issue. The possibility to build on top of the tunnel made the project possible from a financial perspective. High *variety in values* played a role here, for instance, with the municipality having an interest in surface development.

Occurrence III: The phased construction was necessary to keep the rail link in operation during the works, but it did increase the technical challenge, due to the greater incompleteness and instability uncertainties it caused. Hence, a larger *uncertainty gap* was accepted to enable the project to proceed. No negative effect was observed.

Occurrence IV: The rigidly fixed completion date increased the impact of instability and incompleteness uncertainties. Inconceivability uncertainties, moreover, would have increased massively if serious delays had occurred (*uncertainty gap*). Compensations would then have had to be made in the remaining construction schedule or the completion date would have needed to be pushed back. This meant there was little room for unexpected incidents, for instance, regarding the design or technology (dynamics). However, resources did have to be reallocated, for example, additional shifts had to be worked, to make the date possible.

These occurrences of complexity led to the uncertainties presented in Table 8.1, which also indicates the manageability dilemmas involved in Rijswijk Verdiept.

Table 8.1 Uncertainties in Rijswijk Verdiept and related dilemmas.

Occur-rence	Description	Main uncertainties	Dilemmas in consideration
I	Polder construction	Instability, incompleteness, inscrutability	Uncertainty gap, value variety, information asymmetry, rationalisation
II	Overdimensioning	Incompleteness	Uncertainty gap, value variety
III	Phased construction	Instability, incompleteness	Uncertainty gap
IV	Fixed completion date	Instability, incompleteness, inconceivability	Uncertainty gap, dynamics

8.2.5 Benefits and downsides of this set-up

The achievement of optimal functionality (an expanded project scope) for a relatively low cost can be attributed to the conflicting interests and opposing forces between the NS and the most important stakeholder, the Municipality of Rijswijk. A crucial aspect was the involvement of two main stakeholders with production power and blocking power. The balance of power balanced the trade-offs.

Another important factor was the absence of an interface between owner, engineering design and implementation, due to the involvement in all phases of subsidiaries of the client organisation. The absence of interaction-driven uncertainties in the phases after the decision was made to use the polder construction method was particularly notable. It resulted in an absence or minor influence of dilemmas related to information asymmetry and strategic behaviour.

The greatest downside of this approach was that it required a project sponsor with extensive engineering expertise, which is quite rare nowadays. Of the main cases examined in this study, only the Dortmund Stadtbahn project had a comparable set-up. Applicability of such a configuration in modern construction projects in most Western countries is therefore doubtful.

8.3 Post Office Square, Boston

Parallel to the massive Central Artery/Tunnel project, another underground project was being carried out in downtown Boston: the reconstruction of Post Office Square, in the middle of the financial district. The purpose of the project was to improve the urban environment by demolishing an old car park, rebuilding it underground and transforming the freed-up space into a small park. Unlike the organisation of the CA/T project, this was an entirely private-sector initiative. In fact, it gained some renown as the first completely privately financed park in the United States. The car park provided the private financers a secure return on their investment. This section explores the effects of this organisational configuration. The study was conducted multiple years after completion.

8.3.1 Post Office Square project objectives

The first large refurbishment of Post Office Square in downtown Boston took place in 1954: a large, four-storey parking garage was built in the middle of the square. At the time, the City of Boston feared losing retail business to the suburbs and thought the extra parking spaces would help solve the problem. It therefore signed a 40-year lease contract with a taxi and garage operator. Within a short period, most offices moved their entrances, including their addresses, to the other side of their premises, effectively turning their back to the grey, concrete building that also caused regular jams on adjacent streets.

The initiative for the reconstruction started informally after prominent businessman and project developer Norman Leventhal, of The Beacon Companies, acquired an old building adjacent to the square: the former Federal Reserve Bank, which had by then been unoccupied for several years. Leventhal partly cleared the lot, to make way for an office tower and transformed the other part into an upscale hotel. At the hotel's opening in 1981 he spoke of his desire for the garage, which faced the premises, to be demolished. The main obstacle to demolishment was the city's lease with the garage operator, which expired in 1994. With annual net revenues of $1 million from the garage, the operator was not eager to give it up.

In 1983, Leventhal set up a private initiative including abutters of Post Office Square to raise the money for a buyout and reconstruction. It was called the Friends of the Post Office Square Trust. He invited other real estate owners along the square to join the group. Only chief executive officers were allowed to attend meetings, as he wanted to ensure a commitment the highest level in the participating businesses. Robert Weinberg, a Leventhal associate and former director of the Massachusetts Port Authority was a member.[13] (Leventhal was also one of the initiators of the Artery Business Committee involved in the CA/T project, discussed in Chapter 6.)

The Trust soon started negotiations with the car park operator, though the lease contract would last another six years. The operator, indeed, was reluctant to give up this source of income. In 1987, the Trust finally negotiated a $6 million lease buyout. That amount approximated the expected income during the remainder of the contract. Since an extension of the lease from the City of Boston was unlikely, the operator opted for the buy-out.[14]

The project had two important advantages. First, abutting real estate owners were among the project sponsors. As a consequence, they had a very rational attitude towards mitigation of adverse effects of the required construction works. Since they had a direct stake in the project's success, they had no direct incentive to position their own interest above the shared interest. Second, there was a prospect of a certain constant flow of income. Although the loans had to be paid, the income from the car park guaranteed a good position on the capital market. Also, the Trust calculated that it could earn back its investment in a 40 year ownership period.[15]

8.3.2 Project organisation

The Friends of the Post Office Square Trust acted as project owner. Since the project consisted of two main systems to be constructed – a park and a garage – there were two main design contractors. The Trust hired Ellenzweig for the garage and Halvorson for the park. Halvorson, the park designer, was appointed as the main contractor. Ellenzweig became a subcontractor. Parsons Brinckerhoff, Quade & Douglas (PB) did the civil engineering work for the garage. J. F. White was awarded the construction job. The basic ideas for the park were drawn up by a park programme and design committee that was closely associated with the mayor's office and included community members. On the basis of these ideas, some 100 designers participated in the bidding process, which Halvorson won.[16]

The Trust benefited significantly from its good contacts. Leventhal, in particular, had excellent contacts with construction firms, and they held him in high esteem. The clients selected primarily the *proposers*, rather than the *proposals,* and a main criterion was whether a contractor had good managers, rather than whether they were cheapest.[17] In this setting of mutual trust and reliance, the Trust was confident that the job would be well done. Moreover, since the Post Office Square reconstruction was not a public project, the Trust did not have to choose the lowest bidder for tendered contracts. The companies chosen were those in which the Trust had confidence and continuing good relations. This minimised the chance of adverse behaviour.[18]

The project could also afford to hire two permanent "watchdogs": two engineers with good reputations that would oversee the works and properly weigh all of the necessary engineering trade-offs. Management thus maintained a certain distance from the engineers, but via the two representatives remained involved in hands-on engineering. Everyone who raised an issue was listened to. There was a high level of professionalism, meaning that if an issue was raised, it was expected to be relevant.[19]

Under a technical advisory committee, three subcommittees were formed: operations, design and construction. The construction subcommittee was made up of a geotechnical engineer and a construction consultant. The latter provided estimation, scheduling and preconstruction advisory services, and assisted in the bidding process and in monitoring and performance review. The client's engineer oversaw the project.[20]

The contractors were involved in the design phase. Relevant issues were raised early in the process and ambiguity was avoided. This was also in the contractor's interest, since the form of contract used by the Trust stipulated a guaranteed maximum price. The benefits, for the client too, weighed up against the higher costs the contractor calculated for the early involvement. Although the capped price may have been higher than a non-capped price, because contractors had to incorporate a higher risk margin, the clients considered that otherwise a contractor would make sure to get a certain profit anyway, for instance, by reckoning more additional costs. Although this approach may ultimately be as expensive as or more costly than the usual public approach of cost-plus-fee, it did have benefits. Technical data also became immediately available to every actor involved. They checked it from their own perspectives, minimising the chance of surprises. In public projects this contracting method is rarely used, since it is ostensibly less efficient. The Trust considered the regular "public" approach so disadvantageous that it initially had doubts about the preferred bidder, since it had been involved mainly in public projects.[21]

8.3.3 Occurrences of complexity

Occurrence I: Private funding programme

It was clear from the start that neither the City of Boston nor the Commonwealth of Massachusetts had funding available for the project. Therefore, the Trust had to find private financiers willing to invest some $80 million in total. This was the estimated cost of the underground garage and the park. The Trust began by selling $65,000 shares that were repayable in 40 years at an 8% interest rate. These included the lifelong guarantee of one parking space to be leased at market rate. There was an incompleteness uncertainty in whether sufficient investors would be interested, but the lines of communication between the real estate owners around the square were short, and 450 shares were sold, yielding $30 million. The remainder came from a loan from the Bank of New England.

The City of Boston was pleased with the potential quality improvement for the financial district. It could have earned a lot of money if the site were cleared for a high-rise office building, but the Boston Redevelopment Authority, under the city administration, opposed the possible loss of sunlight that would result from building yet another shadow-casting skyscraper. It supported the Trust's idea to build a small park instead.[22] The Trust then promised to contribute parking profits to help maintain the parks in the rest of the city.[23] The city would now receive $1 million for ownership of the site, $1 million in property taxes annually and another $1 million annually as a contribution to park maintenance elsewhere in the city. Moreover, the city had no operational costs for either the garage or the park, which were to be managed by the Trust. Furthermore, the value of the real estate on Post Office Square rose after the opening of the park, which increased the city's tax revenues on other properties.

In the five years following the opening, the Trust met its financial obligations, but had not as yet been able to pay any dividends to shareholders or put money into the city's park maintenance fund. However, prospects were relatively good, due to the gradual increases in parking fees (without losing customers) and the fact that all profits were to flow to the city's coffers once the project had been paid off.[24] These financing schemes meant that the lack of public funding was not a big handicap for the renovation. Money was certainly not the kind of constraint it had been elsewhere. This was evident in the project design and implementation.

Occurrence II: Interdependence with abutting structures

Regarding interdependencies, the physical interface with the Meridien hotel next to the excavation was most risky. Building in some additional robustness, however, prevented mishaps there. The decision to make robustness adjustments was taken when the monitoring programme indicated slight settlement of the hotel building. This was solved with a stoke of ingenuity. The diaphragm wall panels, which had a width/thickness ratio of approximately 3:1, were turned ninety degrees, making the wall at that particular place three times as thick as originally planned. There was little debate about the need for this measure within project management, because the owner of the building was one of the constituents of the Trust.

Occurrence III: Interdependence of functionalities

The project consisted of construction of a new seven-storey underground parking garage for 1,400 cars. It was the deepest excavation in the City of Boston. High prices for parking in the area were one of the main reasons why an underground car park was feasible. Building the structure cost some $34,000 per parking space.

It was built top-down using diaphragm wall technology. The clients hoped to be able to open the upper storeys for parking, while the lower ones were still being excavated. This would optimise costs and revenues and minimise the amount of time without parking facilities.[25] The garage was planned as a full service facility, with for instance, a car wash and a repairs facility, free traffic information and a laundry service.

A few technical interdependencies between the two main functionalities of the project made the undertaking particularly complex. For one thing, the underground structure had to be strong enough to carry a heavy load of soil, to provide enough ground for trees to root. Second, the technical interdependence between the garage and the abutting buildings – relevant due to the risk of settlement – was not much easier here than in many of the CA/T subprojects. Apart from the underground interface, there was also an important external interface between the garage and the abutting structures. The engineers had to be sure that the deep excavation did not cause subsidence in the neighbourhood, so an extensive monitoring scheme was set up.

Occurrence IV: Schedule optimisation

Many activities were planned sequentially, but with some creativity, some of them could be staggered. One example is the elevator shaft. Shafts were always built from the bottom up. If, however, the shaft in this case could be built from the top down instead, construction on it could start earlier and the first floors could become operational sooner. This was hitherto unheard of, but the elevator shaft construction contractor was convinced of the feasibility with the promise of some additional money and the argument that the experience would be an excellent reference for future projects where top-down construction of elevator shafts would be beneficial.[26] This is one example of how optimisations in the project were sought to improve value from a lifecycle perspective.

During implementation, the construction timeline was in fact shortened from 31 months to 27 months. The cost of this truncation was calculated at some $500,000, while the additional benefit from the four months of operation could amount to $2 million. Later, the process was shortened again, by three additional months.[27] Hence, the tight link between the finances of operation and the planning of the project had clear benefits, which could be achieved because the eventual client itself managed the project. An efficiency optimisation was achieved by extending the project management's horizon from preparation and implementation to preparation, implementation and operation.

Implementation was successful, with few serious problems. Technical setbacks remained minimal. Although dividends could not be paid for quite some time, the result of the project has been highly acclaimed. The garage was opened in October 1990 and the park in the spring of 1991.[28]

8.3.4 Uncertainty and manageability dilemmas in the Post Office Square project

Occurrence I: Dependence on funding from real estate owners led to some incompleteness and possibly intention uncertainty, due to the social interdependence it created: the interests of shareholders, who might position themselves opportunistically, had to be taken into account. This introduced some potential *value variety* to the project. In practice, however, it actually reduced value variety, because the shareholders were also abutters. This helped the initiators gain crucial support, and it neutralised the potential for *strategic behaviour*. Giving these stakeholders access to the process generated strong acceptance, even support, in the project environment and consensus on the design.

Occurrence II: The main technical challenge was in the interface with abutting structures. Deviations, resulting either from instability uncertainties (e.g., variability) or incompleteness uncertainties (e.g., incomplete information) could damage shareholders' real estate. Uncertainties were introduced by the relatively high level of ambition of the project (the deep excavation between high-rise buildings) and the *uncertainty gap* this created. Selection of the best available and, particularly, the most trustworthy contractors reduced the uncertainty gap. The inclusion of abutters as shareholders made protection of the environment the main engineering focus, but as indicated above, consensus among the real estate owners was strong. Whereas the relationship between the project organisation and abutters would normally insinuate *value variety*, here it eliminated value variety. The importance of the project environment value was directly felt and motivated the project organisation to acquire extensive knowledge from specialists and to acquiesce with their suggestions (*information asymmetry*).

Occurrence III: The two functionalities, garage and park, set mutual constraints, increasing the challenge of the project and the probability and potential impact of incompleteness uncertainties (*uncertainty gap*). The technical interfaces extended to organisational interfaces between the contractor for the garage and that for the park (*segmentation*). For clarity of authority, the park contractor was appointed as leading, but the clear hierarchy did introduce a potential for *value variety* between the two. Though the sponsor held the contracts, it had little influence on project execution.

Occurrence IV: During implementation, the project management increased instability and incompleteness uncertainties by speeding up the schedule (*dynamics*), to enable an early opening. This increased vulnerability to setbacks. But the risk inherent in this change was considered acceptable, so it only slightly increased the *uncertainty gap*.

These occurrences of complexity led to the uncertainties presented in Table 8.2, which also indicates the manageability dilemmas involved in the Post Office Square project.

Table 8.2 Uncertainties in the Post Office Square project and related dilemmas.

Occur-rence	Description	Main uncertainties	Dilemmas in consideration
I	Private funding programme	Incompleteness, intention	Value variety, strategic behaviour
II	Interdependence with abutting structures	Instability, incompleteness	Uncertainty gap, value variety, information asymmetry
III	Interdependence between functionalities	Incompleteness	Uncertainty gap, segmentation, value variety
IV	Schedule optimisation	Instability, incompleteness	Uncertainty gap, dynamics

8.3.5 Benefits of this set-up

The fact that abutters were the sponsors of the project eliminated potentially problematic interfaces. There was an incentive to make quality the main driver. This resulted in the relatively rare situation that the sponsor retained its focus on quality throughout the project. Typically, sponsors seem inclined to become more cost-focused as implementation gets underway. Interestingly, the owner’s managers did find ways to improve the economics of the project by optimising the schedule. The incentive to do so was the fact that the managers of the project would eventually receive the return on the investment. The trade-off between cost and schedule was therefore made without too much dependence on a contractor and with direct control over the implications for technical quality.

There seem to be few downsides to this set-up, except that it is very rare for a project to be initiated, owned and managed by private abutters. It requires large and powerful constituents with a strong foothold in the construction business.

8.4 The Herren Tunnel

The Hanseatic City of Lübeck in northern Germany wanted to develop a replacement for the Herren Bridge, a bascule bridge on the busy road between Lübeck and Travemünde. Some 20,000 cars passed over the bridge daily, though this traffic was hampered by the frequent bridge openings. The city's ambitions went beyond a new bridge, however, as a new bridge would suffer the same limitations as the existing one because it crosses an important shipping lane between the Port of Lübeck and the south-western Baltic Sea. Instead it aimed to create a fixed link that would enable road traffic to pass without the interfering with shipping traffic, preferably by tunnel. Lübeck, however, with just over 210,000 inhabitants, had neither the staff nor the means to build such a project.[29]

The recently developed alternative "F-modell" of the German federal government provided a way forward. In the F-modell, the role of the client is minimised and a considerable share of the oversight is left to the contractors themselves. By outsourcing the project in accordance with this approach, Lübeck could get the tunnel it desired without bearing the load of a large investment. This study was conducted during construction, with the main structure finished.

8.4.1 Herren Tunnel project objectives

The Herren Tunnel was to replace the bascule bridge on the B75 highway in the Kücknitz district, over the river Trave, between the Lübeck harbour and open sea. The road could not hamper the busy shipping lane to the harbour, which had to remain accessible to large sea ships. Hence, the old bridge was opened frequently, blocking the busy road traffic between the district of Travemünde and the city centre. Also, the bridge's prospective lifespan was foreseen to end in 2005, so some kind of replacement was necessary.

8.4.2 Project organisation

Application of the "F-modell" meant that the project organisation would be configured around a Build-Operate-Own-Transfer (BOOT) contract. Activities of the private contractor consortium were to include everything, from the engineering design process to finance. From the perspective of the whole project organisation, it can be considered a Design-Build-Finance-Maintain-Operate-Transfer (DBFMOT) undertaking. The city, as the project sponsor, drew up only very basic and mainly functional terms of reference, and transferred all the above-mentioned tasks to a private contracting consortium, including the federal subsidy. The contracting consortium was then awarded a concession to operate the stretch of federal highway for a designated period of time (30 years) and allowed to levy tolls to earn back the investment. The construction period was included in the concession period to incentivise the contractors to prevent delays.[30] The conditions of the contract (length of the concession, toll costs) were based on an agreement between the client and federal Ministry of Transport, on one hand, and the contractor, on the other. Tolls were to be established based on the actual cost of the project, preventing too large surprises for the contractors and banks. They did not have total freedom to raise the costs, however. Costs were subject to negotiation, so the contractors had to be aware that too-high additional costs would not be allowed in the reimbursement scheme.[31]

The BOOT contract was drawn up based on a tendering contest, which was won by a consortium of banks (Landesbank Schleswig-Holstein and Kreditanstalt für Wiederaufbau) and construction firms (Hochtief and Bilfinger Berger) operating under the name Herrentunnel Lübeck GmbH & Co. The construction firms had previously been involved in comparable tunnelling projects in northern Germany: the Weser Tunnel north of Bremen and the fourth tube of the Elbe Tunnel in Hamburg. Decision-making lines were within the organisation, which was an advantage in this privatisation scheme. It assured quick decision-making, as there would be no need to wait for governmental approval all the time. The offices of the project organisation were located in central Lübeck and not at the construction site. Apart from the project director, there was no contact between the managers and builders.[32]

8.4.3 Occurrences of complexity

Occurrence I: Tunnel boring through an aquifer

Three alternatives for a new river crossing were considered: a bridge (preferably not another bascule bridge), an immersed tunnel and a bored tunnel. If a bridge were used, it would have to be so high (45 m) that the slopes would either become too steep or would require more space than available. An immersed tunnel would encounter problems as well. The soil under and around the river Trave is rather complex since there are two aquifers in the area: an upper aquifer with brackish water in contaminated soil and a deeper, tertiary aquifer in brown coal sands, which provides drinking water to the city. The two are separated by an impermeable layer of artesian marl and clay. If a trench were excavated through the marl and clay to immerse the tunnel tubes, the aquifer might come into contact with the contaminated soil, polluting the city’s drinking water. This situation was rather unique. A bored tunnel was considered the safest option.[33] A bored tunnel was also the most expensive option, however. Total costs were estimated at €179 million, about half of which was to be federally financed.[34]

The design came with a few instability and incompleteness uncertainties. The Herren Tunnel was designed as two tubes, located at a very constant distance from each other. Among other things, this was so that a interconnecting evacuation tube could be constructed between the two main tubes (using soil freezing and shotcrete). The almost 800 metre tubes of the tunnel were to be bored with a hydro-shield tunnel boring machine and annular grouting would be used to minimise the chance of the contaminated soil and brackish water coming into contact with the drinking water. One of the riskiest interdependencies was that between the tubes and the old bascule bridge. Being at the end of its lifespan, the bridge had become somewhat vulnerable to settlement, which could occur as a result of tunnel boring. Yet, the tunnel builders had to locate the new tunnel in the trajectory of the road connection between Lübeck and Travemünde, directly abutting the slopes to the bridge. The settlement stayed within margins however.[35]

Occurrence II: Boulders in the tunnel path

Construction of the project was generally successful. The boring of the first tube did encounter some setbacks, particularly due to large objects in the tunnel path. Boulders deposited in long-ago ice ages had not been foreseen in the geotechnical reports, a typical incompleteness uncertainty. They regularly caused delays when the shield of the tunnel boring machine ran into them. If known, the boring shield could have been adapted. Now, changes had to be made ad hoc. Occasional repairs, for example, had to be made to the shield. Larger repairs were only possible after the boring of the stretch underneath the river. Some maintenance had to be postponed until more stable soil had been reached. Boulders too large for the shield had to be demolished under compressed air. This technology, therefore, had to be present as a back-up at all times.[36] Sometimes, divers had to manually remove boulders that jammed the bore shield and were too large for the stone crusher (Ehmsen and Otzisk, 2004).

Occurrence III: Dealing with the sensitive environment

There were a few other technical complexities that resulted in incompleteness uncertainties, though they were effectively managed[37]:

- A section of the slope under the old bridge had to be excavated, but the bridge itself could not be allowed to settle due to its advanced age. This was an incompleteness uncertainty for which an extensive monitoring system was set up.
- The engineering design for the tubes provided for a maximum deviation of 5 centimetres from the axis line. This narrow margin was necessary to protect the old bridge from possible impact, particularly related to the northern (westbound) tube. During the works, the maximum deviation mounted to 11 centimetres. Immediate measures were taken: permanent monitoring through measuring, the

tunnel boring machine was steered considerably below the pre-calculated axis and compensation grouting for the annular gap mortar was increased. These measures had the desired effect and stopped further deviations. Despite the deviations, there were no problematic consequences, indicating to the external oversight management that the margins were very tight (Ehmsen and Otzisk, 2004).

Occurrence IV: Privatisation

The federal government provided a subsidy for the new fixed link based on the approximate cost of a new bridge. As mentioned however, the city considered a new bridge undesirable. Yet, the City of Lübeck did not have the financial means to provide the additional money for a tunnel. This meant that either a less ambitious scheme had to be pursued (such as another bridge), or another source of financial means had to be found. Lübeck was not alone in this; the City of Rostock, for instance, had been developing a comparable project under the Warnow Estuary. To this end, the German federal government drew up the so-called *Fernstrassenbauprivatfinazierungsgesetz* (highway construction private financing act) or “F-modell”. Two schemes, the “A-modell” (“A” for “Autobahnausbau” = highway extension) and “F-modell” had been developed to enable private financing of road construction. The A-modell led to a highway toll scheme for lorries, with the revenues redirected to the private parties that implemented road extension. The F-modell was designed for more specific structures, such as bridges, tunnels or stretches of federal road. To these objects a local toll scheme would apply that included all traffic.[38]

The privatised set-up that focused strongly on quality and value made robustness and slack possible if it contributed to better lifecycle value, for instance, by reducing incompleteness uncertainties and optimising the project economically. Experiences built on the (tacit) knowledge of the builders. Several lessons from the works on the first tube improved practices on the second. These concerned both the tunnel boring and the processing of the dirt at the separation plant. Various adjustments were made in the cutters, stone crusher and sieve (Assenmacher, 2003). The prevention of costly repairs and expensive maintenance was also an incentive to choose for high quality. An example of this is the road deck in front of the toll booths, which was made more durable to prevent deterioration as a consequence of braking and accelerating vehicles.[39]

Most of the real problems in the financial management of the Herren Tunnel project arose after opening. The number of cars passing through the tunnel has been considerably less than expected. The operation schedules foresaw 37,000 cars daily. In 2007 the actual number was not much higher than 20,000. This seems primarily an instability uncertainty (variability in demand), but drivers may prefer a five kilometre detour via a nearby highway (A1-A226) that became available after a bridge restructuring in the city. The toll agreed by the city, the state and the joint venture have been increased twice, so the joint venture can earn back its investment. The contract between the joint venture and the authorities includes the possibility to extend to concession period, for example, to 50 years. This could be an instrument to ensure that the private investors eventually earn back their investment. Within the city administration there is little enthusiasm for extending the toll period longer than planned. The city would rather see the tunnel acquired by the federal state, which cannot levy tolls. This would, however, be a veiled way to massively increase the federal subsidy of approximately €90 million for the tunnel. Hence, the chance of this scenario is small. The situation is expected to have become worse since the recent opening of the Eric Warburg Bridge, which shortened the detour. This is a new bascule bridge that looks strikingly similar to the old Herren Bridge.[40] The Warnow Tunnel in Rostock, the privately financed and built tunnel that was considered the other frontrunner for future public-private development along the F-modell, is struggling with similar problems.

Occurrence V: Oversight

The organisation had two control mechanisms: external oversight (as in every German project that receives public funding), executed by GTU and Emch + Berger, and internal oversight. The addition of the latter was important for the contractors and financiers, since they would be responsible for any possible flaws. This was an incentive to avoid technology-related incompleteness uncertainties where possible.[41] Nevertheless, the contracted banks and construction firms decided to organise their oversight differently than done in public projects. Privately owned projects are allowed to deviate from the conventional standards of supervision. Normally, underground construction processes have full-time oversight. The sponsor and the contractors in this case decided to apply "value engineering", in which supervision responsibilities lay more within the responsibilities of the contracted joint venture itself. The functional performance contract allowed quite some room for interpretation, which made the processing of claims between the different parties a bit more difficult. The construction firms were expected to have enough incentives to create sufficient value, considering that they would be responsible for the project for 30 years. This made intention uncertainty less of an issue. The construction firms were nevertheless expected to substantiate quality management plans, instructions relating to methods and work vis-à-vis third parties (Ehmsen and Otzisk, 2004).

The client and contractors agreed to use a different procedure of oversight than in many other German projects, such as the Dortmund Stadtbahn Tunnel. Although external overseers were involved (GTU and Emch + Berger) their role was different here. The contractual arrangement, which made the contractors basically dependent on their own performance, made the actors consider that the contractors would also have the right incentives to provide proper own-oversight, limiting intention uncertainty. Particularly the financial risk-bearing involvement of banks made their expected interest in good oversight evident.[42] This way, oversight resembled practices in projects outside Germany, but with a much more secure contractual arrangement. Meanwhile, in carrying out managerial tasks, the private parties were not under the influence of interpretation uncertainty as could be the result of a traditional relationship with an owner organisation.

8.4.4 Uncertainty in the Herren Tunnel project

Occurrence I: The dilemma in the design choice for the tunnel was in essence which alternative would meet the demands of the client and also be implementable with an acceptable level of uncertainty; that is, what size of *uncertainty gap* was acceptable. The lack of ownership competence created a lurking interpretation uncertainty. Considering the high competence of the organisations involved on the contractor side, the tunnel boring option was selected, based on an outsourcing of the total project, to solve the inevitable *information asymmetry* between owner and contractors.

Occurrence II: The choice for boring implied a stronger dependence on the absence of obstructing boulders in the tunnel path and, hence, on the quality of the geotechnical survey. This uncertainty fed into the dilemma of how to deal with the occurrence of an *uncertainty gap*. If the quality of the geotechnical survey was sufficient and, hence, the uncertainty was instability (a matter of bad luck variability), there is little one could have done to overcome it, and any attempt in that direction would have to be related to the high-level design choice. If the quality of the geotechnical survey was substandard and, hence, the uncertainty was incompleteness instead, it would be related to intention uncertainty, and the associated dilemmas would concern *strategic behaviour* in the operations.

Occurrence III: Further incompleteness uncertainties in the project were mostly dealt with by monitoring programmes (against settlement) or proactive preventive measures (buy-out of abutters). The former rationalised performance measurement, the latter reduced the *uncertainty gap* and acknowledged the *value variety* between abutters and the project organisation. The buy-out suggests this value variety was evaded.

Occurrence IV: The choice for privatisation was a strategy to avoid adverse impacts of possible interpretation uncertainty. The result, privatisation of the project, eliminated any possible intention uncertainty too. The chosen strategy removed the *value variety* between ownership and contractors by giving contractors a direct interest in the end result. Another effect of this strategy was the neutralisation of *information asymmetry*, since most of the decision-making authority on project implementation was transferred to the main information owners (contractors and banks). As a result, *strategic behaviour* was not an issue.

Occurrence V: The potential for intention uncertainty in this project was neutralised by the permanent presence of overseers. The private implementers organised their own oversight. They had no *values* in the project and managed to provide redundant views on engineering issues (*information asymmetry*). *Strategic behaviour*, if it had occurred, could have been neutralised.

Table 8.3 provides an overview of uncertainties and related manageability dilemmas in the Herren Tunnel project.

Table 8.3 Uncertainties in the Herren Tunnel project and related dilemmas.

Occur-rence	Description	Main uncertainties	Dilemmas in consideration
I	Boring through aquifer	Instability, incompleteness, inconceivability, interpretation	Uncertainty gap, information asymmetry
II	Boulders in path of tunnel	Instability/incompleteness, intention	Uncertainty gap, strategic behaviour
III	Sensitive environment	Incompleteness	Uncertainty gap, value variety
IV	Privatisation	Interpretation, intention	Value variety, information asymmetry, strategic behaviour
V	Oversight	Intention	Value variety, information asymmetry, strategic behaviour

8.4.5 Benefits and downside of this set-up

The privatised development of the Herren Tunnel had a few clear advantages for the manageability of the project:

- There was a relatively small uncertainty gap because of the early involvement of the engineering firms.
- Engineers and financiers had a common goal. As a result, there was no diversion of interests and hence no conflicts between drivers such as cost and quality. Only one tunnelling technique met the environmental constraints. Further trade-offs had a pragmatic outcome: they were optimised from a lifecycle perspective, to keep costs low with an eye on maintenance and operation. This meant there were hardly any issues with potentially conflicting values. Also, the divide between information and decision-making authority hardly became an issue,

because there was no strategic value in information provision and no risk of uninformed decision-making.
- There was little fear of strategic behaviour. All parties involved in the daily project execution were involved in the supervision as well.

There was one clear downside. Without a political owner involved, there was no control over ancillary policies. As a result, competing facilities emerged that have jeopardised the ability to earn back the investment. This has made it difficult to transfer this set-up to other projects. The Warnow Tunnel and Herren Tunnel did not get a follow-up in Germany.

8.5 Main observations

8.5.1 Complex versus less complex projects

Despite these projects' generally smaller sizes than the main cases, the projects in this chapter exhibited some complexity features, such as the polder construction method in Rijswijk and the deep excavation pit needed in the densely built-up area of Post Office Square. Some of these features likely challenged their project organisations and managers as much as the main cases. Still particular features made these less of an issue. The division between design and construction was less prominent in these projects than in the main cases, despite use of comparable contract forms. Also, smaller projects may hold more appeal for private parties to get financially involved, perhaps because these projects seem more predictable and risks and uncertainty more manageable. As such, smaller, less complex projects may be able to cope better with the potentially adverse features of underground construction; not just because the challenge is smaller, but also because they have more possibilities to do so.

8.5.2 Uncertainty gap: Public specialists or privatisation

Rijswijk Verdiept was a special case in that it had the strongest public involvement; and it dated from an era in which public agencies still covered many of the engineering and even implementation tasks of infrastructure. It is similar to fully privatised projects, such as Post Office Square and the Herren Tunnel, in that strategic behaviour – or fear for strategic behaviour – hardly played a role in project management. Although the engineering design was innovative and in some ways challenging, implementation overall remained manageable. A high level of professionalism was crucial, as was the incentive to seek this professionalism if it was unavailable or if it was needed to resolve discord. Both worked well. But institutional conditions in The Hague and in Boston, for instance, precluded such arrangements.

8.5.3 Private ownership: Optimisation when operation is included in the project's management

For the managers of the Post Office Square project, optimisation was an undebated strive. Perhaps this was because money was much less a constraint than in many other projects. This eased the ability of the network of actors to achieve consensus on decisions that focused on quality, because there were no actors with an interest in cutbacks that could, implicitly or explicitly, compromise quality. The need for contractors to earn back their investment in a project during the operation phase, rather than entering and exiting a project unaffiliated, evokes a different way of thinking about value. With the inclusion of an operations period, value maximisation largely coincides with efficiency maximisation. This is a well-known motive for using integrated contracts such as BOOT (Build-Own-Operate-Transfer) and DBFM (Design-Build-Maintain-Operate). In the Post Office Square project, indeed, many values and interests, such as finance, robustness, safety of abutting structures and quality, were all united in the ownership organisation. And this particular situation makes it likely that all alternatives and arguments were considered in decision-making. With sufficient certainty of revenues, managers could avoid decision-making under bounded rationality by choosing the most extreme option that would not challenge their capabilities to oversee the consequences.

Such a strategy may have a downside though. It could lead to situations such as seen in the Randstad Rail project, where one board had responsibility for all trade-offs. There is a risk that it may, perhaps unwittingly, overvalue some values, because they are best understood, objective or most clearly connected to the dominant accountability of the board. The example of the Herren Tunnel set-up adds to the normal BOOT and DBFM incentives that the value variety covers multiple stakeholders (including for instance banks); all with their own specialisms and with equal stakes in the project. This could have neutralised the downside of such a concentration of responsibility. In the Post Office Square project, the actors involved had a direct interest and insight, or maybe even expertise, in the most important countervailing values. They had an immediate interest in sound financial management, in protection of abutting structures and in value growth of the financial district.

This suggests that projects are better manageable if operations are revenue-based and the resulting cash flow is directed to the client organisation. Naturally, then private operation must be possible. In The Hague projects and the Dortmund Stadtbahn it was not. In the CA/T project, revenues from usage were applied, but the inbound cash flow in that project was small in comparison to the total expenditure, and involvement of the turnpike authority – which is a public entity by the way – came only after the major design an engineering decisions had already been made, which neutralised the positive incentive. It also caused public upheaval, because much of the flow came from roads far away from the project. On top of this, the overruns required a toll hike. The latter problem could have arisen in the Post Office Square garage project too if overruns had occurred. An extension of the period of reimbursement would have been a practical solution in that case, and the productive relationship with the local authorities suggest such an arrangement might have been possible.

The Herren Tunnel case tells a different story. There were clearly incentives to value quality over cost. However, the operational phase of the project revealed revenues to be a highly uncertain factor. If taken into account during project preparation and execution, this could have been an incentive to be more prudent in spending money. It demonstrates the shift from technical uncertainty to political and financial uncertainty as result of privatisation.

8.5.4 Private ownership: Trust instead of competition

Unlike many public sponsors, private sponsors do not necessarily have to choose the cheapest bid from among contractors. As a result, they can benefit from their experiences and pick the contractor they trust most. This is expected to reduce strategic behaviour. Perhaps the most important mechanism here, is the incentive for contractors not to behave strategically, to continue good relationships, so that they may gain an advantageous position in future tenders. In many public projects, contractors' bids are blind (i.e. anonymous) in order to prevent the development of such relationships, because they could disrupt the level playing field.

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[1] Respondent K. Peters.
[2] An elevated crossing of the tracks never became a serious alternative because it would create a large visual barrier in the middle of the town of Rijswijk.
[3] Respondents F. Lether, A . Verruijt.
[4] Respondent F. Lether.
[5] Later GeoDelft, now Deltares.
[6] Respondent F. Lether.
[7] Respondent F. Lether.
[8] Rijswijk Verdiept, project presentation, by Nederlandse Spoorwegen, BV Articon, Kombinatie Strukton – Ballast Nedam v.o.f, Rijswijk
[9] Respondent F. Lether.
[10] Respondent A. den Ouden.
[11] Respondent F. Lether.
[12] Respondent F. Lether.

[13] Respondent R. Weinberg; Harnik P. (1997), The Park at Post Office Square, Boston, in: Garvin, A. and G. Berens, Urban parks and open space, Urban Land Institute, Washington DC, pp. 146-157.
[14] Harnik, P. (1997),; respondents K. Maffucci, R. Weinberg.
[15] Luberoff, D., Civic leadership and the Big Dig, working paper 11, Rappaport Institute for Greater Boston, Taubman Center for State and Local Government, John F. Kennedy School of Government, Harvard University, May 3 2004.
[16] Harnik, P. (1997), pp. 146-157.
[17] Respondent R. Weinberg.
[18] Idem. Also, when the Artery Business Committee (initially primarily related to the CA/T Project) sought additional backing, it included the community involved in the Friends of the Post Office Square Trust, as well as a business community from the South Station area (Luberoff, D., Civic leadership and the Big Dig, working paper 11, Rappaport Institute for Greater Boston, Taubman Center for State and Local Government, John F. Kennedy School of Government, Harvard University, May 3 2004).
[19] Idem.
[20] Technical advisory committee, Construction subcommittee, minutes of the November 25, 1986 meeting.
[21] Idem.
[22] Respondent S. Muirhead.
[23] Respondents S. Muirhead, R. Weinberg.
[24] Harnik, P. (1997), The Park at Post Office Square, Boston, in: Garvin, A. and G. Berens, Urban parks and open space, Urban Land Institute, Washington DC, pp. 146-157; respondent R. Weinberg; First Amended and Restated Contract Between the City of Boston and Post Office Square Redevelopment Corporation, Pursuant to Section 6A of Chapter 121A of the Massachusetts General Laws; Development Agreement between the City of Boston and Post Office Square Redevelopment Corporation, d.d. 29 January 1987.
[25] Technical advisory committee, Construction subcommittee, minutes of the November 25, 1986 meeting.
[26] Respondent R. Weinberg.
[27] Idem.
[28] Harnik, P. (1997).
[29] Respondent M. Ehmsen.
[30] Respondent M. Ehmsen.
[31] Respondent F. Matthias.
[32] Respondent M. Ehmsen.
[33] Respondent M. Ehmsen.
[34] Project documentation.
[35] Respondent M. Ehmsen.
[36] Respondents M. Ehmsen, R. Otzisk.
[37] Respondents M. Ehmsen, R. Otzisk.
[38] Respondent F. Mathias; Bundesministerium für Verkehr und Bauwesen; Betriebermodelle für Bundesfernstrassen, www.bmvbw.de, February 10, 2004.
[39] Respondent M. Ehmsen.
[40] Der Spiegel article "Tunnelflop bringt Maut-fans in Bedrängnis" by N. Klüver, October 4, 2007.
[41] Idem.
[42] Respondent M. Ehmsen.

9. Analysis

9.1 Introduction

The four previous chapters identified a number of manageability dilemmas. These dilemmas are to some extent interrelated. This chapter examines these dilemmas more thoroughly and identifies patterns of bounded manageability. The case studies illustrated situations that managers of complex projects are likely to face. These situations represent key points in project planning, preparation and implementation at which managers are called upon to make trade-offs that extend further than individual issues with limited impact. Manageability threats revolve around “wicked choices”; that is, trade-offs that managers have to make under uncertain circumstances and often with all options seemingly having mainly downsides. This implies that project managers cannot do their job by adhering to a simple road map and following a preferred course of action.

The previous chapters discussed myriad roles, many unique to the specific actors involved in the different cases. This chapter analyses manageability strategies at a more general level, and therefore requires a more uniform denomination. The common terms “principal” and “agent” will thus be used here in all cases of superior-subordinate relationships, in which principals are the superiors and agents are the subordinates. The principals are the actors on whose behalf agents carry out their work. They are the ones in position to steer or guide developments, insofar as that is possible. Agents can be contractors or subcontractors, consultants including those with engineering tasks and sometimes even insurance companies. That is, agents comprise all actors to which the principal transfers tasks and responsibilities. Principal-agent relationships can be multi-level, meaning that an agent can be the principal of another agent. Principal-agent relationships can also occur within an actor’s organisation.

9.1.1 Six uncertainties, seven manageability dilemmas

The case-study chapters ended with an analyses of how the six types of uncertainty led to a total of seven manageability dilemmas. The uncertainties as categorised in Chapter 3 were the following:

- Instability uncertainty
- Incompleteness uncertainty
- Inscrutability uncertainty
- Inconceivability uncertainty
- Interpretation uncertainty

- Intention uncertainty

In the case studies, manageability problems persisted despite attempts to respond to the occurrence of uncertainties. In fact, responding to uncertainties appeared to go hand in hand with a number of typical dilemmas. The manageability dilemmas found in the case studies (chapters 5 through 8) were labelled with the following seven terms:

- Uncertainty gap
- Segmentation
- Value variety
- Information asymmetry
- Dynamics
- Strategic behaviour
- Rationalisation

Table 9.1 presents an overview of concurrences of the six types of uncertainty and the dilemmas that emerged in the case-study chapters.

Table 9.1 Concurrences of types of uncertainty and manageability dilemmas in the case studies.

	Insta-bility	Incomplete-ness	Inscrutability	Inconceiva-bility	Interpretation	Intention
Total	***27***	***37***	***9***	***10***	***22***	***23***
Uncertainty gap	23	34	8	10	13	9
Segmentation	10	16	4	3	15	13
Value variety	13	18	6	3	13	15
Information asymmetry	12	15	7	3	15	13
Dynamics	12	12	5	4	7	6
Strategic behaviour	7	6	3	1	11	14
Rationalisation	9	9	8	1	8	7

As table 9.1 shows, inscrutability and inconceivability uncertainties occurred less than the other uncertainties. This can be explained by the fact that incognition in these cases only reveals if extreme situations of bounded manageability occur; whereas variability (instability uncertainty) and discrete risk events (incompleteness) are typically omnipresent. The table also shows the importance of the uncertainty gap in knowable uncertainties and segmentation, value variety and information asymmetry in interaction-driven uncertainties.

9.1.2 Occurrences of uncertainty and related manageability dilemmas

Instability uncertainty. Since stochastic uncertainty and parametric variability are inevitable features of projects, an "*uncertainty gap*" always exists: there is a gap between the knowledge and information available and the knowledge and information required. Typically, the greater the ambitions of a project, the larger the gap, because the amount of variability typically grows along with the size of the challenge. The occurrence of instability uncertainty is therefore strongly related to how the project is defined (its scope or functionality, the level of quality sought).

Incompleteness uncertainty. Like stochastic uncertainty and parametric variability, the occurrence of risk is largely determined by the challenge that the project definition imposes on the project organisation (*uncertainty gap*). But in addition, incompleteness uncertainty can emerge during project implementation, as a result of particular *dynamics* that arise during the project period. Emergent developments can pose new challenges for the project organisation, though managers may either be receptive to them (e.g., adapting scheduling and budgets) or try to fend them off (rejecting potentially indispensable adjustments).

Inscrutability uncertainty. This type of uncertainty relates to the knowledge that may be implicitly available to parties in the project organisation, but is revealed only on a situational basis. When that happens, it is typically the most informed parties, usually contractors or other agents, that have exclusive access to it. This leads to three dilemmas. The first is *information asymmetry*, which is a typical phenomenon in project organisations. That is, availability of information and authority to make decisions are often vested in different roles in the project organisation. Furthermore, as tacit knowledge is typically revealed only on a situational basis, its asymmetry may not be explicitly addressed when considering how to deal with information asymmetry. Second, implicitly available knowledge is typically revealed when particular *dynamics* arise. Many developments emerge in the course of agents' work, and the agents closest to operations typically have the most knowledge and information on these developments (e.g., diverging soil conditions where the contractor is working). The third dilemma is that this information is seldom objectifiable *(rationalisable)*. It concerns unwritten, not explicit knowledge and can for that reason be disputed. The choice is then whether the decision-maker receiving input on the basis of tacit knowledge will accept this knowledge, or fend it off. The advantage the tacit knowledge owner has relative to the decision-maker can be used strategically, and therefore this uncertainty is often strongly related to intention uncertainty.

Inconceivability uncertainty. This type of uncertainty expresses the greatest loss of control, but it was rather rare in the cases studied. Where it did occur, the typical *"I knew it all along"* reaction did not seem entirely uncalled-for. There were clues that engineers in agent positions indeed doubted some technical solutions, but they were overruled by higher-level managers, because receptivity to their doubts would have compromised other values, such as cost control. The root causes of inconceivability uncertainty lie in the way a project is defined and the primary trade-offs. As under instability uncertainty, these factors determine the size of the *uncertainty gap*. They typically lead to a particular dynamics for responding to negative events.

Interpretation uncertainty. This type of uncertainty results from the divide between the principal or main decision-maker and agents, which carry out the principal's policies. Delegation of tasks comes with a few dilemmas. First, how *segmented* will the project organisation be? This roughly concerns the required specialisms and the number of handovers. Second, and related to the first, how much *variety* will be allowed in attained *values*? Third, how will the principal deal with its knowledge and information disadvantage in relation to the agents (*information asymmetry*)? Typically, when principals have to make trade-offs regarding inputs from agents, they try to resist emergent *dynamics*, because changes make it more difficult for managers to stay on schedule and keep costs under control.

Intention uncertainty. The essence of this uncertainty is the problem that agents may behave strategically; that is, in their own interest. The core dilemma for the principal is what to do about it. A whole series of dilemmas feed into this or relate to tactics for avoiding strategic behaviour: *segmentation* (linked to the level of control in the hands of the principal), *value variety* (including values strategically sought after by the agent) and ways the principal deals with its information deficiency (*information asymmetry*). There are also project-related *dynamics* in which actors pursue or are perceived as pursuing their own interests (change requests being used or perceived as an opportunity to claim additional costs). Finally is the question of what to do with the type of information that is most likely to accommodate strategic behaviour (*rationalisation*).

9.1.3 The seven manageability dilemmas briefly introduced

The uncertainties resulted in the seven key dilemmas introduced below.

1. Uncertainty gap. This concept, proposed by Galbraith (1977), defines the main uncertainty of a project as a gap between the principal's purpose and the potential solutions offered by the agents involved. The dilemma is to either embrace more complex technical solutions and their challenges and assume that organisational capacity and capabilities will rise to that challenge, or accept organisational limitations in dealing with uncertainty and consequently reduce technological options in complexity and uncertainty.

2. Segmentation. The dilemma of having more or less actors involved in the organisation plays a role in two regards: sequential segmentation and parallel segmentation. Parallel segmentation will be discussed under information asymmetry. Sequential segmentation concerns the number of handovers in the course of the project; that is, the extent that different tasks are assigned to different agents.

3. Value variety. Providing that different actors are involved in the project, their interests and values can vary, with both differentiation and interdependence observable. How to deal with this? Should the principal be receptive to or ward off agents' values, some of which may conflict with the principal's own values? The values of different agents, too, can diverge or even compete. The same can occur between different departments within the principal's own organisation and at multiple levels within the project organisation. This often relates to the multitude of tasks that must be completed or a sponsor-owner divide.

4. Information asymmetry. Presence of multiple actors in the project environment is a given. These have diverse information resources, though all often need to be delivered. Integration of information and decision-making is somehow needed, but the inequality in resource availability extends to power positions in the multi-actor network of a project organisation. The transfer of information has a horizontal and a vertical dimension. Horizontal transfer occurs when sender and receiver are involved sequentially; that is, in a handover situation, as discussed under the segmentation dilemma. Vertical transfer occurs when the sender and receiver are involved simultaneously; that is, in a principal-agent situation. Typically the agent is the sender of operational information to the principal as receiver (specialist knowledge, updates from the field, etc.). The principal is typically the sender of strategic information (political and tactical decisions on the project, such as requirements) that has to find its way into designs and project execution. Management can choose various ways to deal with information exchange, roughly on a spectrum between two extremes: integrate or separate the actors for information provision and decision-making. There is a second dimension to this. Information available to the project organisation is not automatically available to the principal, which is typically the decision-maker. There are two broad options for getting the right information into the decision-making process: the principal gets the information or the agent decides. As we will see later, there is also a fifth variable, which is adding redundancy.

5. Dynamics. Issues emerge during project implementation that might require changes to the project, but it is up to project managers to decide whether to be responsive to such dynamics or to try to keep them out of the project. Responsiveness can result in uncontrolled growth of the project or to the need to return to earlier phases, reversing some of the progress already made. Acceptance of these project-related dynamics often has a cascading effect and, due to the existence of interfaces, it challenges configuration control. These are reasons for managers to resist changes. The dilemma relates primarily to interpretation uncertainty, since potentially disruptive dynamics are often evoked by changed requirements or circumstances.

6. Strategic behaviour. A combination of information asymmetry and value variety may lead to strategic behaviour. The occurrence of extreme and unchecked strategic behaviour of agents can jeopardise the manageability of project implementation. The case studies, however, showed that a principal's bolstering against strategic behaviour may exclude valuable input from agents. So, should the principal bolster, or be receptive despite the risk of becoming a victim to strategic behaviour?

7. Rationalisation. To avoid falling victim to adverse developments as a result of information asymmetry in combination with value variety, principals often allow objectifiable – i.e. quantifiable, measurable – information to prevail, in an attempt to rationalise decision-making. In doing so, they may exclude valuable unobjectifiable information. The alternative, being responsive to unobjectifiable input, implies acceptance of the bounded rationality characteristics of the decisions to be made.

These seven dilemmas manifest at different levels of project management and in relation to different project phases. The uncertainty gap dilemma is fairly high-level, and typically occurs in the front-end phases of projects. Emergent dynamics, strategic behaviour and bounded manageability are at the other end of the spectrum. They typically appear in the detailed decisions made during the daily management of project implementation. Segmentation, value variety and information asymmetry are in the middle, at the organisational level. They concern the appearance of and behaviour in the organisation, which links the ambitions set at the front-end of the project with the daily operations to fulfil them. Yet, they occur throughout the whole project trajectory.

The following sections (9.2-9.8) cast these seven core dilemmas the form of major dilemmatic trade-offs. The sections are structured uniformly. Each starts with a formulation of the dichotomy of action perspectives. Managers can opt for the multi-actor or the solo perspective, though they may sometimes choose something in-between. Subsequently, examples are drawn from the cases to demonstrate the choices managers made and how those choices worked out. This points to possible manageability effects of the responses. Section 9.9 presents a few examples of how the dilemmas and trade-offs interrelate and form patterns. Finally, section 9.10 presents three potential solutions, in the form of a set of instruments for arriving at sensible comprehensive dilemma outcomes. The assumption is that the dilemmas cannot be eliminated, but their possible adverse effects can be mitigated. Successful project management is not about making the right choice among options in a dilemma. It is about being aware of the ramifications of each option and ensuring that good mitigation measures are in place to neutralise any adverse effects.

9.2 Uncertainty gap

Chapter 3 introduced the notion of the uncertainty gap to describe potential shortcomings of knowledge and information in a project organisation for the task to be performed. The concept is based on the relationship between the knowledge and information available to the project organisation, on one hand, and that required for the task, on the other hand.

9.2.1 The dilemma: Acquiring information versus curbing ambitions

As Chapter 3 showed, Galbraith's uncertainty gap can be closed in two ways:

- By increasing the information available to the project organisation, particularly to project management and, more specifically, to the decision-makers on the principal's side, in order to achieve high ambitions
- By decreasing the information required by lowering the ambitions of the project

These options have both advantages and disadvantages:

- Increasing information enables the principal to attain high ambitions, but the project becomes vulnerable to the disadvantages of the other dilemmas, such as strong dependencies, strategic behaviour and poor interpretation ability (since most information comes from agents), as well as all six types of uncertainty. The difficulty of the uncertainty gap is not only its possible existence, but also that the managers involved do not know how large the gap is. They may therefore be unaware of what knowledge and information they need to bridge it.
- Decreasing the demands or challenge (and hence the information required) implies either downscaling ambitions or increasing costs to realise a more robust design and, hence, less uncertainty. But politicians often perceive higher expenditure or a less ambitious scope as inefficient or undesirable.

The dilemma occurs mostly at the project definition level, typically in the first project phases, when the scope is being defined and an appropriate project organisation is being composed – or even earlier, when objectives are being considered. As a result, the strategy adopted in this dilemma may set the conditions for other dilemmas, often occurring in later phases, when preparing and executing the project. The uncertainty gap occurs because of all six types of uncertainty, but decisions on it relate mostly to instability, incompleteness and inconceivability uncertainties. This means that the level of uncertainty in the project is initially defined by incognition-driven uncertainties, which are often related to the differentiation and interdependence features of a project and hence to the defined scope and quality.

9.2.2 Examples of occurrence

As introduced in Chapter 3, the uncertainty gap is created by the uncertainties involved in managing project risk. The occurrences in the case studies raise the fundamental question of whether the technical system defines the organisational system or vice versa. This dilemma originates in the issue, seen in all the projects, of the ratio between the availability of knowledge and the required competences to implement the project. A few prominent examples are the following:

- *Lack of competence.* In the case studies, knowledge and expertise fell short on a number of occasions. The trouble was not only that there may have been a mismatch between the knowledge required and the knowledge available, but also that a lack of competence may have been concealed by a lack of competence. In other words: principals may not have been aware of the knowledge they lacked, precisely because they did not have the requisite knowledge. This phenomenon corresponds to the Dunning-Kruger effect (Dunning-Kruger, 1999). In the Souterrain project, for instance, the complexity of the project increased along with the growing ambitions around the project, without the principal realising that the complexity of the project was outgrowing the competence of its own organisation.
- *Interaction-driven aspects*. Knowledge may be available within a project organisation, but not to the principal, because of limited willingness to share. Knowledge and information, after all, have strategic value. This is known to occur (see also the dilemma on strategic behaviour), but it is unknown to what extent it arises. This was observed in every project studied.
- *Unknowns*. Some identified risks and dynamics will come to pass and some will not. But it is not known how many and which will happen. Also, events that could not be anticipated will happen. These risks are easy to ignore, because they are merely hypothetical, as happened in the Souterrain and Randstad Rail projects.

Project organisation set-up

All project management organisations in the studied cases tried to close the uncertainty gap by increasing the information available, either explicitly or implicitly. In fact, any case of hiring a specialist firm is an example of increasing the information available to a project organisation. This occurs in every complex infrastructure project. Three examples in particular show the possible effects of this option:

- The Dortmund Stadtbahnbauamt hired specialist consultancy firm IMM to produce a reference design and provide support during construction. This situation was special in that the bidders were asked to participate in a process of information exchange with IMM, so that optimal bids could be obtained.
- In the CA/T project, the Massachusetts DPW hired consultant B/PB for project management, including provision of the preliminary designs and construction oversight.
- The Souterrain project management hired an engineering consultant for engineering design and construction oversight.

In all three cases, additional external support was hired. Although this suggests that the basic strategy of the three principals was comparable, it worked out differently in terms of manageability in each case. The Dortmund project was overall fairly manageable, while the CA/T and Souterrain projects turned out to be much less so. By outsourcing tasks such as engineering design, oversight and management to specialist firms, principals expected to cover the most serious uncertainties. With such a strategy, the principals assumed that they could get by with fewer in-house skills. But the threat of bounded manageability then shifted from the technical system to the organisational system.

Decision-making in the project

Although trade-offs in this domain are made at a generic level to apply to the whole project, they may, as mentioned, also occur at a very concrete level in single, detailed decisions. The Souterrain and CA/T projects had the most illustrative examples, with the trade-offs on the grout arch sealing and the bolt-and-epoxy fixtures, respectively. Both designs could have been made more robust, reducing the need for information and minimising technical uncertainty. But in both cases the project managers received input from agents, but had reasons to set this input aside. The Souterrain managers doubted the sincerity of two of the three agents, as they knew a more robust design would reduce these agents' own risks, which might limit their liabilities without providing clear benefits to the owner. In addition, a change of the designs was considered undesirable, because it would require reconsideration of the politically important benchmarks time and cost. For similar reasons, the CA/T project managers neglected input from agents who warned of the bolt-and-epoxy fixtures. They did not want to reconsider existing contracts with suppliers or work already completed.

Both cases concern situations of intention uncertainty: the principals had less expert information on the trade-off they needed to make than other contributors to the process. This made them vulnerable. In contrast, managers of the Dortmund Stadtbahn acquired information both from an independent source (general engineering knowledge) and first-hand from the construction site (their own overseers providing specific information on implementation).

9.2.3 Relevant considerations for a trade-off

Decreasing the information required: A third way

As mentioned, the most common way to achieve manageability is by reducing the information required. One option would be to limit ambitions regarding functionality, though this aspect is typically decided at a political level. The other clear option would be to increase robustness or technical redundancy. This reduces the chance of failure, though is likely to come at a cost.

But a reduction of the information required can sometimes be obtained differently; that is, by seeking to achieve the same functionality, but with a less complex system design. System complexity can, for instance, be reduced by making use of the divisibility of a system to enable piecemeal engineering. It should be noted that in such cases, managers can actually benefit from higher differentiation, a feature that Chapter 2 characterised as a complexity characteristic.

System complexity features did not feature as explicitly important in the planning and organisation of the studied projects, except for the Dortmund Stadtbahn Tunnel. Considering system complexity aspects from the start does, however, present opportunities for optimising the coherence between the technical system and the project organisation. Some possible advantages of such a strategy are the following:

- Project clients can adjust their project to the capacity and capabilities of their owner organisation (see Dortmund Stadtbahn).
- Standardisation of project components (internal standardisation) offers opportunities to learn, making subsequent activities on comparable systems and subsystems better manageable (see the Herren Tunnel project).
- Use of proven technology, that is, technology that has been applied before, offers more certainty than first applications.
- Sequential development gives principals the opportunity to select agents based on “good behaviour” in earlier contracts, avoiding the adverse selection trap that is common in principal-agent relationships. This also provides agents an incentive

to do a good job, as good performance increases their chance of gaining future contracts from the same principal.

- A long period of consecutive works makes it worthwhile to invest in a highly professional sponsor organisation with a "critical mass" of knowledge and expertise (see Dortmund Stadtbahn).

This strategy can both increase the information available (due to greater available experience) *and* reduce the information required (sequential works divide a larger development into smaller, more manageable steps). Projects that can be decomposed but have a high variety of different subsystems or strong interdependencies, and projects that can be decomposed but consist of works that have to take place simultaneously, may not benefit as much from these kinds of advantages. One should also be aware of the downside: at some point, the parts will have to be welded together to create a functioning whole. A larger coordination effort will also be needed and interfaces will have a larger influence. A typical example was found in the Dortmund Stadtbahn, where completed sections not yet in operation had to be partly rebuilt due to the adoption of low-floor rolling stock, and maintenance costs had to be paid for sections that were as yet not operational.

Increasing information available: Creating new uncertainties

The cases show two liabilities that can occur in the acquisition of more information, strongly related to the information asymmetry dilemma:

- Souterrain managers retained decision-making authority, which meant that the engineering specialists could only provide input; they could not make decisions. As a result, the project still depended on the *limited assessment and interpretation skills* of the principal's project management.
- The CA/T management, which transferred a bit more (but far from all) decision-making authority to the hired project management consultant, had *difficulty overseeing the outsourced work* done by the contractor. This created a situation in which the decision-maker as principal can easily fall victim to strategic behaviour.

So, increasing information available to solve Galbraith's uncertainty gap may in fact create a new uncertainty gap. It could move uncertainty away from the lack of information (epistemic uncertainty) towards the interpretation and oversight by the decision-maker (interpretation uncertainty). In other words, while increasing the information available may be perceived as an uncertainty reduction, it could in fact merely transfer uncertainty. A hazard is that actors become convinced that their actions have solved uncertainties, when in fact they've neglected other uncertainties or even created new ones. There are various reasons for this. The principal might overestimate its own assessment abilities. It can also reject valuable information on the grounds that could be strategic. Or, it may feel an unwarranted confidence that project management procedures will ensure that transferred information is always reliable. This underlies the final three dilemmas (dynamics, strategic behaviour and rationalisation).

Uncertainty in decision-making can be strongly influenced by the way a decision-maker frames the trade-off and the information used for it. The principal has to assess the transferability of outcomes of models, tests, references and analogies to the situation at hand. These instruments are supposed to reduce uncertainty. But they can create false comfort. Decision-makers sometimes gain confidence from positive outcomes without giving much further consideration to their level of representativeness for the new application. They may therefore again remove uncertainty, but also create new uncertainties. In the Souterrain project, managers referred to grout layers in Strasbourg and Duisburg, but the soil structure and composition and the kind of applications there were different from those in The Hague. Also a grout layer test was done, but less deep than the real application and without a watertightness test.

9.3 Segmentation

Chapter 2 discussed the origin and nature of complexity using the concepts of differentiation and interdependence, in line with Baccarini (1996). From a project organisational viewpoint, this was translated in the case studies to the possible occurrence of handovers between actors involved in different tasks.

9.3.1 The dilemma: Handovers versus no handovers

Sequential segmentation implies handovers.

- The principal can choose to segment the project on the basis of tasks and, in doing so, include handovers.
- The principal can choose to integrate tasks and, in doing so, avoid handovers.

Both options have advantages and disadvantages:

- Including handovers enables a project to make optimal use of specialisms, for instance, in engineering design, construction and possibly operation and maintenance. The choice for each contractor can be aligned to the particular task. Also, handovers provide an opportunity for intermediate checks to improve control. The downside is that handovers may be difficult to manage. They require a greater coordination effort and can raise conflict.

- Avoiding handovers prevents liability disputes between task implementers. Also, lack of clarity and possible gaps left between tasks can be avoided. As a result, there could potentially be less interpretation uncertainty. The downside is the greater dependence on the fewer actors involved.

This is an organisational dilemma typically occurring at the front-end of a project, when the project organisation is being composed and a contracting strategy drawn up. The dilemma relates to organisational differentiation and interdependence and the uncertainty created in the sender-receiver relationship upon each handover, with the sender being the actor handing over the work and the receiver being the one picking it up and proceeding with it. This relates mostly to interaction-driven uncertainties.

9.3.2 Examples of occurrence

Segmentation occurred, for instance, in the Souterrain project. Originally, the owner planned to involve the construction contractor in the design process. Eventually this was abandoned, introducing a hard divide between the engineering design and construction. The handover became crucial when discord arose about the grout arch design. Also, the sponsor's request to the contractor to elaborate on its ideas on the matter were fended off because the contractor had not been contracted for those tasks. In the CA/T project, the handover between the rough designs made by the project management consultant and the detailed section designs were an issue. This handover reduced efficiency, because section designers had to redo some of project management consultant's work. The Herren Tunnel is an example of a project with very few handovers. The same consortium of financiers and contractors was responsible for engineering, construction and operation and maintenance.

9.3.3 Relevant considerations for a trade-off

Considerations regarding handovers could concern the specialisms required for the tasks of the project and the coordination effort that handovers require, in combination with the capabilities of the project team to manage them. Redundancy can eliminate the downsides of a handover. This links the segmentation dilemma to the information asymmetry dilemma. In the Souterrain project, for instance, the initial idea was to include the construction contractor in the design process. Doing so would have increased clarity and prevented conflicts. The idea was abandoned for efficiency reasons, as it is costly to hire two parties for one job.

9.4 Value variety

The next dilemma concerns whether the principal should focus on a single set of values – normally the values most strongly advocated by its own organisation – or include multiple values in trade-offs. Value variety can occur both within the principal's own organisation and between the principal's organisation and agents, which adds an additional dimension to the dilemma.

9.4.1 The dilemma: Incorporate value variety or not?

- The principal can manage the project driven by its own set of values and being as impervious as possible to value inputs from other actors, particularly agents. However, multiple values may exist even within the principal's own organisation, for instance, between different departments, or between the principal and agent(s), though one may be dominant, for instance, for political reasons. This dominance may not have been explicitly decided.
- The principal can accept multiple values, including those held by others, for instance, by giving multiple departments equal powers or ensuring that multiple values are weighed within the responsible department, or by being receptive to values held by others in interactions with other organisations (such as agents).

Both options have advantages and disadvantages:

- Singular values reduce management complexity and give the principal's managers (ostensibly) more control. A strong focus can increase the chance of achievement of that one particular value. Yet, as a result, that value may outshine other values and overall quality may suffer. Due to the strong influence of the principal, interpretation uncertainty is likely to result. A focus on a singular value may develop, for instance, at the insistence of politically powerful stakeholders. If a value is uniquely held by the principal and the principal is powerful and dominant, that value will likely push out other values, undermining balanced trade-offs. If the principal is not powerful, its prime value will likely be outshined by other actors' values.
- Multiple/competing values keep checks and balances intact, often reflecting the social responsibility of, particularly, public owners in the role of principal. They maximise the chance of the principal receiving all valuable input, hence providing a greater chance of a trade-off in which all values have appropriate weights. In such a situation, the final trade-off outcome will likely be higher quality and more balanced overall. The chance of various types of conflicts is greater though, and the responsible managers may have difficulty keeping the project under control.

> Interactions with other organisations make the principal more vulnerable to strategic inputs and, hence, intention uncertainty.

This is an organisational dilemma too, relating to the attitude of actors when functioning in the multi-actor network of the project organisation. It relates to differentiation and interdependence and the uncertainty that may emerge by reduced unity of leadership. Hence, it concerns interaction-driven uncertainties.

9.4.2 Examples of occurrence

A few examples of internal single-value dominance can be found in the case studies. In the Souterrain project, for instance, the principal focused on the project environment. It was physically vulnerable and the abutters were important and powerful. The result was a large scope expansion which made the project much more complex. This ultimately led to inclusion of innovative technology and cutbacks that undermined project manageability. Something similar happened in the CA/T project, with its accent on a diversity of nuisance mitigation measures straining the project. In the Randstad Rail project, administrators were strongly focused on the scheduled opening date of the infrastructure. The impact this had on the manageability of the conversion and testing period – and subsequently on the quality and safety of the system – was disregarded, despite engineers' worries.

In both cases in The Hague, the decision-maker within the principal organisation ignored input from engineers, ostensibly due to single-value dominance in a context in which diverging values threatened to arise. In these cases, the objectifiable values prevailed (see also the rationalisation dilemma). In the Randstad Rail, the principal's decision-makers fiercely maintained their time schedules despite the needed additional works, while engineers considered a time extension desirable for process manageability.

In the Post Office Square project, the sponsor focused on the technical robustness of the design and the impact of the construction works on abutting structures. Other values, even cost, were made subordinate to these. This project's focus can be explained by the fact that the principal's interests were fully aligned with the abutters', because in most cases these were one and the same. The abutters were therefore, in a way, internal to the project organisation. The secure return on investment was an additional positive condition. In the Herren Tunnel, value dominance moved in the opposite direction to the above examples: from principal to agents, as a result of the complete outsourcing. In both cases values were balanced because they came together in the multiple interests of one actor.

An example of external value variety can be found in the Souterrain project. Three different external parties advised against the suggested grout arch design, but the sponsor maintained it for scheduling and budgetary reasons. The CA/T project trade-off on the redesign of the drop-ceilings in the I-90 connector tunnel is another example. Subcontractors advised against the bolt-and-epoxy fixtures, but the principal maintained the design because of existing contracts and the limited financial benefit of a redesign.

The case studies also produced an example of inclusion of competing values from different actors. In the Rijswijk railway tunnel project, the owner was forced to consider values other than cost, implementation time and structural quality, because the local municipality was a powerful counterpart. This ultimately required an expansion of the project scope. In combination with the refusal to accept compromises on its own values, this led to an optimum design.

9.4.3 Relevant considerations for a trade-off

The relevant considerations discussed in this section apply both to internal and to external value variety. Actors involved in a project can – possibly unwittingly – develop a dominant focus. For agents, such as contractors and engineers, time and schedule extensions or reduced scope can be attractive. Principals on the other hand, try to obtain the highest level of functionality for the lowest cost and in the shortest implementation time. In fact, the values time and cost are very visible to the public, and infrastructure projects are infamous for being over time and over budget. Politicians therefore often make great effort to protect these values. Agents, such as designers and contractors, are the ones directly confronted with the possibilities and impossibilities of the technical system. They are typically best able to assess technical values, particularly regarding the desired quality (robustness) of a system. The problem in this situation lies mainly in the interpretation uncertainty and intention uncertainty that is typical of principal-agent relationships.

Value preference or dominance is an important reason for strategic behaviour by agents and for flawed interpretation by the principal. Yet, it is very difficult to suppress. It develops unwittingly. An actor may not be aware that it is making trade-offs that have implicit effects on, or are driven by, certain project values. Herein lies an important difference between the preoccupations of principals and agents. Agents usually know that their information or decisions may affect time schedules and costs. This study’s empirical research, however, suggests that principals are unaware of the effects that their steering based on objectifiable values is likely to have on less objectifiable benchmarks, such as quality.

Concerns regarding value variety are linked to almost all of the other dilemmas. Multiple values facilitate strategic behaviour and therewith increase unpredictability, because they provide actors with a path to launch input supportive of their own interests (see the strategic behaviour dilemma). This may prompt principals to fend off competing and potentially strategic values. In the case studies this led to situations in which the principal's values become unwittingly dominant.

Other issues must be considered as well:

- Value trade-offs are often implicit. But many explicit decisions do affect values. Managers, for example, make decisions on changes that imply a scope expansion or compromise robustness. Safety as a value is generally undebatable; trade-offs affecting it are usually unacceptable. But decisions related to other values may affect safety, as Randstad Rail showed. The effect of a decision on the coherence of values may be overlooked.
- Value trade-offs have a strong political interface, which makes them partly exogenous and difficult for project managers to control. Value focuses are often imposed by political representatives who are relatively disentangled from the complex job to be done.

9.5 Information asymmetry

Drawing on the cases, the concept of information asymmetry can be further elaborated for complex infrastructure projects. Intertwinement and disentanglement are the terms used in this section to describe, at a high level, the strategies for dealing with a divide between information availability and decision-making authority. These terms are derived from Koppenjan and Klijn's (2004: 212-213) characterisation of the network society.

9.5.1 The dilemma: Intertwinement versus disentanglement, in five possible strategies

An intertwinement strategy has as the advantage that decision-making and information are brought together, resulting in the largest chance of well-informed decisions. The downside is that it may create unilateral dependence of the principal on information from agents or engineers, and it may blur responsibilities.

The principal can choose to keep information and decision-making separate in order to maintain checks and balances between principal and agent: disentanglement. This either requires acquisition of own information, to remain able to make good decisions, or acceptance of bounded rationality in decision-making, with the risk of going astray. A disentanglement strategy limits unilateral dependence, but makes it more difficult to close the uncertainty gap (the gap between the information available to the project organisation and the information required to realise the system). Disentanglement comes in four varieties. This yields a total of five strategies for dealing with information asymmetry:

Strategy 1: Transfer information to decision-maker (disentanglement). Transferring information to the decision-maker gives the decision-maker more input to make high-quality decisions. But due to the decision-maker's limited knowledge and expertise, its interpretation and assessment might nonetheless fail. There is intention uncertainty involved in this.

Strategy 2: Transfer decision-making authority to information owner (disentanglement). Transferring decision-making authority to the information owner makes high-quality decisions likely, because the entity making the decision is probably the most knowledgeable. But the sponsor may lose control of the project. There is interpretation uncertainty involved in this.

Strategy 3: Integrate information owner and decision-maker organisations (intertwinement). By integrating the information owner and decision-maker organisations, information and decision-making are brought close together, theoretically enabling better informed decisions. If the organisation is truly integrated, interpretation uncertainties and intention uncertainties are also expected to be eliminated. The downside is that this creates a strong dependency on one particular information owner and in reality interests can be difficult to align. Although integration should mitigate interpretation and intention uncertainties, they might remain intact since public and private interests diverge.

Strategy 4: Create redundancy of the information owner (disentanglement). In this strategy, the decision-maker and information owner organisations are kept separate but redundancy of the information owner is created by involving one or more other information-owning actors to diversify sources. The downside is that this reduces efficiency, since more actors are involved that have to be remunerated. In addition, if multiple sources are conflicting, uncertainty may actually grow.

Strategy 5: Create redundancy of the decision-making organisation (disentanglement). In this strategy, the decision-maker and information owner organisations are kept separate but redundancy of the decision-maker organisation is created by involving one or more other actors that can provide assurance or countervailing power to the principal. There is inefficiency in this strategy too. The potential for intention uncertainty remains but its effect is mitigated.

All five strategies aim at a quality increase. The difference is mainly in the level of control that can be attained. The level of control increases from alternative 1 to 5. The reason for not always pursuing the higher-control alternatives is cost efficiency.

This is the third dilemma occurring at the organisational level of project management and organisational set-up. It sometimes results from the occurrence of tacit knowledge, typically related to interaction uncertainties. It concerns interpretation uncertainty in situations where information or directives are sent from principal to agent and intention uncertainty in situations where information is transferred from agent to principal.

9.5.2 Examples of occurrence

Intertwinement

- The CA/T project management set up the Integrated Project Organisation (IPO), intertwining expertise of the contractor with the decision-making authority of the owner. The principal in the Herren Tunnel project in Lübeck went so far as to transfer formal decision-making authority to private agents. Both strategies brought information and decision-making closer together.
- The integration of the design engineering and project director tasks in projects such as the Souterrain and the Rijswijk railway tunnel represent a form of intertwinement as well.

Establishment of the IPO in the CA/T project did ostensibly make project management more efficient, but it had downsides too. Unilateral dependence became larger, particularly as the principal was unable to provide sufficient oversight. This situation, according to the Inspector General, worsened when some of the principal's own managers were eliminated to streamline the project organisation. As a result, the activities of the project management consultant (the agent) could not be adequately overseen and project management was not always able to control quality and assess the underlying reasons for additional work and costs.

So, the IPO's success is doubtful. It had some negative manageability effects, too, receiving harsh criticism, particularly, from the Inspector General of Massachusetts. While both the owner (the principal) and the contractor (the agent) organisations declared their cooperation fruitful, the disappearance of the "arm's length principle" removed a considerable part of the control mechanism that usually exists between an owner and contractor. The main consequence was in the financial management. The client was hardly able to reclaim additional costs as a result of malfunctioning subsystems.

Another, possibly troubled, intertwinement was the integration of the design engineer and the director tasks in the Souterrain and Rijswijk projects and, to a certain extent, also in the CA/T project. One could reason that no one is more capable of overseeing proper construction of a design than the designer itself. In practice, however, this raises problematic organisational issues. The more complex a project is, the more likely that design issues will be subject to discussion between the designer assuming the principal role and the contractors in the agent role. If the designer is also the project director, doubt is automatically cast on the director's ability to effectively evaluate the validity of doubts raised by agents about the principal's work. This is particularly troublesome if the agents are more skilled than the principal in some regards. This is not rare, since many agents have ample experience in implementation of construction works and first-hand knowledge of possibilities and impossibilities. Managers of The Hague's inner-city tunnel projects, which included, apart from the Souterrain, also the Konings Tunnel, noted that the Konings Tunnel was better manageable. This can partly be ascribed to the lower level of complexity. However, the Konings Tunnel's management was also a contributor. In that project, the engineering design was produced by the municipality itself. A project director unrelated to this design was hired. The director could therefore, if necessary, take an independent role as referee between design and construction.[1]

The Herren Tunnel project was also better manageable. Whereas in the CA/T project only *de facto* decision-making shifted to the agent, in the Herren Tunnel, all implementation-related decision-making authority was deliberately transferred to a joint venture of banks and construction firms, and the principal and agent remained disentangled. Because ownership responsibility was transferred along with the decision-making authority, a technically robust design was achieved with a minimum financial risk for the principal. These manageability features were a consequence of actors' interest in the end-result, rather than them exiting from the project with no further interests or values in it, once the contract ended. This strategy enabled maximum rationality because decisions were made by the actor with the most information and assessment capabilities and information were as public as possible. The downside is the impossibility for the public client to make changes (e.g., optimisations) throughout project preparation and implementation. It helps in such cases if the conditions in which the project is to be executed (e.g., the applied technology) are stable.

Disentanglement

The Dortmund Stadtbahnbauamt kept its own management strictly separate from the contractors' management. There was only one exception. The project management and contractor acquired joint insurance to prevent possible conflicts in case of mishaps. Otherwise, the principal and agents remained strictly disentangled.

Full disentanglement is only possible if the principal does not depend at all on information from agents. It was not observed in any of the occurrences of bounded manageability in the projects studied. Non-dependence on information from others is rare, since in complex construction projects the owner is likely to depend at least on input from contractors to learn about the things that happen on the work floor. The Dortmund case nevertheless comes close, because of the full-time expert oversight executed in the construction pit by the owner's overseers. The Dortmund Stadtbahnbauamt exercised vigilance towards its contractors. It could do this thanks to its own expertise. The sponsor's own owner staff could rationalise decisions to a fair level and was able to assess the inputs of the engineering consultant and the construction contractors. Being the director of the actual implementation works provided a good opportunity to control the contractors' work. Thus, most information was public here, unlike the CA/T project, in which most information was in the hands of the contractors, which could select what information would be passed on or kept private.

The advantage of redundancy is that it establishes checks and balances. A downside is that it can raise conflict and costs money. Interesting developments with regard to parallel segmentation occurred in the CA/T project. First, the second opinion committee of the principal, established to do essential checks on the engineering, was disbanded and not restored. Later, the IPO removed all redundancy between principal and agent (PMC). As mentioned, this increased efficiency and brought decision-makers closer to essential information, but it was also criticised as eliminating checks and balances. In the Souterrain project, the idea of a design trajectory with redundant engineering expertise (involving both a design engineer and a contractor) was abandoned for cost reasons. Yet, it could have prevented the major engineering conflict that occurred later in the project.

9.5.3 Relevant considerations for a trade-off

The following considerations should be made when making a trade-off on the information asymmetry dilemma:

- Disentanglement of owner (principal) and contractor (agent) can be done successfully only if ownership is transferred as well or if the owner is not overly dependent on information from contractors. This may be, for instance, because the owner has extensive knowledge itself, can assume sponsorship tasks and can execute hands-on oversight of implementation. Otherwise values will diverge to such an extent that the owner may lose control. Also, the less complex the project, the easier it is to apply a disentanglement strategy.
- Intertwinement can raise the potential for conflict. Intertwinement of the design engineering and the director roles, for instance, may imply that questioning the

design is perceived as questioning the authority of the director. This may be particularly true when there is a large uncertainty gap, because the owner then experiences its lack of knowledge most acutely.

Uncertainty and information asymmetry[2]

Uncertainty in complex underground construction projects can find its origin in information asymmetry. As mentioned in Chapter 3 regarding the "Johari Window", there are two types of information asymmetry:

- *Private information*. Private information is available to the principal, but not to the agent. This type of information asymmetry leads to interpretation uncertainties.
- *Blind information*. Blind information is available to the agent, but not to the principal. This is the typical principal-agent problem. Blind information leads to intention uncertainty. It can be transformed into public information (available to everyone), for example, if the principal can get access to the information of the agents by integrating decision-making (principal role) and information (agent role), thus closing the gap between principal and agent. This strengthens the interdependence between the two. Since the principal is the demanding party, the interdependence is in fact a unilateral dependence of the principal on the agent.

Attempts to resolve information asymmetry may run up against interpretation uncertainties, for various reasons:

- The principal may not appreciate that the design team/agent needs the information.
- Internal disagreements within the principal body may hinder it from arriving at a clear position, and disclosure may also be restricted to hide this state of affairs.
- The principal may not give its representative the authority to make decisions, leading to a disclosure process that is slow and insecure and decisions taken being overridden later by senior management.
- The principal may not have the organisational capabilities to communicate its needs clearly to the design team.
- The principal may not devote enough resources to being a principal.
- The principal may behave opportunistically towards the design team; that is, information flows may be stymied because the principal does not trust its designers.

Attempts to resolve information asymmetry may run up against intention uncertainties, again for various reasons:

- The design team may think that the principal does not want the information.
- The design team may be incapable of clearly communicating the possible range of design solutions.
- The design team may be searching for ideas, and need more time to bring them to maturity.
- Scarce resources may be deployed on other contracts.
- The design team may behave opportunistically towards the principal; that is, withholding information because it does not trust its principal.

Possible effects of information and decision-making authority transfers in intertwinement and disentanglement scenarios

Transfer of either information or decision-making authority occurs in disentanglement scenarios, both with or without a redundancy strategy:

1) *Traditional principal-agent relationship.* The principal assembles information (1a) from the agent(s) or(1b) with help from an independent expert. Agents have limited influence on assessments, but ample opportunity to colour and select information. This places a large strain on the assessment capabilities of the principal, and interpretation by the principal may be flawed.
2) *Outsourcing.* There is a transfer of responsibilities (possibly including ownership) from principal to agent, removing incentives for strategic behaviour and the hazard of false interpretation by decision-maker. But this might also remove ownership benefits from the principal (e.g., possibilities to change scope during implementation).

Things are different in an intertwinement scenario. The idea of intertwinement is that explicit transfer of information or decision-making authority is not necessary, since principal and agent(s) make management a joint effort. The empirical evidence, however, shows that *de facto* dominance of the agent can occur. Likewise, the opposite – dominance of the principal – is conceivable as well. Two scenarios may result:

- *Partners but with dominant principal*. The agent provides information, but has full power over what is provided and how. Formal decision-making authority remains with the sponsor. Decision-making is *de facto* influenced by the agent. Interpretation by the principal tends to be correct and otherwise will be corrected. The principal and agent are partners, but agents may be more powerful than they seem and the principal's control may be illusory.

- *Partners with dominant agent*. The principal is at the agent's mercy. The agent makes decisions while the principal keeps responsibilities. This occurs mostly *de facto* and unintendedly. Interpretation of information will be mostly correct, but the principal loses control of the project.

In both scenarios the dependency is mostly in one directional. The principal depends on the knowledge and attitude of the agent(s). This fuels the idea that intertwinement and disentanglement may work counter-intuitively to some extent. Intertwinement can shift the principal's power instruments to the agent, instead of the intended move from the agent to the principal. Disentanglement may provide more control mechanisms as long as interests in the end-result are transferred from principal to agent or if there is little intention uncertainty.

Relation to other dilemmas
The information asymmetry dilemma is particularly relevant in situations where the information available is increased to reduce the uncertainty gap. It is much less prominent in strategies to reduce the information required, because in such a strategy the need for information for decision-making is less acute. There is also a clear relation to the segmentation dilemma (particularly with regard to redundancy) and value variety (diverging values of principals and agents). For the transfer of information, the strategic behaviour and rationalisation dilemmas are relevant.

Increasing the information available and the traps that come with it
When trying to move as much information as possible to the decision-maker, a few things should be kept in mind:

- When transferring information from agent to principal, there is no guarantee that the information is complete, due to the possible existence of "unknown information".
- Transfer of information is likely to be easiest in an integrated project organisation, although the possible adverse effects of intertwinement may then also be most in play.
- The Souterrain example showed how difficult it can be for a non-expert sponsor to make a sound decision in a situation of intention uncertainty. This suggests that blind information actually consists of two types of information: (1) The usually documented flow of information on designs and implementation, in accordance with regular project management procedures, that takes place on a day-to-day basis. The part of it that is sent to the principal becomes "public", but it is unknown what remains undisclosed. This relates to the strategically

motivated behaviour discussed in dilemma 5. (2) The tacit knowledge available to actors, consisting of experience and expertise (e.g., professional background).

So, a transfer of information to the sponsor does not always include all available information and can therefore not be considered a guarantee for success.

Transferring decision-making authority and the traps that come with it
When transferring decision-making authority to information-owning agents, several things should be kept in mind:

- The sponsor loses control over decisions and, therefore, has no instruments to protect its values. This implies that a transfer of decision-making authority to agents should be accompanied by a transfer of values, for instance, through co-ownership or financial stakes. This strategy can be problematic in combination with strong value variety.
- When decision-making authority is transferred, the project organisation will likely be better capable of dealing with emergent developments (see also the dynamics dilemma) because of the greater availability of information for decision-making. But a transfer of cost and time values is also needed to prevent bounded manageability. Otherwise agent-driven dynamics might lead to uncontrollability.
- An integrated project organisation may seem the most logical set-up to transfer decision-making authority, but it may result in a sponsor's perception of continuation of control that is not really there. Although the original decision-maker is nearby, it has limited control over the interface between information (including strategic interests) and decision-making.

Redundancy
A sponsor could align the amount of redundancy in the project organisation to its own capabilities. The Dortmund Stadtbahnbauamt could do much of the engineering-related work itself. It did hire an external design engineer, but it led the project itself and put its own oversight in place. In a sense it provided the needed redundancy itself. There are reasons to assume that more redundancy leads to better results in day-to-day judgements. An additional pair of eyes can neutralise strategic behaviour and improve decisions.

9.6 Dynamics

Complex projects often require complicated preparation and decision-making procedures. Inevitably issues arise that were unexpected or not taken into account in advance. These are most problematic when they present themselves as trade-offs with negative aspects on both sides: dilemmas regarding whether project management should try to stay the course or change tack.

9.6.1 The dilemma: Defence against versus responsiveness to change

The related trade-off is the following:

- Be responsive to emergent developments and change
- Or resist emerging dynamics and change

The impact of change is often indirect and implicit and therefore difficult to foresee. It can be overlooked, or its possible impact neglected. Yet, emergent developments can optimise a project. Greater functionality or cost or time reductions may be achieved if new insights can find their way into the project. This suggests the following advantages and disadvantages:

- Resisting and fending off emerging dynamics reduces some uncertainty (particularly intention uncertainty), but disables managers from adjusting to new situations and optimising the project throughout implementation. It can also result in exclusion of possibly indispensable input and insights that could help to mitigate incompleteness uncertainty.
- Responsiveness to emergent developments and dynamics enables optimisation, but can make the implementation process erratic and difficult to control. It can also result in difficulty managing time and costs due to greater uncertainty, as it implies flexibility in the implementation phase. This strategy may also make the principal vulnerable to strategic behaviour, because flexibility may be an incentive for agents to try to obtain desired project features. The piecemeal character of emergent developments contributes to potentially untameable and uncontrollable developments (a slippery slope). Accepting change in line with an explicit trade-off is more prudent, though this too can mean that budgets and schedules have to be adjusted.

This dilemma occurs at the project execution level; that is, in daily project management. Sometimes it results from incompleteness uncertainty (when more information becomes available), inscrutability uncertainty (when the principal is receptive to unobjectifiable input from agents; see dilemma 7) and inconceivability uncertainty (when unforeseen events impact the project to the extent that project outcomes are in peril). Possibly the most difficult trade-offs on dynamics, however, relate to potential interaction-driven uncertainties. Agents and other stakeholders may request changes instigated by their particular position in the stakeholder network, the market or the project environment. This behaviour relates strongly to the strategic behaviour dilemma.

9.6.2 Examples of occurrence

The case studies provide several examples of emergent dynamics at the front-end of projects. In the CA/T project, extensive numbers of requests for compensation and mitigation were submitted and approved for political reasons. Also, the redesign of the Charles River crossing had a dominantly political background. In the Souterrain project, the scope was massively increased with inclusion of the car park, which was a political decision to gain support from stakeholders, though it greatly complicated the project. The grout arch redesign was an important change that occurred as a presumed optimisation of engineering and cost.

The larger Randstad Rail project was probably the most receptive to emergent developments. This was particularly because it started out with very basic terms of reference, which were only later elaborated in detail. But, it was also due to discord with stakeholder ProRail and to further optimisations resulting from windfalls during the contract tendering phase. The sponsor was always willing to reconsider the terms of the project. In the end, however, this willingness was limited to optimisations that could be realised within the framework of the set time schedule. Once this threatened to be overrun, the owners fended off further changes from emerging engineering trade-offs.

In the Dortmund Stadtbahn a massive change was approved: inclusion of an additional branch to Borsigplatz. This change had relatively little effect on the project, however, because it was not fully included in the existing contract. Tendering it as a separate contract did establish a hard interface, and accompanying coordination efforts had to be made.

Most of these changes were predominantly politically motivated. The Souterrain and Randstad Rail project changes did have an engineering background, but their eventual approval had a strong political component.

The cases also provide several examples of fending-off change in the later phases of projects. In the CA/T project, managers fended off the inputs of engineers when reconsidering the bolt fixtures design. In this case, the engineers’ concerns deviated from management’s preferred solution, and taking the engineers’ advice would interfere with earlier arrangements with third parties. Prior to the start of construction, however, the sponsor was rather receptive to emergent developments, judging from the fact that the required budget almost doubled in that period and several interest groups managed to get their desired adjustments and additions into the project. Such a development in attitudes was seen elsewhere as well. So, throughout projects, trade-offs on emergent developments seem to became more and more explicit and reluctance to change seems to grow. Considering the advantages and disadvantages, this makes sense. It also shows how unique the change from metal to concrete slabs in the I-90 tunnel ceiling design was. This furthermore points to the substantial impact of such a change throughout a system, due to interfaces and technical interdependencies.

In the Souterrain project, once the project approached the budget limits in the design phase, inputs questioning the reliability of the design were fended off, even though design reconsiderations were most urgent at that point. Major changes after the calamity were harshly fended off until, after more than two years, there was no other way to continue.

9.6.3 Relevant considerations for a trade-off

The earlier in the project changes are made, the easier they are to incorporate. Since much of the work still has to be done, later work can start from the new terms of reference, providing that good configuration control is in place. The later in the project changes are made, the more difficult they are to carry through and the more difficult it is to comprehend all the implications for all subsystems, given the numerous interfaces and possible knock-on effects that may be difficult to control or oversee. This does not necessarily mean that early changes have little impact. The occurrences of bounded manageability in the Souterrain and Randstad Rail projects can be related to the large changes made early in the projects. The links to those early decisions may not always be obvious, but the case analysis demonstrates that they exist.

The further along in implementation, the more likely it is that cost extensions were already necessary, making additional extensions later on more problematic. Besides, late changes are far more expensive than early ones. The additional value they must create for the project to make them worthwhile grows as the project progresses. Also, late changes may be a more nasty source of delay, because lost time in later stages is more difficult to make up, which may make managers reluctant to approve them. Therefore, the later in the project, the larger the tendency to ward off emergent dynamics. In later phases, too, sponsors tend to be bound by signed contracts (e.g., the contracts for concrete in the CA/T drop-ceiling case) or path dependency may start to play a role (e.g., the issue with the low-floor trams in Dortmund).

The main peril of responsiveness to emergent developments is ending up on a slippery slope, the chance of which is largest if no explicit trade-offs on changes are made. The clearest examples come from the Randstad Rail and Souterrain projects. The Randstad Rail project became more complex step by step. Each time the scope was stretched a little without seeming to make the project unmanageable. By the time the actual construction took place, the project was plagued by chaos and very vulnerable to all possible setbacks. In the Souterrain project, redundant technical features were quietly removed to meet both the building inspectorate's requirements and tight budgets. This was done without much awareness of the implicit consequences for project manageability.

9.7 Strategic behaviour

One of the uncertainties identified in Chapter 3 was strategic behaviour, arising from the principal-agent problem. In relations between the owner and the contractor(s) (Jensen and Meckling, 1976), it occurs as a consequence of the information flow from the agent (contractor) to the principal (owner). The relationship between the agent and principal is subject to adverse selection and moral hazard. Adverse selection is the mechanism by which the principal selects the agent it does *not* want, for example, when the principal chooses the contractor with the lowest bid. After all, the bid may be lowest because the contractor cannot get other work. That contractor would also have the largest incentive to seek costs additions. Moral hazard is the mechanism by which the contractor presents information in a way that is most favourable to its own interests, usually not in the interest of the principal.

9.7.1 The dilemma: Defence against versus responsiveness to potential strategic input

The essence in this dilemma is not whether strategic behaviour will occur, but how the principal responds to the possibility of its occurrence:

- The sponsor can be receptive to all information, including potentially strategic information.
- The sponsor can be selective in interpreting information, seeking to fend off contractors' strategic input.

The advantages and disadvantages of the options are as follows:

- Fending off excludes possible strategic behaviour of agents, but may exclude valuable input with it, for instance, to deal with incompleteness uncertainties (throwing out the baby with the bathwater).
- Being receptive maximises information, but makes the principal vulnerable to strategic behaviour (intention uncertainty).

This dilemma also occurs at the project execution level, related to the possible occurrence of intention uncertainty; that is, in the flow of information from agent to principal.

9.7.2 Examples of occurrence

Probably the clearest example of fending off potentially strategic information was found in the Souterrain project. The principal's managers decided to put aside the advice of three agents (the construction contractor, the insurance company and an independent engineering firm) to change the grout arch design. They reasoned that particularly the construction contractor and the insurance company had an interest in either having the design changed or just expressing concerns. If the design was changed, the work process would be less risky, so the contractor would have an easier job delivering the system without flaws or construction problems. This would reduce its chance of bearing liability for faults. For the insurance company, there would be a smaller risk of having to pay out on claims. Expressing doubt enabled the insurance company to shift liability to the sponsor. For the sponsor, this was sufficient grounds to be very averse to this input. Something similar happened in the Randstad Rail project when agents suggested that the principal extend the conversion period and in the CA/T project when engineers suggested to project managers that the design of the drop-ceiling should be changed, after the earlier change from metal to concrete slabs.

Examples of the opposite approach are rare. Generally speaking, receptivity to input of any kind was largest in the Post Office Square and Herren Tunnel projects. In both, there was less fear of strategic behaviour, mainly due to the ample expertise within the principals' organisations.

9.7.3 Relevant considerations for a trade-off

Strategies to bring the owner or sponsor and contractor closer (actor diversity and information asymmetry dilemmas) can cause larger oversight problems. The contractor's powerful position, which results from the principal's dependence, can prompt the contractor to pursue its own interests in the provision of information to the owner or sponsor. It is not just the occurrence of strategic behaviour that flaws decision-making. The sponsor's fear of it is a hindrance too. Knowing that the agent might act strategically, some sponsors bolster against it (this was seen, e.g., in the Souterrain case). Even if the contractor is sincere in its information provision, the sponsor might still set aside sensible input and take the wrong course.

This dilemma relates strongly to the rationalisation dilemma discussed next, but also has strong ties with the considerations discussed earlier regarding strategies for dealing with information asymmetry.

9.8 Rationalisation

The rationalisation dilemma essentially concerns the extent that unsubstantiated input can find its way into decision-making on the project.

9.8.1 The dilemma: Defence against versus responsiveness to unobjectifiable input

The principal as the main decision-maker with limited information will try to frame the information it receives in order to distinguish valuable information from strategic information and make sensible decisions. Input from agents, such as contractors, comes in various forms and various degrees of objectifiability, varying from log files to intuition. The rationalisation dilemma relates to the value and hazards of unobjectifiable input, such as hunches and heuristics-based input. This dilemma is the one most directly concerned with tacit knowledge as an occurrence of uncertainty.

The dilemma is as follows:

- The decision-maker can reject unobjectifiable input.
- The decision-maker can be receptive to unobjectifiable input.

Each option has advantages and disadvantages:

- Excluding unobjectifiable input yields the largest chance of not falling victim to strategic behaviour. But in complex projects, information is not always quantifiable and measurable. Hence, complexity is not always measurable. Keeping unobjectifiable information out would therefore imply ignoring information that is possibly indispensable for good project implementation, since it would deal with, most profoundly, incompleteness uncertainties.
- Including unobjectifiable input ensures that the project organisation makes use of all the information and knowledge that is available among its contributors. But it would also imply accepting possible strategic behaviour, and hence intention uncertainty.

The same dilemma applies to values. Objectifiable values are the ones that can be quantified and measured in advance; that is, in terms of implementation time and costs. Unobjectifiable ones are those that are based in part on experience and tacit knowledge, predominantly related to quality. In most cases, the contractors are the most important information providers. Sponsors (or owners) usually make decisions and hence trade off values.

This is the third dilemma that occurs at the project execution level. The dilemma concerns inscrutability uncertainty and interpretation uncertainty, since tacit knowledge tends to be unobjectifiable, which may make principals wary of a possible moral hazard in being receptive to it (strategic behaviour dilemma).

9.8.2 Examples of occurrence

Randstad Rail offers the clearest example of a project in which the principal predominantly pursued an objectifiable value (time) and relied mainly on objectifiable information to achieve the scheduled opening date. After numerous scope changes, the engineers involved in project management feared that the period for converting the old railway lines into the new light rail system might be too short. Many construction activities had to take place in such a brief period that manageability would certainly be seriously compromised. The engineers, however, did not manage to get this message across. They could not objectify where the shoe would pinch. The schedule was theoretically achievable, but the engineers knew from experience that things would not always go as expected. The principal, not receiving any clear indicators of unfeasibility, assumed that the possible consequence would be failure to have the system operational on the established opening date; it did not consider quality or safety risks. The sponsor did not intend to compromise on unobjectifiable values, but was simply not as savvy as the engineers. During construction, coordination of activities was so problematic that unforeseen events happened and sometimes even went unrecorded.

Several conditions can explain a dominant focus on objectifiable aspects:

- The principal may perceive its primary public responsibility as adherence to budgets and time schedules, since it is spending public money.
- The principal may lack the kind of experience that makes other actors aware of implicit hazards.
- The principal may seek to avoid falling victim to strategic behaviour.

Other examples of a dominant focus on objectifiable values can be found in the events of the catastrophic technical failures in the Souterrain project and the CA/T I-90 connector tunnel. In the Souterrain, the design engineer/project director determined that the risk of a grout arch failure would be irrevocable collapse. However, extensive safety margins were defined in the terms of reference and the director reckoned that, as long as the construction contractor respected these margins, the risk could be averted. The contractor itself, however, reckoned that if the consequence of failure was irrevocable collapse, the construction method should not have been chosen, no matter how extensive the safety margins were.

In the drop-ceiling collapse in the CA/T I-90 connector tunnel, the bolt-and-epoxy fixtures were accepted because the official product specifications indicated that they should be able to hold an even larger weight than they had to in the specific application. When approving the design, the managers appear not to have given full thought to the extreme vulnerability of the installation process. The structural integrity would, for instance, be compromised if the dust and dirt was not removed completely from the drilled holes. The same applied to the improper mixing of epoxy components (even a slight deviation from the proper proportions was a potential hazard). The installation in harsh weather conditions and drilling the holes too deep were other potential hazards. It is uncertain to what extent each contributed to the fixtures giving way. But it is broadly considered likely that one or more of these aspects played a role, considering the outcome of the tests conducted after the incident.

9.8.3 Relevant considerations for a trade-off

Interrelatedness with other dilemmas

Two phenomena seem to have a generic validity:

- Principals seem inclined to overvalue objectifiable values and information (particularly on time and budget/expenditures). The impact of objectifiable values and information is easiest to understand and objectifiable information is best at alleviating the inherent distrust of the sponsor towards the contractor or engineers. Not all principals do this, but there is a clear logic behind it.

- Agents seem inclined to disregard budgets and time schedules. This is not because they want to ignore them, but because they have an interest in easing tight schedules and claiming higher costs.

The examples of deviance indicate that inclusion of unobjectifiable information is indispensable in the management of complex projects, particularly because much information on technical manageability (quality, safety) is experience-related and therefore tacit and unobjectifiable. Understandably, few project managers would accept quality or safety compromises if they were explicitly aware of them. But project managers do, also very understandably, still want to avoid falling victim to strategic behaviour on these issues. This results in the deadlock presented in Table 9.2.

Table 9.2 Dominant values/information deadlock.

	Principal focuses on objectifiable information in decision-making	Principal allows for unobjectifiable information in decision-making
Susceptibility to strategic behaviour	Low, but valuable heuristics-based input may be ignored	High, but heuristics-based information is included, which is the type most suitable for strategic purposes
Chance of quality/ safety compromise	High, but challenges of quality and safety assumptions are often heuristics-based	Low, but this can lead to proliferation of emergent dynamics and, hence, render project control problematic

As noted, the strategic behaviour and rationalisation dilemmas are strongly related. The sponsor's managers try to fend off strategic behaviour by focusing on objectifiable information. The effectuation of strategic behaviour is strongly related to the existence of information asymmetry. Both ways to counter it – moving contractors' information to the decision-maker and moving decision-making authority to contractors – facilitate such behaviour.

Groupthink

In supporting the decision-maker in reaching a decision, an outside information provider under pressure might embrace the decision-maker's perspective too much and lose its role as outside expert, being encapsulated into the groupthink of the project. The Souterrain project designer SAT Engineering and the Dutch Ministry of Transport's engineering department put great effort into finding solutions to meet the Building Inspectorate's requirements concerning the project environment within the tight budgetary space available. The subsequent design cutbacks, as it turned out, compromised the robustness of the technical system. This does not mean that an actor such as SAT was reprehensible. But such an actor may reach a point where the line between conservative and risky engineering is unintendedly and unwittingly crossed.

9.9 Interrelatedness of the dilemmas

Now that all dilemmas have been elaborated, they can be positioned in relation to one another. First they will be categorised in accordance with the level of project management they occur. Subsequently, the relations between these levels will be explored.

9.9.1 Three levels of dilemmas, different uncertainties

The seven dilemmas relate to different levels and different phases of project management. The uncertainty gap is an issue that defines the highest level of bounded manageability, because the two determining variables concern the ambitions of the sponsor (technical complexity) and the capabilities of the owner's organisation. These aspects relate to the **project definition level**. In the earliest project phases (initial proposal and political approval) the ambitions for the effort are outlined, often resulting in a required scope and functionality. This phase is also where the main decisions on the organisational system are made, though adjustments can occur up to the completion date. The segmentation, value variety and information asymmetry dilemmas reflect the tactical choices made by the principal for the organisation that will take charge of the project, with the defined scope and functionality as its end-result. These choices play out at the **organisational level**, at which point the complexity of the defined project should be known. Finally, dynamics, strategic behaviour and rationalisation are dilemmas that occur not only in the daily management of the preparation phase (procurement, design), but in the execution of the project too. This is the **project execution level**. According to Jones and Deckro's (1993) role theory, functional specialists are usually found working at the project execution level, whereas project managers are more involved at the organisational and project definition level. Table 9.3 presents the dominance of the dilemmas at each level in the project trajectory.

Table 9.3 Overview of dominant occurrence of the dilemmas over the project trajectory and in the project hierarchy.

Hierarchical level	Time *Early*		*Late*
High	Project definition level dilemma		
Middle		Organisational level dilemmas	
Low			Project execution level dilemmas

When one considers the three levels of dilemma in relation to the types of uncertainty distinguished in Chapter 3, patterns emerge that develop from predominantly incognition-driven uncertainty at the project definition level – i.e. at the front-end of the project – to the interaction-driven uncertainties that derive from incognition-driven uncertainties at the project execution level. In between is a sort of nexus in which the project organisation translates the defined project into operations, where occurrences of uncertainty are entirely interaction-driven. For example, at the front-end of a project the principal defines the scope and quality expected and, in doing so, defines a level of exposure to uncertainty. The more differentiated and interdependent the system and its subsystems, parts and units are, the greater the complexity and, hence, the more the project organisation is exposed to instability and incompleteness uncertainties and the more one can expect inconceivability uncertainty might manifest.

At the project execution level, the involved actors are confronted with the consequences of the choices made at the project definition level. Instability, incompleteness and inconceivability uncertainties manifest in actual risks or unforeseen events. The situation requires decisions to be made by managers who are subject to interaction-driven uncertainty. Are agents behaving strategically in providing inputs for decision-making? Do agents sufficiently understand the objectives of the principal? The conditions under which these daily operations are executed are set at the organisational level. Here, the potential for the occurrence of interaction-driven uncertainty is determined in organisational differentiation, values and the relationship between information and decision-making.

9.9.2 Chains of manageability dilemmas

The seven dilemmas are strongly interrelated. Indeed, elaboration of the dilemmas in the previous sections emphasised that the dilemmas cannot be considered independently. A trade-off on one dilemma has implications for other dilemmas. Chapters 2 and 3 distinguished four main manageability elements, leading to four tiers of dilemmas: differentiation, interdependence, uncertainty and the information/decision-making divide. Chapter 2 started with differentiation and interdependence, because at that point bounded manageability was being approached from the perspective of system complexity. In project management, however, considerations often start with the expected uncertainty, because political deliberations and terms of reference set the challenge, and decisions are often related to which actors will be involved and how. If uncertainty did not occur, there would be no manageability issue. Figure 9.1 positions the seven dilemmas at the three manageability levels.

Manageability of complex underground construction projects depends less on which direction managers choose to take in individual dilemmas, than on how managers deal with the coherence of dilemmas: chains of interrelated manageability dilemmas. The double-bind nature of the dilemmas implies that each possible course has downsides. A successful manager is one who manages to mitigate or compensate for the hazards of one direction of choice with measures on another. As a result, bounded manageability occurs if managers do not acknowledge the ramifications of their trade-offs. This section provides a few examples of patterns through the dilemma tree that have led to bounded manageability. Needless to say, there are plenty of other patterns possible. They, too, however tend to touch upon the same regularities and can be countered with the remedies that will be suggested later.

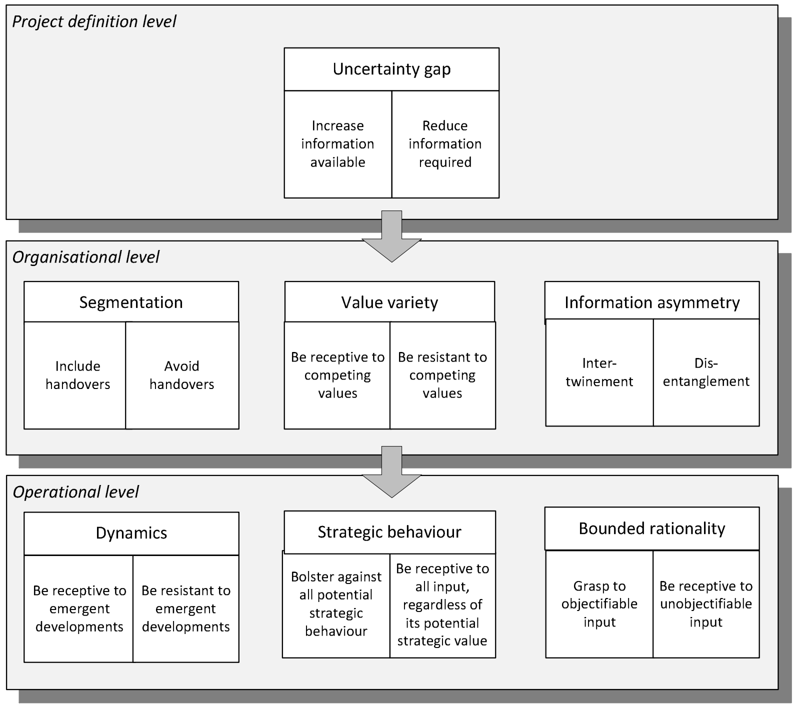

Figure 9.1 The main dilemmas in the management of complex underground engineering projects.

9.9.3 Patterns of bounded manageability in the case studies

With the seven dilemmas divided over the three levels of management, it is now possible to trace patterns of bounded manageability through the dilemmas. In the case studies, we found concurrences of certain dilemmas. A few of these are described in this section. The examples are not a definitive list. Case studies of other projects would likely turn up new examples of bounded manageability resulting from the directions chosen in those.

Pattern 1: Grasping control; the tension between project definition and operations

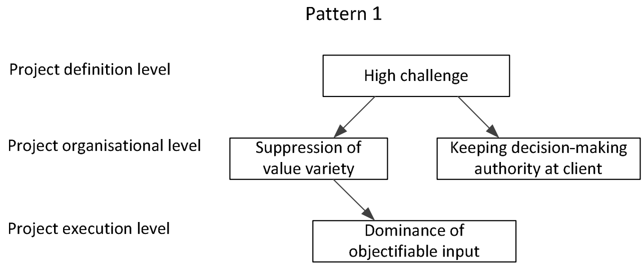

Figure 9.2: Pattern 1

The “grasping control” pattern starts with a large uncertainty gap, which requires many specialist parties (segmentation), implying value variety, which the principal wants to suppress. This typically translates into a strategy to maintain control of decision-making and to acquire information to do so. The principal’s dependence on information gives information owners (agents) a powerful position (for potential strategic behaviour). The principal is inclined to counter this by rationalising decisions, only being receptive to objectifiable input.

A project such as the Souterrain started with a high level of instability and incompleteness uncertainties. The impact of groundwater and the presence of peat layers in the soil are typical examples. When looking at the main occurrences of bounded manageability in the projects, actual daily decisions concerned dilemmas at the lowest level. The attitude of the sponsor in these dilemmas was, however, explained by the directions taken at higher levels, on segmentation, value variety and information asymmetry, and ultimately by the uncertainty gap. In the Souterrain leakage, the sponsor’s fear of strategic behaviour by the contractor (project execution level) followed from the fact that a handover had to take place from the design engineer to the contractor (organisational level). This led to intention uncertainty. The sponsor assembled its own information, but was suspicious of its trustworthiness. Unwittingly, the accuracy of the information became much less relevant than which actor the sponsor expected to provide the best information. The sponsor was most concerned with which actor it expected to exhibit the least strategic behaviour. Apart from decisions based on lower quality information, this mechanism presented strong potential disadvantages, such as groupthink and reliance on information providers with little incentive to be critical. Also, differences in viewpoints and maybe even attitude towards risk became evident between the design engineer and sponsor, on one hand, and the contractor, on the other (value variety). Apart from intention uncertainty, this suggests interpretation uncertainty, since the risk interpretation by the sponsor manifested in the contractor’s work.

The Souterrain and Randstad Rail projects provide examples of sponsors that sought to focus on objectifiable information. Both projects had sponsors that desired clear information on exactly where bounded manageability would occur. But the information that became available was derived predominantly from tacit knowledge: the kind most susceptible to strategic behaviour. The clearest example in the Randstad Rail case were the doubts expressed by engineers about the very tight conversion schedule. The sponsor's board (BORR) ignored signals of bounded manageability, because they could not be substantiated. In the Souterrain something comparable happened in the discussions between sponsor and contractor about the grout layer. The contractor distrusted the design, but could not indicate where exactly the predicted failure would occur.

Inclusion of the contractor in the engineering design work, as originally planned in the Souterrain project, would have eliminated the handover, removing also interpretation and intention uncertainties. Also, applying redundancy as a strategy to overcome information asymmetry would have changed this situation. Attempts to resolve the information asymmetry were mostly the sponsor's efforts to acquire more information via other actors than the contractor. No decision-making authority was transferred. The sponsor kept control, but the interpretation of information remained problematic. Hence, the sponsor's response to the perceived intention uncertainty created interpretation uncertainty: the contractor's uncertainty about how the sponsor would perceive and interpret the input. The different attitudes towards risk, as a manifestation of value variety, were further fuelled by additional value variety between particularly the sponsor (most affordable solutions, mitigating nuisance) and the contractor (secure technical solutions that happened to be costly). The sponsor feared strategic behaviour in these cases and wanted to keep as close as possible to set budgets.

The Stadtbahnbauamt in Dortmund followed a similar strategy at the organisational level. But that project seemed better manageable, because since the uncertainty gap at the project definition level was smaller, the chance for interpretation uncertainty to emerge was smaller as well. Moreover, due to previous experiences, the uncertainty gap was pretty well known to be small. The Herren Tunnel project suggests that less segmentation could have reduced the value variety and hence both intention and interpretation uncertainties.

A comparable pattern occurred in the Randstad Rail conversion period. Managers, in this case, fended off emergent dynamics in the conversion period. They rejected unobjectifiable information, due to their fears of strategic behaviour. Added to this was the strong influence of the sponsor's main driver (time) and the quite extreme change of attitude, from receptivity to emergent dynamics in the preparation phase to reluctance to allow any changes at all during project execution. This change was also evident in the

Souterrain project (scope growth during project definition). But receptivity ended for the most part after the project was transferred to the City Management Department. In Randstad Rail, the divergence of opinions on whether to adjust work schedules demonstrates the strong variety of values between decision-makers and implementers. The sponsor's need for control was dominant here, also fuelled by the circumstances such as external dependencies.

Typical of this pattern is a strong focus on control at the project execution level to compensate for an earlier focus on certain drivers in project definition (e.g., time in the Randstad Rail project and scope in the Souterrain and the CA/T projects).

Pattern 2: Scope as main driver

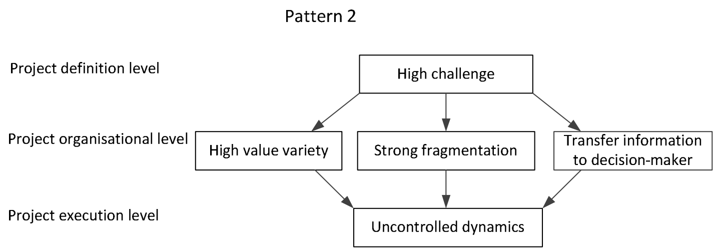

Figure 9.3: Pattern 2

Another possible concurrence of dilemmas forms an alternative to pattern 1. In this "scope-driven" pattern we see a large uncertainty gap, strong segmentation and high value variety too, but now the principal, instead of acquiring information and relying on own assessments, transfers decision-making authority to one or more agents. In many forms of contractual relations, agents have an inherent incentive to make the project grow, and since the principal is poorly informed, it accepts agents' decisions and the project grows.

Pattern 1 revealed some effects of the dominance of project drivers or project promises. The early phases of the CA/T project might be the most illustrative case of how this led to unmanageability. The CA/T project's financial manageability problems were related to quite extreme receptivity to dynamics in the early phases of the project, which were related to a considerable extent to the variety in values between the project organisation and its environment, potentially leading to interaction-driven uncertainties. In the early phases, the sponsor depended largely on input from others. This pattern occurred in a situation in which there was a strong focus on optimisation of scope and quality, which was largely stakeholder-centred and resulted in more than a thousand mitigation commitments.

Pattern 3: Integration of owner and contractor

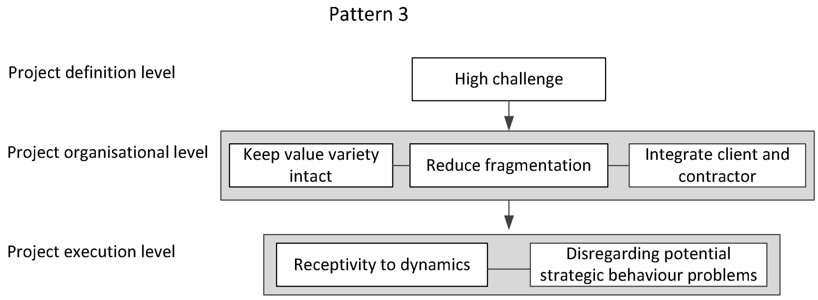

Figure 9.4: Pattern 3

The CA/T project, in particular, sought a third way to solve the information asymmetry problem: an integration of the principal's decision-making authority and the agent's information into an integrated project organisation. This "integration" pattern came with a remarkable series of interpretation and intention uncertainties and strategic behaviour-related problems.

Actors may perceive the separation of information and decision-making authority as a problem, because it disables them from making rational decisions in the field of tension between high-level demands (project definition level), on one hand, and engineering design and project execution (project execution level) on the other. In the CA/T project the client attempted to solve this issue during implementation by integrating the contractor and owner organisation into one project management organisation. This was to bring decision-makers as close to the information as possible. The attempt was, according to *ex post* evaluation, not completely successful, because despite the intertwinement of staff, value variety between the owner (seeking efficiency) and the project management consultant (seeking profit), and hence interaction-driven uncertainties, remained. So, segmentation and value variety were cosmetically reduced through the IPO to improve control, but in reality still existed. The owner's failure to regain control in the later phases also relate to the attempts to eliminate information asymmetry through the IPO. The consequences were unclear accountability, ambiguous professional and contractual liabilities, authority bifurcation-type conflicts and the contractor becoming responsible for identifying the causes of cost overruns and delays associated with its own work.[3]

In essence, the interdependence between the two main actors remained and so did the owner's susceptibility to strategic behaviour. If the owner has such confidence in the project management consultant that it becomes receptive to non-objectifiable input, it can easily lose control of the implementation process, which is what threatened to happen in the management of claims and changes in the CA/T project. In an earlier phase something similar occurred in design changes and management of requests for mitigation measures.

This pattern shows the strong interrelatedness of the segmentation and value variety dilemmas. These dilemmas should be considered jointly and preferably early in the process. CA/T management first acted on the basis of the value variety with the second opinion committee, but it gave up on this strategy later. The IPO could be considered an attempt to rectify this. From the moment the managers of the owner and project manager B/PB merged into one organisation, the contractor could lead the dance.

The Herren Tunnel project did not experience problems related to this dilemma, because the project organisation was set up in a way that prevented strong value variety despite intertwinement. Here, the value variety between owner and contractor was eliminated by the financial participation of the contractor in the client organisation. So the issues of strategic behaviour and unobjectifiable input were taken care of in advance. The client handed over ownership and hence decision-making authority to the information owners, which were both contractors and financiers (countervailing power), and made that consortium responsible for all tasks.

This is, however, a model that would have been difficult to achieve in the CA/T project, because despite its access to toll revenues, ownership by the MTA prevented such a set-up. A public-private joint venture between MTA and B/PB might have been possible, but then a profitable business case for B/PB would probably have been necessary to create a willingness to invest. Even then it is doubtful whether a private party would have accepted the risks involved in such an endeavour.

Pattern 4: Sticking to a convenient solution

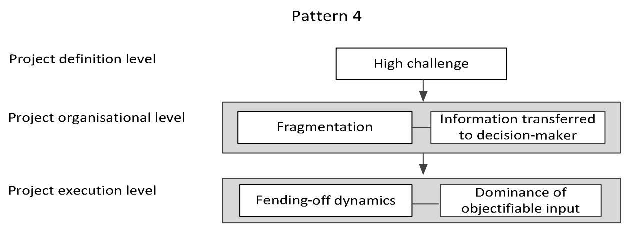

Figure 9.5: Pattern 4

In the “convenient solution” pattern the principal’s managers are involved in decisions at the daily operations level and seek to avoid any changes made to project plans.

The CA/T ceiling collapse resulted from dynamics regarding the engineering design. The design change was made for cost reasons, as well as to resolve installation and functionality problems. Here, the uncertainty gap manifested strongly, mainly as incompleteness uncertainty. This occurrence points to no strong organisational dilemmas, but it does demonstrate a strong mutual relation between operational dilemmas (like the Souterrain and Randstad Rail projects). The decision to rely on the epoxy fixtures was made principally based on the objectifiable information from the specifications that the epoxy should hold. Doubts about design integrity did not have the same impact. Neither did more objective indicators, such as tests on bolt loosening. The incontestability of the specifications and strength calculations was debated, however, after small-scale tests. An upside for the sponsor was that because the specifications were the only objective evidence available, this put the blame for the calamity on the epoxy manufacturer. An overall image of a strong control focus emerges in this pattern. Here too there is no clear relation to the project definition level, other than that the uncertainty gap was created in earlier phases.

In the cases that did not experience these manageability problems the information processing dilemmas were not put under strain. There it is difficult to say whether a comparable control focus might have led to the same manageability issues. But even with the same control focus the outcome would likely be different, related to the configuration of the project organisation. To give an example: in the Post Office Square project, a crucial dynamic redesign of the diaphragm wall on the most vulnerable side of the excavation was easily accepted, because the abutters were co-owners and money was less of an issue than in other projects. The Herren Tunnel was different. Here, the contractors were included in the ownership organisation, so there was little segmentation or value variety, despite the same number of actors being involved as elsewhere. There was also little fear of strategic behaviour and emergent dynamics, and so there was no need to be receptive only to unobjectifiable information. In the Stadtbahn tunnel project in Dortmund the sponsor had ample engineering knowledge at its disposal and actually took the opportunity to introduce some redundancy to ensure control and check quality.

9.9.4 Findings on the basis of bounded manageability patterns

Combining the positioning of the dilemmas at the three different levels with the occurrences of uncertainty and manageability dilemmas, and ultimately considering the patterns from the previous section, a number regularities emerge:

1. Trade-offs on project definition and operational issues are made at different levels and, hence, manageability-influencing events occur at a different level than their causes. If managers do not recognise the overall interdependence of the dilemmas, they may not understand the origins of bounded manageability or the potential for bounded manageability to result from their choices. This, for instance, seems to be the case when potential deviations emerge, as in pattern 1.
2. The project organisation level is pivotal. Here is where organisational features can be tweaked that can have key impacts on how trade-offs are made. But at that particular level, trade-offs seem to be made mostly with within-level characteristics in mind, and without consideration of the interrelatedness with trade-offs at other levels. The patterns show some variety in organisational strategies. But their ramifications at the project execution level seem to be uncontrolled effects.
3. In decision-making at the project definition level, there tends to be little consideration of the project execution level. All patterns start with the notion of a large uncertainty gap, reflecting what was found in the case studies. As pattern 2 suggests most specifically, managers at the project definition level match the desired scope, quality, budget and schedules to their ambitions, not to attainability and the timeframe in which the project actually has to be implemented.
4. The patterns suggest that the organisational level could better reflect potential problems at the project execution level. The attitudes of managers at the project execution level can be guided by the steering given to the project organisation regarding segmentation, value variety and the information/decision-making divide, but only if the expected effects at the project execution level are meticulously plotted.
5. The observations from the case studies suggest that if a pattern develops, the outcome will likely be one of two extremes: a very dominant focus on delivering scope and quality, which could lead to poor performance on budgets and schedules (such as in the CA/T project), or a very dominant focus on delivering the project on time and on budget, with a larger chance of poor performance on quality and possibly scope if overruns have to be compensated for (such as in Randstad Rail and the Souterrain).
6. The lower one gets in the hierarchy, the stronger the focus tends to be on budget and schedule control, probably for the simple reason that these are the variables that are most visible and best measurable, and this is what managers are often held accountable for. This was seen in specific occurrences in Randstad Rail (e.g., the decision to stick to the schedule), the Souterrain (e.g., initial rejection of the

proposed completion techniques) and the CA/T project (e.g., sticking to use of the concrete slabs despite engineers' doubts).

9.10 Overview of observed responses

There may be ways to deal with the manageability dilemmas so that the patterns of emerging bounded manageability can be broken. To choose a proper arrangement, the principal should try to understand what kinds of dilemma may occur during implementation of the project with the chosen set-up and how one dilemma may feed into another. What will happen when technical problems occur and the principal becomes dependent on information from project execution level? Can the principal retain control over events? Or, what will happen if financial pressure develops? Is the principal inclined to let its main drivers prevail? So, the principal should not just align the organisational arrangement to its needs, but should also use the organisational arrangement to create a framework for its own future behaviour. Such a framework should take not only the owner's or sponsor's own deficiencies into consideration, but also for example, the expected pursuit of values by other actors. It should consider not only where information is available, but also which strategic values and interaction-driven uncertainties are attached to it. This goes beyond a choice for a certain type of project organisation. It requires a consideration of all seven dilemmas and their coherence. This section explores solutions for mitigating the adverse side effects of the paradoxical dilemmas that managers encounter.

9.10.1 Double bind in the dilemmas

The typical trade-offs on the seven dilemmas discussed in this chapter can be roughly plotted around extremes that all the dilemmas have in common: to create monitorability, predictability and controllability by a joint effort of the involved actors on one hand and as a solo effort by the principal on the other (Table 9.3). Included are not all, but some of the clearest examples of responses to the dilemmas from the case studies.

Table 9.3 Overview of manageability dilemmas.

	Dilemma	Manageability as multi-actor effort	Manageability as a principal's effort
1	Uncertainty gap	**Reduce information required** *Not observed in the case studies*	**Increase information available** *Observed, e.g., in Souterrain, CA/T*
2	Segmentation	**Incorporate handovers** *Observed, e.g., in Souterrain, CA/T*	**Avoid handovers** *Observed, e.g., in Herren Tunnel*
3	Value variety	**Embrace value variety** *Observed, e.g., in Rijswijk, Post Office Square*	**Avoid value variety** *Observed, e.g., in Randstad Rail, Souterrain*
4	Information asymmetry	**Integrate** *Observed, e.g., in Souterrain, CA/T*	**Separate** *Observed, e.g., in Dortmund*
		Transfer decision-making authority to information owner *Observed, e.g., in CA/T, Herren Tunnel*	**Transfer information to decision-maker** *Observed, e.g., in Souterrain, Dortmund*
5	Dynamics	**Receptivity to dynamics** *Observed, e.g., in CA/T (early phases), Post Office Square*	**Resistance to dynamics** *Observed, e.g., in Randstad Rail, CA/T (later phases)*
6	Strategic behaviour	**Receptivity to potential strategic input** *Not observed in the case studies*	**Resistance to potential strategic input** *Observed, e.g., in Randstad Rail, Souterrain*
7	Rationalisation	**Receptivity to unobjectifiable input** *Not observed in the case studies*	**Resistance to unobjectifiable input** *Observed, e.g., in Randstad Rail, Souterrain, CA/T*

A principal that tries to attain manageability by a multi-actor effort will include many actors to generate many views and values and give the other actors in the network an important role, for instance, transferring decision-making authority to them. The owner or sponsor will also be receptive to all input, regardless of whether the input may be strategically motivated or unobjectifiable. An owner or sponsor at the other end of the spectrum will try to retain manageability by delegating little, keeping diverging values out and resisting emergent dynamics and input that cannot be verified. Both directions can work, but as sections 9.2 to 9.8 showed, in all cases they also have downsides.

All seven dilemmas have dichotomous alternatives for solutions with downsides as adverse as the problem they intend to solve. This makes them "double binds". It becomes impossible for managers to "do the right thing", even though that is usually their purpose. Hence, the key to success is not to choose the right solution direction, but to mitigate or to compensate for the adverse ramifications.

9.10.2 Dealing with the double bind

What to do with individual double bind dilemmas? How to choose the best pattern of interrelated options? Managers have to find a, preferably coherent, strategy for the project as a whole, rather than for individual dilemmas. At the level of an individual dilemma, they can then either choose between the two options presented by the dilemma, or try to find a balance between the options. In any case, managers will have to deal with the adverse effects of their choices to make their strategies work.

The dilemmas occur as the problematic convergence of information, values held by owner or sponsor and contractors and the decisions the owner or sponsor has to make. The configuration of the project organisation seems a logical instrument to use in planning for good trade-offs. But the studied cases suggest that the typical dilemmas have not been applied as input for the organisational configurations. Various configurations were found in the case studies, such the integrated project organisation of the CA/T project at one end of the spectrum and the "arm's length model" of the Dortmund Stadtbahn at the other end. The main considerations in those cases were contractor incentives, resolving owner deficiencies and efficiency.

Strategies are not typically communicated explicitly. Strategy choices are often not even made explicitly. They cannot be if the managers involved do not see the implicit dilemmas they involve or the interrelations between dilemmas. The way strategies, uncertainty and ultimately (un)manageability spread through a project is via information used for decision-making. So, the management of most complex engineering projects revolves around the management and processing of information: top-down provision of terms of reference, schedules, work breakdowns, etcetera, and bottom-up provision of specialist knowledge, logs, claims for changes, etcetera. But, as the case studies showed, these procedures cannot guarantee sound implementation, because of typical interaction-driven uncertainties:

- Information is not always produced the way the receivers of the information want it (value-related interests and strategies are involved that can colour or contaminate information and create interaction-driven uncertainty).
- Information is not always used for decision-making the way the sender of the information intended (assessment flaws may be involved due to the different frames of reference between principal and agent).

Another complication is that information exchange takes place between the three levels of management: at the project definition level, the organisational level and the project execution level. Bounded manageability spreads through the three levels too.

Predictability at the project execution level, for example, can be improved by interventions at the organisational level.

There is another reason why a desired operating mode is not obtained by finding the optimum in each dilemma individually: in many cases there is not any. To avoid the adverse effects of the most extreme options, it may seem logical to pursue a middle-of-the-road approach. But, first, there is not always an option in the middle, for example, in the uncertainty gap dilemma. Second, there is not always a binary choice. The information asymmetry example, for instance, has a multitude of options, categorised in five major directions. Likewise, in the value variety dilemma, an option in-between could be many different things. It could mean allowing some but not full variety, it could mean alternating between modes, or it could mean allowing full value variety on some aspects and no value variety on others.

An optimum can only be obtained as an equilibrium across a whole chain of dilemmas, from top to bottom. When looking at the cases, it appears to be important to create awareness of all dilemmas at the project definition level. This implies that when scope and quality are being defined, the principal tries to understand the ramifications at the project execution level and tries to compensate for downsides. This can be done either by finding an equilibrium (which is challenging at best) or by developing an explicit strategy for the intermediate organisational level. The problem with any choice of pattern is that there is still no guarantee that the adverse effects of some dilemma will not reduce manageability at some point.

9.10.3 Cross-level management and the importance of the organisational level

In the dilemmas that confronted managers in the studied cases, as well as in the patterns of bounded manageability, a striking dissimilarity is seen between the trade-offs made at the project definition level and the trade-offs made at the project execution level. The primary concern at the project definition level is to translate the main value drivers into a definition of the scope of the project with a defined quality; that is, establishing an ideal reference, mainly influenced by political values. At the project execution level, the main concern is to deliver these values in the face of the unruly reality of dynamics and diverging interests that are typical of efforts like this.

As observed in the case studies, at the project definition level there tends to be a strong focus not on the manageability of the actual implementation but on optimisation of the quality of a project’s end-product; that is, achieving the largest possible scope and functionality with highest design quality for the lowest cost and in the shortest possible implementation time. This goes beyond the desired level of scope definition. It is a well-known pattern in project management that a high level of scope definition at the front-end tends to lead to fewer change requests during implementation. But the uncertainty gap can also, for instance, increase the likelihood of strategic behaviour. It implicitly defines how parties involved will act. At the project execution level there tends to be an urge to keep the project controllable, because there is a better understanding of the practical implications of policies drawn up at the project definition level. Hence, improvement should be sought in cross-level management. At the project definition level more awareness of control in project implementation needs to be attained; at the project execution level the scope and quality of the end-result should be safeguarded. For example, if the ambitions with regard to scope and quality are very high at the project definition level, and hence the uncertainty gap is likely to be large, one can expect that at the project execution level there will be more emergent dynamics and trade-offs for dealing with potentially strategic behaviour, and objectifiability of input will be more influential on the manageability of the project.

So, arrangements are required to solve these problems at the highest and lowest levels of aggregation, both in front-end development and in execution phases and aimed both at the principal role (owner/sponsor) and at the agent role (contractors and other implementers). Several general ideas for improvement can be proposed:

- Countervailing powers could be established to solve the principal's information gap and correct possibly flawed interpretations. This could be an actor with good information interpretation capabilities, well-armed against strategic behaviour in project execution and aware of the implementability of the plans at the project execution level. According to theories on checks and balances, a countervailing power can keep a decision-maker from straying to decisions that could harm the manageability of a project.
- Incentives could be put in place to prevent contractors and other implementers from acting strategically when providing information.

These two strategies aim for monitorability (understanding what is going on) and controllability (doing something about it). But they may raise discord between actors, particularly between the principal and agents. Therefore, a third type of arrangement may be valuable to provide the necessary foundation of mutual trust:

- Process arrangements can be crafted to prevent the other two measures from ending in conflict. Such arrangements could predefine reactions to events and conditions for future decisions. This would remove unpredictability and with it an important source of conflict.

These three solution directions – countervailing power, incentives and process arrangements – are complementary and not interchangeable and account for all three defined features of manageability.

A crucial position in this is reserved for organisational level trade-offs. Countervailing powers can be created through mechanisms, for instance, for allowing value variety. Strategies for putting incentives in place are strongly related to trade-offs on segmentation and information asymmetry, as the next subsections will demonstrate.

9.10.4 Countervailing powers

Findings from the empirical research suggests that interdependencies in project organisations are in practice often unilateral dependencies: decisions depend on information, not the other way around. Hence, the principal primarily depends on the agents. Two countervailing powers could be arranged in a project to counter the adverse effects of this dependence. One power would prevent the neglect of indispensable, possibly unobjectifiable information, and one would prevent agents from providing strategically contaminated information, in case principals are open to such information. The former would be installed on the receiver side of input (the principal), the latter on the sender side (the agents). Both can be organised with back-up for the principal. Project managers on the principal's side would be helped by someone able to assess whether agents' inputs are reliable. This independent assessor could improve the principal's interpretation of information and balance the pursuit of maximised scope/quality and control, while assuming a vigilant and critical attitude and respecting the "arm's length principle". The back-up would add to the knowledge available and, as a result, expand the assessment capabilities of the principal. It would also prevent strategic behaviour, because the agents know that the principal cannot be easily fooled. If an agent attempts to do so anyway, the back-up acts to correct this for the principal. This implies redundancy, which can be perceived as inefficient, due to overlap and duplication. But the case for not perceiving it as waste has already repeatedly been made (cf. Landau, 1969; Low et al., 2003).

The back-up knowledge provider must be fully independent of any further interest in the project, thus steering clear of groupthink in the cooperation with the principal. To achieve this, principals may consider inclusion of a third party. In the Konings Tunnel project, successfully implemented in The Hague in parallel to the Souterrain, the principal drew up the design itself and hired a third party to direct the implementation. In the Dortmund Stadtbahn project, the Stadtbahnbauamt worked the other way around: it hired an independent design engineer and oversaw implementation of the design itself. In both cases the design engineer was the main information provider to the principal and had no interest in compromising the robustness of the design. The CA/T project started with a “second opinion committee” precisely for the back-up purpose suggested here. But the committee disbanded early in the process and was not restored. In the Herren Tunnel project, an overseer was part of the project organisation throughout the whole implementation process.

With an additional assessor, the processing of information could be organised in two ways. The actors may either be positioned in line, with all information passing through the back-up before ending at the principal’s project management desk, probably with advice on how to act. Or, information goes in parallel to both the principal’s project management desk and to the back-up. The cases provide little indication of how much vital information might be blurred or lost in the additional communication line between the back-up and the principal’s management or how much benefit the principal’s management could have from “pre-selection” by the back-up. The CA/T and Souterrain actors were positioned in line, but their knowledge back-ups were not fully independent from management. The Dortmund and Konings Tunnel projects were organised in a triangle configuration.

A configuration with three actors requires some expertise from the principal, perhaps more than many principals can offer. To that end, inclusion of a fourth party might be wise, particularly if the knowledge back-up is not independent from the project organisation. A second weakness is that the third or fourth party would not usually have blocking power in these set-ups. Therefore, there is little certainty that flawed interpretations by the principal would be averted. The countervailing powers would ideally be configured very early in the project. They could then play a crucial role in project definition, ensuring that control issues are sufficiently taken into account.

As with the double-binds, countervailing powers can also be achieved by trading-off courses of action in dilemmas, instead of in project organisational set-ups. For example, they might be achieved by alternating between possible courses of action. Strategies of acceptance of value variety and avoidance of value variety can change depending on the most favourable approach when trading off benefits and downsides over time. Downsides that may occur at one stage can possibly be compensated for later with an opposite approach.

Alternatively, countervailing powers could be achieved by pursuing opposing courses of action in different but related dilemmas. For example, a strategy of being receptive to emerging developments and dynamics could be compensated for by resistance to unobjectifiable input. This can be a risky strategy though. Emerging developments may be supported by input that simply cannot be objectified, for instance, because it concerns new technology that has not yet been fully crystallised. Also, some directions simply do not go well together. Resistance to inputs that potentially were provided for strategic reasons does not go well with receptiveness to unobjectifiable input.

9.10.5 Incentives

Incentives in a conflict-driven process

A situation of countervailing powers could result in a conflict-driven implementation process. In many cases the principal may consider its organisation insufficiently powerful to weigh up against the contracted agents. A solution could be found in providing the agents with similar incentives. The appeal of such incentives is that they solve the principal's oversight problem, not by requiring a lot of investment and effort to build control mechanisms, but by encouraging desired behaviour. As mentioned earlier, complete outsourcing of project implementation and operation can create such a situation. In such situations, information and decision-making authority can be integrated with less threat of bounded manageability. Meanwhile, the principal should have an incentive to listen to all input and rely on the absence of strategic information. To do so, the principal should acknowledge its shortcomings and, hence, be critical of its own capabilities. The Dortmund Stadtbahn project shows another solution. In this project, potential contractors conferred with the design engineer, which also provided a countervailing power to the principal regarding engineering designs in the tender phase.

Principals should be aware that their dependence on information from the agents' side of the organisational network could be a source of perverse incentives. Unknown information (as in Rijswijk) may seem more negative than blind information (as in the Souterrain and CA/T projects), because in the case of blind information at least one actor has the information. But where information is unknown, there is at least equality in the handicap. As a result, there are no opportunities for information owners to exploit their position at the expense of the principal. This could happen in the case of blind information. Here the information owner is in fact more powerful than the actor that hired the information owner. At the project organisation level, it would entail making sure that actors with divergent interests, particularly the contractors, share the principal's values so that they have an incentive to block unsound trade-offs and pursue the optimal end-result from the principal's point of view. This could be by, for instance, giving them an interest in the end-result.

Set of incentives

Different kinds of incentives are required to discipline principals and agents:

- Principals are often unaware of the implicit effects of their decisions due to a lack of knowledge. Incentives should create awareness.

- Agents are usually well aware of the effects of their behaviour and must be incentivised to align their interests with the principal's, so that the information they provide is not strategically coloured.

Two additional incentives can improve manageability:

- Incentives can ensure that the agent will pull the emergency brake when the principal is about to recede from minimum quality and safety margins. In normal contractual relationships, an agent's blocking of the process might be perceived as insubordination. An interest – financial or otherwise – in the end-result might change this, because the agent then has an incentive to block the process if it considers this necessary, but also because the principal would probably understand that there might be good reasons and not consider it insubordination. This disciplines its trade-offs. Normally it would make the principal susceptible to becoming a victim of strategic behaviour. But when the agent has an interest in the end-result, it disciplines the agent too.
- Incentives can prevent the principal from ignoring or neglecting indispensable, but "unwelcome" information.

Contracting

Different types of contracts result in different incentive structures. Below, the most important effects are discussed in the three main forms of contracts.

Fixed price*.* If the owner (principal) and contractor (agent) have a fixed-price contract, the contractor disciplines the owner. After all, decisions that would jeopardise the quality or safety of the project would be countered on the basis that the contractor does not want to be victimised by the owner's flawed decisions. The contractor has an incentive to only enter into the project if it has sufficient confidence that it will not have to pay for cost increases resulting from risks or failure. The main hazard occurs when the project is poorly defined in the fixed-price contract and the contractor can argue after the contract is signed that required additional work was not covered.

Randstad Rail is an exception here, which can be explained by the awkward role of the alderman of The Hague (the agent's main administrator). The alderman was also the regional authority's administrator responsible for transport. He approved major scope changes as long as they remained within budget, regardless of their effects on manageability in implementation. This deviates to some extent from what is considered normal practice. Fixed-price contracts are usually applied in routine projects, while in more complex ones cost-plus-fee contracts are more usual (Winch, 2002).

In a fixed-price contract, there is no way for a sponsor to be responsive to emergent developments. If it wanted to include them in the works after the contract has been agreed, the contractor would negotiate toughly and only accept additions under conditions favourable to it, hence unfavourable to the sponsor.

Cost-plus-fee. Unlike fixed price, in a cost-plus-fee contract, the contractor could be too eager to include emergent developments on top of the agreed terms, as these are likely to make the project larger and hence more attractive to the contractor. A percentage fee is particularly likely to stimulate the contractor to put up scant resistance to any possible growth of the project. In the aftermath of the CA/T project, reporters and investigators mentioned this mechanism as one of the factors that made the costs of the project spiral almost uncontrollably. Management consulting contractor B/PB received cost reimbursement plus a fee on these extra works. There were suspicions of misuse by B/PB (denied by B/PB itself), but painstaking effort is needed to find project events where growth or other changes indeed unequivocally occurred for this reason.

Private involvement and ownership. An interest in the end-result can prevent the adverse effects mentioned. This would require outsourcing, as done in the Herren Tunnel project. In such a case, the owner or sponsor should realise that consideration of possible emergent developments becomes the responsibility of the contracted party. Another, less fundamental instrument could therefore be the use of incentives for timely and within-budget project completion. This might, for example, be achieved with a bonus. This way, the agents share the principal's values along with their own. Yet, this strategy has a disadvantage. There is a risk that contractors will rush the work and neglect their engineering responsibilities in order to receive the bonus.

The above analysis of possible incentive arrangements shows that none provides a definitive answer to all the project manager's needs. Each option requires some provisions for countervailing power and process arrangements.

9.10.6 Process arrangements

Predictability

Process arrangements are intended to reduce conflict between actors, particularly those on either side of the principal-agent divide. They are indispensable in conflict-driven processes. Process arrangements can converge perceptions of information and interests. They can also reduce clashes by increasing predictability.

If the principal determines in advance how information will be processed and oversight executed, its actions can be objectified and justified in advance (providing that it respects its own rules). The principal should be clear to the agents how, and on what basis, it will conduct its assessments. Agreements should also be made in advance on how agents' representatives will be involved in the principal's decision-making and how their input will be valued. Such pre-arrangements may not only prevent conflict, but also discipline the principal in its own decision-making. They prevent decision-makers from ignoring input from independent actors. Each preference of one value over another would have to be justified. It is important for agents to incorporate the principal, insofar as possible, into their considerations. This should create awareness.

Dynamics

Emergent developments can never be fully excluded in complex projects, as these projects almost inevitably include unknown information and almost always blind information as well. This means that rational decision-making is not always possible, and also that it may be unclear in advance when and what important trade-offs may occur. Ways to deal with the dilemma should provide sufficient adaptability to emergent developments while keeping time and costs controllable. The project manager should therefore constantly tack between two strategies (Koppenjan et al., 2011):

- A "predict and control strategy", in which the project manager tries to adhere to established plans.
- A "prepare and commit strategy", in which the project manager prepares for certain possible emergent developments and reserves the means to accommodate them. This requires a pre-selection of issues that should evoke changes of plans and issues that should not. Concerns about safety, for example, should always find their way into the management of terms of reference and planning schedules. In order to keep agents from expressing false concerns as a result of opportunistic behaviour, such arrangements should be combined with countervailing power and incentives.

Koppenjan and Klijn (2004: 162) suggested a form of adaptive management to manage uncertainties in a network environment. They suggested avoiding early fixation on problem definition, furthering substantive variety and favourable conditions for learning and intermediate adaptations when dealing with solutions. Substantive variety largely implies receptiveness to emergent developments. This may be favourable for decision-making, but it is hazardous in the management of complex infrastructure construction projects. This is because managers may fear losing control of costs and implementation time. Substantive variety typically evokes changes in later phases, when they are most difficult to incorporate. Learning and intermediate adaptations can, however, be valuable.

Implementing process arrangements

How to implement process arrangements? Koppenjan and Klijn (2004) presented a few ideas on process arrangements when managing uncertainties in networks. One of them is goal intertwinement. This corresponds to the shared ownership suggested under "incentives". Shared ownership would also be the only way to include the compensation or negotiation that Koppenjan and Klijn (2004) suggested, because it removes the hierarchy among actors. This implies that the principal is unlikely to perceive a need to give in on any core value for the benefit of an agent, unless some form of public-private partnership is being pursued. A principal that is willing to move towards its agents may get valuable information in return. Hazards are involved though. If a principal gives in to agents' interests, it must expect sincere input in return. The question remains whether agents are willing to be so honest. They might abuse the situation with strategic behaviour. Therefore, proper incentives remain necessary and could also help to extend the strategy into more concrete project management efforts, such as joint risk management (cf. Rahman and Kumaraswamy, 2002).

Another suggestion by Koppenjan and Klijn (2004) is to manage the information on which decisions are based by creating substantive variety. This would provide a choice of solutions and depoliticise the ones available. They mentioned a few important conditional issues as follows (Koppenjan and Klijn, 2004: 174):

- *Selection criteria*. Agreements on how to assess proposals should not be based on an *ex ante* formulated, detailed and coherent set of criteria. Uncertainty does not allow for substantiated criteria. Criteria will be amended, adapted and refined under the influence of changing environmental conditions and learning. This plea for receptiveness to emergent developments may seem to conflict with earlier suggestions to make the implementation process, and particularly the outcomes of trade-offs, predictable. But this is not necessarily so. Actors can still make agreements on procedures without laying down rigid criteria on substantive proposals (see also "*how is the selection done?*").
- *Who selects?* Parties' involvement in selection can vary from advising to co-deciding. The principle of joint ownership, comparable to some suggestions made regarding countervailing power and incentives, could be a way of bridging the differences between the actors.
- *How is the selection done?* Agreements are necessary on decision rules, conflict management mechanisms and complaints and appeals procedures. These should, for instance, provide means for actors who do not agree with a proposed solution to counter it.

- *When is the selection made?* There should be enough time for actors to consult others, such as parent companies and independent advisors.

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[1] Respondent Van Gelder mentions this in his reflection on the management of the Souterrain project.
[2] Luft and Ingham, 1951; Stanley, 1991.
[3] The Commonwealth of Massachusetts Senate Post Audit and Oversight Committee, Road blocks to cost recovery, 2004.

10. Conclusions

10.1 Introduction

This chapter looks back at the research questions formulated in Chapter 1. Drawing on Chapter 9's analysis, it formulates answers for each. These refer back to the literature introduced in chapters 2 and 3, while developing new insights on the differentiation, interdependence and uncertainty features of projects. Sections 10.2 and 10.3 answer the research questions. Section 10.4 presents recommendations for improved manageability. Section 10.5 wraps up the findings.

10.2 Bounded manageability and separation of information and decision-making authority

Research question 1 was the following: "what explains the apparent bounded manageability of many complex underground infrastructure construction projects?" This research operationalised this as two subquestions: (1a) "how does bounded manageability emerge" and (1b) "why does bounded manageability emerge" (1b). The aim with these was to provide insight into why in complex projects unplanned events happen, some of which could perhaps, in hindsight, have been avoided.

10.2.1 How does bounded manageability in complex underground construction projects emerge?

Bounded manageability in theory: Six uncertainties

Bounded manageability in projects manifests as unplanned and unforeseen events with a perceivable effect on the project goals. All of the projects studied exhibited these events, despite efforts to the contrary, and these oftentimes took the projects beyond the normal realms of controllability. Chapter 2 established that the roots of bounded manageability lie in various forms of complexity. That chapter then elaborated on those forms of complexity. It concluded that particular aspects of complexity, in particular, Baccarini's concepts of differentiation and interdependence (Baccarini, 1996), are relevant to the management of projects. Likewise, Chapter 3 elaborated on Williams' (1999) addition to theory on uncertainty, both at a high level of aggregation (the concept of the uncertainty gap) and in operational decision-making processes. Summarising, unexpected events originate from the differentiation and interdependence features of a project, which are the result of managerial choices in the face of complexity-induced uncertainties. Six types of uncertainty were identified (Table 10.1).

Table 10.1 The six types of uncertainty.

	Incognition-driven uncertainty		Interaction-driven uncertainty
	Ever-present uncertainty	Potential uncertainty	
Knowable to manager	**Instability uncertainty**	**Incompleteness uncertainty**	**Interpretation uncertainty**
Unknowable to manager	**Inscrutability uncertainty**	**Inconceivability uncertainty**	**Intention uncertainty**

Operationalisation: Occurrences in the cases

To understand "unplanned and unforeseen events with a perceivable effect on the project goals", we must return to the different types of risks and uncertainties discussed in Chapter 3. In the projects studied, events occurred that illustrated uncertainties, but the unexpected events proved manageable. Examples were the challenges faced in Dortmund (medium-sized leakages), in the Herren Tunnel (unexpected boulders in the cutter head trajectory), in Rijswijk (greater inflows of groundwater) and in the Post Office Square excavation (the extra strength needed for a diaphragm wall).

Major deviances. The cases showed a few events where manageability was highly challenged indeed. The most radical occurrences of bounded manageability were these large ones:

- *Souterrain leakage*. The chance of a leakage in the grout arch had been indicated in the risk analysis, but the sponsor/design engineer disagreed with the contractor about the likelihood of such an event. Also, little consideration was given to the difficulty of finding alternatives in case the event did occur. These are issues related to information processing and uncertainty. One could say, however, that this bounded manageability originated from external interdependence. The municipality was dependent on actors in the project environment, which resulted in the early scope expansion to include not only a tram tunnel but also a two-storey underground car park. This expansion increased the complexity of the project and required the technical features that ultimately failed.
- *Randstad Rail conversion period*. Some events that contributed to the reduced manageability of the Randstad Rail conversion period were considered risks individually. But there were also events that did not really fit into the risk analysis procedure, such as the effects of the various scope expansions and external organisational dependencies (e.g., dependence on ProRail and HTM). These

interdependencies indirectly led to difficulties with specifications, though full awareness of these issues only came after mishaps had occurred. In addition, the owner's decision-makers did not consider the cumulative effect of multiple risks occurring when a decision had to be made on the scheduling of the conversion period. This led to limited coordination abilities, rash commissioning and, ultimately, derailments.

- *CA/T project cost escalation*. Part of the escalation of costs was exogenous to the project, beyond the control of the owner's managers. It originated in the relatively open and accessible process that sought to optimise allocation, design and mitigation, but cost increases also resulted. This was partly due to the extensive external dependencies. Inflation was another factor, though this is a general uncertainty that technically would not be categorised as a cost overrun, or as a risk event coming to pass. Still other factors were technical changes, unforeseen site conditions and rectification of completed work. The sum of this conflation of factors was larger than expected, due in part to the owner's internal dependencies on the project management consultant and subcontractors.
- *CA/T project drop-ceiling collapse*. The collapse of the drop-ceiling was an unexpected event because according to specifications the fixtures should have held. This event can be related to various dependencies. Strong wind and the vent system being put on maximum power caused the original drop-ceiling to vibrate, and the drop-ceiling fixture depended on the presence of steel beams in the outer tunnel walls. Cost optimisations were also in play. Strong interdependence occurred with a new, apparently vulnerable fixture system using epoxy that otherwise would not have been chosen. The trade-off made can be related to information processing and uncertainty: engineers and managers who decided to change the design did not understand the full ramifications of their decision.

Typical responses to uncertainty – of which the most common is to acquire more information – do not always lead to more manageability, because responses face dilemmas with a double-bind character: each course of action creates other dilemmas. Eventually every possible response strategy for solving some of the uncertainty creates new uncertainties, introducing new double-bind dilemmas. Manifestation of these uncertainties in the real-life cases studied led to the formulation of seven key dilemmas. Bounded manageability develops as a pattern of manifestation of these manageability dilemmas, possibly even with mutual amplification of the downsides of possible response strategies.

Additional uncertainty-related observations. Other observations on uncertainty can be made from the cases:

- What may be an incompleteness uncertainty for one actor, can be an inconceivability uncertainty for another, depending on their knowledge and familiarity with the technology.
- Interaction-driven aspects can play a role in incognition-driven uncertainties. The windfall in the tendering and contracting in Randstad Rail, for instance (instability uncertainty), eventually contributed to bounded manageability, because the sponsor used it as an opportunity to extend the scope of the project (interpretation uncertainty). Likewise, engineers' inscrutability uncertainty was perceived as potential intention uncertainty, because of the engineers' inability to objectivise their knowledge.
- Uncertainties in external interfaces can feed into internal interfaces. The dependence on specifications for the rolling stock, for instance, became an issue in Randstad Rail through uncertainty in the internal technical interface with the rail specifications. In the Souterrain project the demanding environment caused introduction of the grout arch in the design.
- Uncertainties in organisational interfaces can feed into uncertainties in technical interfaces. ProRail's unwillingness to temporarily provide electricity for the Randstad Rail grid meant that new technical features (power stations) had to be added to the system.
- Uncertainty due to inscrutability (tacit knowledge) can relate to interpretation uncertainty or intention uncertainty (depending on who the owner of the tacit knowledge is). Tacit knowledge cannot be made explicit. It is therefore unobjectifiable and may evoke suspicion among other actors. This can be reflected in other actors' assessments of the input provided by the tacit knowledge owner. In the Souterrain project this was clearly visible in PTC's assessment of the input provided by tacit knowledge owner TramKom related to the grout arch design.
- Instability uncertainties can become instability certainties by repetition. If an operation is to be repeated many times, as with installation of the grout columns, the negative variability beyond the predefined tolerance is statistically increasingly likely to occur.
- Principals may tend to be more occupied with intention uncertainty and agents with incompleteness uncertainty. To both applies that their main concern gets priority.
- Many risks have both instability and incompleteness uncertainty factors. Incompleteness implies that knowledge on probabilities and impacts is limited.

Instability implies that uncertainty remains. If the probability of occurrence is 10%, it cannot be known whether now is the one occurrence in ten in which the risk will come to pass, or if it will be one of the nine occurrences in which the risk does not transpire.

- A combination of instability and incompleteness uncertainties can have an adverse effect on performance. Incompleteness uncertainty may make people less aware of the variability (instability uncertainty) that occurs in work done. It can make the instability uncertainty less understood.
- A substantively strong ownership role mitigates intention uncertainty, but does not necessarily mitigate interpretation uncertainty due to separate decision-making and implementation tasks within the owner organisation.
- Other reduction of instability and incompleteness uncertainties can be expected if good assessments can be made due to ample knowledge. Ability to draw on experience can reduce surprises.

10.2.2 Why does bounded manageability in complex underground construction projects emerge?

A few observations can be made based on the occurrences described above from the studied cases:

- In all occurrences of bounded manageability, except the CA/T drop-ceiling collapse, the ultimate origins lay in the project environment, which impacted the project through external interfaces, both technical and social. Both occurrences of bounded manageability in The Hague and the early cost escalation of the CA/T project can be attributed to the PESTLE factors (political, economic, social, technical, legal and environmental). Chapter 2 used these factors in the operationalisation of external interfaces.
- Most of the above-mentioned bounded manageability events manifested as engineering-related issues (the early cost escalation in the CA/T project being an exception). Engineering issues may seem static and objective, but they regularly originate from PESTLE factors and lead to strong managerial dynamics.
- Eventually, some of the events developed into trade-offs, in which the owners experienced a threat to budgets and schedules through potential strategic behaviour and emergent dynamics. In many cases, the result was decision-making based on a desired process outcome (stability, no changes, completion within time and budget), rather than based on the reality of the day (unforeseen circumstances, occurrences and developments urging for changes). In the Souterrain project, the sponsor did not want to reconsider the engineering design

> when the contractor raised concerns about the grout arch. In Randstad Rail, the sponsor’s manager refused to extend the conversion period when engineers raised concerns about the achievability of the schedule.

This reveals a divergence between the perspectives of the different organisations involved and the reality of managing projects. The origin of this divergence lies in misperceptions of the type of uncertainty one is dealing with. Project organisations, particularly the parts on the owners’ side, seem to focus on a stable project: “business as usual” with few dynamics and no threat to budgets and schedules. The cases suggest that unexpected events and the associated bounded manageability inject strong new dynamics into projects. Stable execution, as per plan, is the exception rather than the rule. Deviations may therefore be perceived as interaction-driven, while they often seem to have an incognition-driven origin. Why does this erratic and to some extent uncontrollable dynamic occur?

One reason why the above-mentioned events were uncontrollable is that their causes and implications occurred at different levels than where the project managers acted in their daily routine. This level of the daily routine is packed in operational decision-making regarding the planning and implementation of the project, as well as in efforts to deal with emerging events. Yet, there are two levels of strategic key dilemmas at which the principal often does not make conscious decisions or does not follow a conscious strategy. Or – if the principal is aware of such strategic key dilemmas – the principal overlooks the link between these dilemmas and operational trade-offs. This is because strategic key dilemmas are only implicitly present in the manifestation of daily events. If the principal makes a conscious decision on these strategic key dilemmas at all, it often does not seem to be done with understanding of the effect on operational decision-making. For example, a sponsor’s conscious decision to ignore input from a specific contractor is pre-framed by other, often implicit choices. Whether or not a manager is receptive to strategic and unobjectifiable input depends on various other dilemmas related to the variety of the actors involved and their interdependence: issues on which organisational dilemmas exist at a different level.

10.2.3 What factors contribute to bounded manageability?

Project organisations and contracts

This research studied cases in which both high manageability and bounded manageability occurred side by side. Considering that bounded manageability is partly the result of limited comprehension and fending off threats to the status quo, an interesting question would be in what circumstances is bounded manageability most likely to take root. The Souterrain and Randstad Rail projects worked with traditional contracts with separate design and construction tasks and outsourced directorship (although in the case of

Randstad Rail this directorship was carried out by a public body and the Souterrain project management was changed after the calamity). The CA/T project was carried out with a project management consultant. The Dortmund Stadtbahn used a traditional contract with an external design engineer and the directorship in the hands of the sponsor. Of the three reference cases, one project (Rijswijk) had a traditional contract set-up with separate design and construction responsibilities, but with strong involvement of the main stakeholder. Next to this, there were two privatised projects: one being a private initiative with a private sponsor (Post Office Square) and one being an outsourced project (Herren Tunnel).

As read above, the traditional organisational configuration with a sponsor, owner and separate contracts for the design engineer and construction contractor has various downsides. There is problematic segmentation in the form of a crucial handover between engineering design and construction. Likewise, the project management consultant configuration used in the CA/T project had a problematic handover between the rough design and detailed design. These handovers often lead to conflict, because they offer opportunity for shifted blame and debated liability. Furthermore, they provide little incentive for constructive integration of information and decision-making authority.

In some situations, segmentation may reduce these kinds of conflict, particularly where the roles of (partial) designer and implementation director are combined. But, this may lead to new conflicts as well. When two tasks with mutually diverging values are combined, the result can be one outshining the others. Also, conflict may spread to roles that would otherwise be unrelated to the conflicting values. For example, doubts about or objections to a design, for instance, from the contractor, might automatically undermine the authority of the director if the director and designer are the same. This potentially harms the director’s decision-making authority. It is valuable to have at least one neutral actor between the diverging values existing in the project organisation. That actor could, if necessary, act as a referee.

Design-and-construct contracts are supposed to remove at least one handover, reducing the segmentation. This reduces conflict, because there is no value variety between the designer and construction contractor. But it does create a strong dependency of the sponsor on that particular contractor. This is an issue because the value variety between contractor and owner still exists. This makes integration of information and decision-making problematic.

Information processing and decision-making

The projects with the smallest distance between information ownership and decision-making authority, for example, Dortmund and Post Office Square, were better manageable than the projects with a larger distance between the two. The problem is not a lack of information, but rather the way information is processed; that is, in the transfer of information from source to decision-maker and adequate interpretation by the decision-maker. Information transferred could be strategically coloured. That could alter the information's purpose from enabling better assessments by the decision-maker to pursuit of the individual interests of the information source (usually the contractor). Interpretation by the decision-maker is then characterised by the heuristics associated with this role. Does the decision-maker assume that the input was strategically motivated? If so, such things as fear and hesitancy play a role in the use of the information. This occurred most in the Souterrain/Randstad Rail project and to a lesser extent in the CA/T project. These cases demonstrated the distrust that can emerge when issues are raised that can threaten budgets and schedules.

Alternative project organisations

The information processing problem was observed mainly in the largest and most complex projects. Size and complexity could indeed explain this issue. Coordination and span of control problems (with involvement of many contractors) are more common in efforts with more unique features and "first-offs" and many interfaces. It could perhaps be considered striking that alternative organisational set-ups, in which the gap between information availability and decision-making authority was a lot smaller, tended to occur in the somewhat more diminutive and less risky projects.

The cases seem to indicate that there are two kinds of projects. First, there are projects in which a public sponsor organisation possesses ample engineering competence itself: the Rijswijk railway tunnel and, to a lesser extent, the Dortmund Stadtbahn. These sponsors could make (or oversee the process of making) their own engineering designs and adequately assess input from other actors, such as the municipality of Rijswijk as a major stakeholder. These sponsors were capable of dealing with the moral hazard that could occur in the form of strategic behaviour. Second, there are projects in which engineering and implementation are outsourced to private parties; the sponsor role is assumed by a usually private organisation. Examples are the Post Office Square and Herren Tunnel projects. In these, the private sponsor either hired contractors but could match their expertise or had a long-term relationship of trust and mutual dependence with the contractor (Post Office Square). Or the contractor assumed the sponsor role based on a concession that included operation, which gave it ample incentive to optimise quality and efficiency (Herren Tunnel). Both cases had in common, by the way, a relatively certain, but at least clear prospect of return on investment.

Why the observed alternatives may be merely pious hopes
Why are the "alternative" organisational set-ups so seldom seen outside the smaller projects? Could they provide a way to improve decision-making and information processing in larger and more complex projects? Here, hypothesising is necessary. The first type (public owner organisation with ample engineering competence), to which we could also add the Dortmund Stadtbahn, seems to have become a relic of the past. Engineering departments in public organisations have been privatised in many places. We saw this in the Netherlands, in the privatisation and splitting up of the NS after the Rijswijk tunnel project as well as the changing role of Rijkswaterstaat just before the Souterrain and Randstad Rail projects. We also observed it in the United States, with the extensive dissolution of the Massachusetts DPW prior to the CA/T project. The Stadtbahnbauamt of the City of Dortmund was quite unique in that sense. It is unlikely that the future will see drastic change in this trend.

The reason why we do not see large and complex projects of the second type (private management of the entire project) may lie in the risk adverseness of private parties. Many public institutes that are involved in project management may seek to privatise risky projects with the thought that the actor most capable of bearing a risk should be made responsible for it, or at least that risks can be shared. But this, in fact, clashes with contractors' objective of responsible (i.e. safe) business management, particularly in an economy that places construction firms under severe market pressure. So far, very few of the largest and most complex projects – at least those in urban environments – have had a clear prospect of return on investment, which would enable BOOT type contracts. The CA/T project changed in this respect during implementation, when ownership passed to the Massachusetts Turnpike Authority. But it is unlikely that the project will recover all costs incurred. Moreover, the transition raised new problems, as turnpike users up-state were loath to pay for massively expensive infrastructure that they rarely used. Moreover, unlike private parties, public sponsors can settle overruns in other budget items. This makes transferring risks through project privatisation unlikely.

10.2.4 Resume

The main characteristics of bounded manageability can be summarised in a few key observations from the research:

- Bounded manageability occurs because trade-offs on project definition and operational issues are made at different levels. There is a pivotal level where organisational features can be tweaked which can have an important impact on how trade-offs are made. But at that particular level, trade-offs are generally made with within-level characteristics in mind and without consideration of interrelatedness with trade-offs at other levels.

- The typical tension here occurs in matching information processing with decision-making.
- Alternative project set-ups seem to work for less complex projects, but are probably not transferrable to more complex ones.

10.3 Empirical bounded manageability

This section revisits the second research question: "what can be done to respond to the boundedness of manageability in projects?" If we accept the assumption above, that a return to the era of large public engineering departments is unlikely and perhaps also undesirable (because it requires substantial public funds and provides no guarantee of flawless implementation), and if we also consider it unlikely that private parties will change their attitudes regarding risk and prospects of return on investment, a way out can nonetheless be found in two directions. First, we need to better understand the fundamental dilemmas facing the project manager in complex projects and the patterns that interrelated dilemmas form. Second, the conditions in which decision-making and project implementation take place need to be set in such a way that the downside effects of the dilemmas can be mitigated or the dilemmas can be shared.

10.3.1 Recognising bounded manageability patterns in the common project management dilemmas

Chapter 9 demonstrated that the occurrence of bounded manageability in projects does not manifest in just one decision which may seem to have led to a certain observed outcome. As indicated in the previous section such a decision in fact tends to be a manifestation of a fundamental dilemma on which only implicit trade-offs are made. Conditions and context also play important roles, and these are to a considerable extent defined by other fundamental dilemmas and accompanying trade-offs. The analysis presented thus far has made these dilemmas more explicit, as well as the relationships among the dilemmas.

The dilemmas

The framework for identifying the key dilemmas was set out in chapters 2 and 3. The concepts of complexity (differentiation and interdependence) and uncertainty provided the starting point for the analysis of bounded manageability. While the literature examined in those chapters suggested that uncertainty follows mainly from the complexity of a project, the case studies suggest that bounded manageability develops to a considerable extent through an interaction between uncertainty and complexity. Uncertainty, after all, contributed to complexity in the projects studied.

Project definition level: The uncertainty gap. The uncertainty gap is a common phenomenon in complex projects. This dilemma is positioned at the project definition level. The uncertainty gap is defined as the gap between the information required to bring the project to a satisfactory completion and the information available within the project organisation (Galbraith, 1977). In the practice of managing complex projects this uncertainty lies not only in a possible competence or knowledge shortfall, but also in the occurrence of "unknowns" and the fact that managers do not know which risks will actually transpire. That makes the relevant dilemma the following: should, for manageability reasons, the amount of information required be reduced, or should the project organisation rely on the information flows that will develop in the project?

Project definition level dilemma

Uncertainty gap. If the decision is made to adjust the level of information required to the level of information available in the project organisation, the management of the project becomes a "tamable problem". This can for instance be done by reducing the scope (e.g., functionality) or, in the technical realm by reducing technical interfaces. Once the gap is rendered as small as possible (full closure is impossible due to unknowns), the project should be sufficiently manageable.

The alternative lies in relying on information flows. With information flows, functional optimisation (highest quality) can be achieved. This is problematic for three reasons. First, since knowledge and information invariably fall short of the knowledge and information required, there is usually no way of knowing how much and which knowledge and information are required to fully fill the gap. Second, many manageability problems occur as unknowns, which cannot be eliminated completely. Third, it is in the processing of information and making decisions with it that various dilemmas threaten manageability.

Organisational level: Complexity. Part of the uncertainty gap is defined by the complexity of the task at hand, because this is what determines the challenge. The other part is defined by the way the project organisation tries to meet the demands and deal with uncertainties related to them. The "increasing the information available" strategy is challenged by three fundamental dilemmas related to **complexity** (i.e. differentiation and interdependence; Baccarini, 1996): **segmentation, value variety** and **information asymmetry**. The three dilemmas at this level concern, specifically, the relation between **information processing and organisational configuration and conditions** within the project. They concern strategic trade-offs regarding the organisation of the project and are therefore called the technical level.

Organisational level dilemmas

Value variety. Should singular or multiple (competing) values be pursued? Multiple values usually arise through the involvement of departments of the client organisation with diverging tasks and through input and information transfer from contractors, external design engineers, interest groups and other stakeholders. Multiple values usually increase quality since more relevant aspects tend to be taken into account in decision-making. This also means, however, that the client may lose some control, because its values do not always remain dominant. It can also lead to many suggestions and claims for changes. If a singular value is attained (usually the client's) control is a lot easier, but valuable input that could safeguard quality might be missed.

Segmentation. Segmentation occurs in the form of handovers between involved parties and interfaces between tasks and roles. Should the number of handovers and interfaces, and with them the number of executing actors (contractors, designers), be large? Or should the number be limited? Segmentation occurs in hierarchy (tiers in the line-of-sight), in scope (subsystems/subprojects) and in time (phases). The trade-off is complicated here, because both a high and a low degree of segmentation could help in attaining the same goals. Having available the multiple specialists that are typically necessary in the more complex projects should improve the quality of the project. Yet, handovers could diminish quality, because no one party may feel responsible for the overall outcome. Segmentation increases the coordination effort, contributing to bounded manageability. Yet, each handover is a point of control for the sponsor.

Information asymmetry. This dilemma deals with the inevitable gap between information and decision-making authority in projects. Five strategies are possible here:

1. Transfer decision-making authority to the information owner.
2. Transfer information to the decision-maker.
3. Integrate the information owner and decision-making organisations.
4. Keep the information owner and decision-making organisations separate, but create redundancy of the information owner.
5. Keep the information owner and decision-making separate, but create redundancy of the decision-making organisation.

All five strategies aim to increase quality. The difference is mainly in the diverging levels of control that can be attained. The level of control increases from alternative 1 to 5. The reason for not always pursuing the higher-control alternatives is cost efficiency.

Project execution level: Information processing and attitude. The directions taken in these dilemmas impact three other dilemmas that, again, come forth from the interrelatedness of the complexity and uncertainty features of a project. But that interrelatedness now concerns dilemmas that affect decisions in project execution. They emerge from the relation between the technical challenges faced in operational processes of project execution, the information processing that results from this and the attitude of the decision-maker, usually the sponsor, in this situation. How to deal with emergent dynamics? How to deal with possible strategic behaviour? How to deal with rationalisation in the assessments that follow from it? At this level, Wynne's (1988) concept of *unruly technology* takes effect. Here, managers are confronted with the situation that technology's rules and standards clash with the daily practice of management in a multi-actor project organisation, in which "practical rules" unwittingly develop. These dilemmas again reflect a desire for quality, but also a fear of losing control. In an attempt to do a good job, decision-makers are led by both their interpretation of the *substance of information* and by the *expected behaviour of the input providers*.

Project execution level dilemmas

Dynamics. Should the sponsor fend off dynamics or be receptive to emergent developments and change? Fending off implies that budgets and schedules can be controlled, but improvements based on emerging developments will not be incorporated. Those improvements could be made if the sponsor is receptive to change, but then control over budgets and schedules might be lost.

Strategic behaviour. Should the sponsor be receptive to or resist potentially strategically coloured input from contractors? Being receptive may mean that the sponsor loses control over possible strategic behaviour and therefore ends up paying too much. But quality rarely suffers as a result of this. On the contrary, this could lead to "gold-plating" and otherwise inefficient spending that will earn the contractor more money. Resisting, on the other hand, means that control is retained in the sense that strategic behaviour will not come into play. But inputs that could be important for high-quality decisions will be excluded too.

Rationalisation. Should the sponsor be receptive to or reject unobjectifiable information? Being receptive may increase quality because all possibly relevant information, regardless of its nature, is included in decision-making. But it does make the sponsor susceptible to strategic behaviour and hunches, which could cause the sponsor to lose control. Rejecting such input excludes potentially "contaminated" input, which ensures greater control. But quality may be compromised due to the possible exclusion of valuable input.

10.3.2 Main drivers in trade-offs

This research suggests that "tacit trade-offs" exist and that they are to a large extent interrelated in the sense that taking a certain direction in one trade-off implicitly sets the conditions for another. For example, trying to solve information asymmetry by moving information to the sponsor makes the sponsor potentially more vulnerable to strategic behaviour and unobjectifiable information.

Scope/quality and control
As in most construction projects, sponsors in the cases studied needed a wide variety of contractors to achieve the scope and quality desired. The requirements set through political processes and the abilities of the client/sponsor organisations were such that segmentation, and with it value variety, imposed challenges to project management. Control was another issue. Control is here considered the ability of the sponsor to keep project delivery on-track (ultimately in terms of cost and schedules), to achieve performance benchmarks within the defined boundaries and to tweak them if necessary. In challenging projects, a tension was observed between pursuit of a maximised scope and high quality and pursuit of control. The two are typically at either end of the dichotomy of dilemmatic choices or strategies. Pursuit of a maximised scope and highest quality implied leaning further towards parties with diverging interests. Likewise, pursuit of strong control implied keeping an arm's length distance from the values and interests of such parties. The two proved difficult to combine.

Control as a main driver closer to operational decision-making
When looking at patterns of occurrences of bounded manageability in the case studies, sponsors appear mainly to have chosen control, the closer one gets to day-to-day decision-making; that is, in all dilemmas at the project execution level. Although decision-makers normally did not sacrifice quality consciously, this tended to be the implication of their control focus in the operational phase.

The picture is more diverse at the organisational level. Many strategies at this level developed during project planning and preparation, unless they concerned reorganisations, such as establishment of the IPO in the CA/T project and the new contract after the calamity in the Souterrain project. The focus on quality seemed a bit higher at the organisational level, since some sponsors actively sought engineering support to solve information asymmetry and some actively sought redundancy in the earlier phases of the projects.

- With regard to segmentation, the image is ambiguous. Handovers provide opportunities for control. Yet, they also imply the presence of different contractors, often for specialisms. The choice for segmentation did not always seem to be made with quality maximisation in mind. In the CA/T case, law prohibited design-and-construct contracts. In the case of the Souterrain, the strict handover between engineering design and construction was a matter of cost efficiency. In Rijswijk, the sponsor had different specialists for design and construction. In Dortmund, the sponsor's expertise included engineering, but not construction.

- Regarding value variety, high segmentation typically leads to high value variety, but the competing values that result from it and which could be useful to safeguard quality, rarely have this effect. In fact, in such a situation the sponsor's values tend to prevail, optimising control, but not necessarily quality. None of the sponsors studied actively sought competing values. Still, they did have influence in some cases. For example, in Rijswijk competing values led to design optimisation. In the Souterrain, a strong sponsor focus on the project environment had a huge impact on the scope and complexity of the project. In Randstad Rail, values clashed between the sponsor's administrators and engineers, though the sponsor's values remained dominant.
- With regard to information asymmetry the image is not clear. Integration does increase the quality of decision-making. But perceptions diverge on whether separating or integrating information and decision-making increases or decreases control. In the CA/T project (IPO) and Herren Tunnel, integration of information and decision-making authority was chosen. But in both cases this was initially done with finances and a smooth process in mind, so not explicitly driven by quality. In other cases we found a separation of information and decision-making authority. Whether information should be transferred to the decision-making authority or vice versa is likewise unclear. A transfer of decision-making authority to the information owner clearly implies a loss of control. But having information transferred to the decision-making authority (owner or sponsor) may have a similar effect. The patterns suggest that if the sponsor does not hedge against potential strategically motivated input at the project execution level, information may be contaminated. After all, the source of the information can share it on its own terms: selective and possibly strategically coloured. Nevertheless, this strategy tends to be chosen with both control (clinging to decision-making) and quality (collecting as much information as possible) in mind. If the sponsor does hedge against potentially strategic information, it can retain control but it may sacrifice quality due to its own poor interpretation and assessment competences. Information gathering seems overvalued as a way for the sponsor to make quality decisions. Integration may provide a perception of control, but the CA/T project's IPO suggests the opposite effect is possible. Redundancy would be a quality safeguard and should help realise control, but delivery performance would be affected by the extra cost involved. It is therefore a matter of weighing the additional investment against the potential cost savings. The sponsor of the Souterrain project initially planned to incorporate redundancy by involving the contractor in the designing. The CA/T project organisation started with a second opinion committee in addition to a project management consultant, which was also a redundancy strategy. The Souterrain sponsor abandoned its goal for

redundancy for efficiency reasons. The CA/T sponsor abandoned it due to new leadership with different views on control and efficiency.

Little consideration of the project execution level upon project definition and vice versa

At the project definition level all owners chose an increase of information rather than reduced ambition. The latter would have been the preferable option to optimise control. The project definition level is predominantly scope- and quality-driven. This became evident, for example, in the scope expansion of the Souterrain project with the addition of an underground car park; in the CA/T project with its numerous tie-ins; in the Dortmund Stadtbahn with the addition of the branch to the north; and in the Randstad Rail project with numerous additions to the system, plus the added rail replacement. All these scope optimisations were approved under political influence and without a clear consideration of their impact at the project execution level. In the reverse direction, in the day-to-day decisions made at the project execution level, the focus on control was strong. Here, however, the implications of decisions on the project's overall ability to meet its original drivers unwittingly became faint.

Weak policy coherence between the organisational and project execution levels

Although the patterns discussed earlier demonstrate the interrelatedness between the organisational and the project execution levels, and the organisational level is the obvious place to configure the project such that it is optimally manageable at the project execution level, in reality coherence between the two levels is often unclear. The trade-offs at the organisational level seem often to be prompted by aspects other than manageability at the project execution level. Segmentation as a characteristic of the project organisation in, for instance, the Souterrain was to a considerable extent a result of political decisions regarding efficiency. Value variety in the Souterrain project was toned down from its initial dominance in the owner organisation's dealings with social actors and environmental factors. With regard to information asymmetry, many examples can be found. The IPO in the CA/T project was established for efficiency reasons (although the CA/T project management also claimed that seamless management was a motive). The plans in the Souterrain for redundant engineering capacity in the design job were abandoned primarily for cost reasons.

Project execution level decisions now seem options-driven and based on rules-of-thumb

In the current operating mode with regard to trade-offs on the identified dilemmas, it appears that a distinction can be made between decisions that are options-driven and those based on rules-of-thumb, or a combination of the two. Though here the literature and case studies provide too little information for definitive conclusions. When options-driven, the available options determine a trade-off outcome. That means the trade-off outcome is not necessarily good, but it is the outcome that seems most favourable among the available options. When based on rules-of-thumb, however, trade-off outcomes reflect the fear of certain mechanisms coming into play in the expected behaviour of other actors. This comes closest to an elaboration of Wynne's "practical rules" that develop in dealing with complex technology.

One of the clearest examples from the case studies in which both occur is in the discussions between the PTC group of the Municipality of The Hague as sponsor of the Souterrain and contractor TramKom. When TramKom aired its doubts about the grout arch design, the municipality waived off its objections on both bases. A design change, first of all, would have had too large an impact on the whole planning (cost and schedules) and the perceived problems could ostensibly be resolved simply with some overdimensioning of the grout columns (an easy engineering solution). These were options-driven decisions. Yet, the municipality in its role as sponsor also feared strategic behaviour, and thus resorted to a rules-of thumb approach. Contractors were assumed to have an interest in claiming additional work and in setting the stage for a later possible denial of liability in case of failures. So it was expected that they might act in accordance. The effect was much the same, by the way. As above, control (lowest chance of overruns, smallest changes to the status quo) seemed dominant.

In options-driven decisions, receptiveness to emergent dynamics seems influenced more by the available solutions than by the need for changes resulting from problems encountered. Receptiveness seems greater when there is room for manoeuvre. Dynamics are fended off when they threaten the status quo, even if there are indications that change might be wise. This often seems to be the case when there is no objectifiable information available supporting the need for change. Hunches and tacit knowledge come off worse in such cases. There is a reluctance to sacrifice the status quo even later on in projects when emergent dynamics results in bounded manageability. This was the case in the Souterrain design alterations (removing a separate water sealant and searching for a solution following the leakage calamity) and in the CA/T ceiling collapse (change from metal to concrete slabs). In the Randstad Rail project, the sponsor was very receptive to change throughout the whole preparation phase, even beyond the design freeze, as opportunities arose. But it became very resistant during implementation, when changes would have resulted in delayed completion, though in the latter case, the necessity, from a manageability point of view, was larger.

In rules-of thumb-driven decisions, it is not necessarily strategic behaviour, but the fear of strategic behaviour that is harmful to projects. Strategic behaviour is difficult to prove, because actors rarely admit it. But even if it did not occur in any of the projects studied, the possibility that strategic behaviour might occur was influential, particularly in the projects in The Hague, for instance, in the decision to use the grout arch and in fending off of schedule changes during Randstad Rail implementation. As a result, even if all input from contractors to the sponsor was transparent and in accordance with due diligence, there was still the possibility that the sponsor would interpret the input as potentially strategic, simply because the principal-agent type of relationship led the sponsor to expect contractors might behave strategically. Therefore, even with perfect transparency among actors, flawed decisions may be made. This relates to strategies and attitudes taken on such issues as segmentation in the project organisation and its environment, the value variety in the organisation and its environment, and the way information asymmetry is dealt with.

Incompleteness uncertainty solutions for instability uncertainties

Some of the main risks that transpired in the studied projects can be related to instability uncertainties, for instance, the unobjectifiable concerns about the tight schedules of the conversion period of Randstad Rail, the possible flaws in installation work of the Central Artery I-90 connector tunnel ceiling and the large number of claims and changes in the CA/T project. However, the strategies for closing the uncertainty gap that these stimulated did not reflect those characteristics. Gathering more information on the critical potential deviances was most typical for incompleteness uncertainties. Although there was no evidence from the cases, this may be because gathering more information is a tangible, objectifiable way to deal with uncertainties. Although it may be costly, it often requires the least effort from the sponsor. Better ways to deal with instability uncertainties could lie at the organisational level of management, particularly in ways to resolve information asymmetry. In addition, there are instability uncertainties that simply cannot be responded to, for instance, because they concern unknowns. The main solutions for these would be large contingencies and reduced the challenge – and hence ambition – in the scope/quality definition.

10.4 Suggestions for higher manageability

Managers can improve manageability of their projects by taking a view on their project that extends beyond their own specified task. A scope that leads to a more manageable project is one that reflects not only demands, but also uncertainties during implementation at the project execution level. This applies particularly to the managers involved in the project definition phase, as they are typically the ones in a position to set the conditions for the project organisation. The forces for balancing scope, quality, time and cost at these two levels work in opposite directions. The project organisation level, in the middle, should be the focal point for absorbing collisions that might occur, notwithstanding the broader consideration of scope, quality, time and cost.

The purpose of improved manageability should not be to prevent options-driven decisions or to make rules of thumb explicit. These heuristics have a function. Attempts to make all rules of thumb explicit could make the process too inflexible to cope with the day-to-day challenges of a complex project. Instead, project managers should set the conditions for higher manageability. To that end, three suggestions can be made for organising the relations between sponsor and contractors such that a higher chance of successful completion is achieved.

What possibilities for improvement could there be if the patterns of dilemmas are so common? The greatest manageability among the projects studied seemed to occur in two rather unusual organisational set-ups (the Herren Tunnel and Post Office Square projects) that appear to offer little prospect for most complex projects. First, a sponsor could choose to reduce the uncertainty gap at the project definition level, by reducing the challenge, rather than acquiring more information. The sponsor would then not be subject to the adverse effects of the typical multi-actor network characteristics that project organisations have. The reality, however, is that owners and the sponsors they work for rarely accept scope reductions, and attempts to use less challenging technologies or designs are often bound by circumstances (a simpler technology or engineering design cannot do the job) or budgetary considerations (the cheapest technology or design should be chosen).

Cross-level management

The findings from this research suggest that quality and control should be better balanced. This implies that improvements might be achieved with a stronger influence on control at the project definition level. The ability to control the work at the project execution level should be taken into account ideally from project initiation. But it should certainly come into play at the project definition stage, when political demands are translated into a project scope. Managers in the project definition process therefore need to ask certain questions. How many emerging issues and associated dynamics are to be expected (it is less important what exactly the emerging issues might be)? What capabilities does the sponsor have to assess input on complex issues? What behaviour of other actors, such as contractors, is to be expected? What uncertainties will be faced in responding to risks, incompleteness or instability? Even at that early stage, it might appear better to adjust the scope of the project to the capabilities of the organisation than the other way around.

Likewise, managers at the project execution level should realise that the choices they make in operational decisions are structured to a considerable extent at higher levels of management. This works through the way the project organisation was set up, the way the sponsor deals with value variety and the tactics used to resolve information asymmetry issues, possibly extending all the way to the focus in project definition (the defined scope and quality).

The options sponsors have for tactically organising the project may have more value when they are more clearly related to control at the project execution level. The choices at the organisational level now often reflect political views and demands, not the realities of project execution.

The organisational level

Coupling manageability to uncertainties provides a clearer view on how uncertainties can best be addressed. Incognition-driven uncertainties define the uncertainty gap from the requirements side: what information is required to complete the project successfully. They can therefore best be addressed on that side as well: in the composition of the system in terms of differentiation and interdependence. Interaction-driven uncertainties relate mostly to the project organisation mandated to create these systems. They are therefore best addressed in the composition of that project organisation, which is done at the organisational level.

The organisational dilemmas can define the level of success possible in keeping the project manageable at the project execution level. For example, consider strategic behaviour as an uncertainty factor. External value variety, which may be introduced at the project definition level, can evoke strategic behaviour, generate emergent dynamics and evoke unobjectifiable input. Segmentation can present opportunities for strategic behaviour. Redundancy as a means to respond to information asymmetry can neutralise strategic behaviour by providing competing values. Resolving information asymmetry by moving information to the decision-maker can introduce strategic behaviour and urge a modus operandi for possible unobjectifiable input.

Some organisational optimisations can be implemented to resolve this, neutralising the adverse effects of a dominant pursuit of quality or control. There are three main categories of such optimisations:

- *Incentives*. These should discipline the contractor in its information provision. They can compensate for a lack of sponsor control if the sponsor opts for quality.
- *Countervailing power*. This should discipline the sponsor in its interpretation of information. It can compensate for quality problems if the sponsor lets control prevail.

- *Process arrangements*. These can prevent conflict and unpredictability, particularly in information-processing dilemmas.

How to organise these? Incentives are typically organised in contracts. Contract arrangements should be chosen by balancing scope/quality, on one hand, with control in execution, on the other.

Countervailing power can be achieved in the project organisation. It is typically done by hiring experts. With the privatisation of public engineering bureaus, this seems to have lost some popularity, and a full U-turn of the development is unrealistic. But particularly public sponsors seem to suffer from the Dunning-Kruger effect (Dunning and Kruger, 1999). That is, they fail to recognise their own lack of skill in making good trade-offs, because they lack the competence to be aware of their own shortcomings. These sponsors may be incapable of understanding all of the ramifications of their policies.

In other project management-intensive industries, value assurance procedures have an important role in successful project delivery. These procedures could possibly be improved in complex infrastructure engineering projects – which often have a public sponsor – by institutionalising a well-defined role for experts. In industries such as oil and gas, large multinational firms have repeatedly developed major and complex projects in which such procedures are continuous and part of standard operations. This is not normally the case in public infrastructure construction projects, which are typically unique endeavours for clients.

It is crucial that the role of these experts be well considered. The key point is that experts must be truly independent, and not involved as stakeholders. According to De Bruijn et al. (2010: 150-152) experts involved as stakeholders are generally considered authoritative, but biased. Independent experts can easily retain a neutral position, but their input may not be considered authoritative. Since stakeholders hold a position in the project, their input may be strategically coloured. Because independent experts have no stake in the process, they are unlikely to treat non-compliance as a crime. The case studies showed examples of both. In the Souterrain project, contractor TramKom was the stakeholder expert. Its viewpoint had to be reckoned with, but was considered tainted due to its possible strategic motivation. Parties like Keller and Horvat were the more independent experts, but their input was easily ignored if it was inconvenient. Likewise, in the CA/T project, project manager B/PB could not be ignored, but it had a position in the project. The experts in the second opinion committee were more independent, but the committee was easily eliminated when a new administration entered office.

In both situations, the right incentives are necessary. In the former case, the stakeholder experts need incentives to provide unbiased input. In the latter case, the sponsor needs incentives to consider input from independent experts authoritative. The former can be arranged through contract forms in which contractors participate in risk-bearing, although, as observed earlier, this is less likely for the most complex and risky projects. The only alternative then seems involvement of independent experts under the condition that the sponsor is sufficiently disciplined to consider that input authoritative. This can be organised in part through process arrangements.

Both countervailing powers and incentives can mitigate the adverse effects of strategic behaviour and contribute to progress in a project. The main factor to be added by process arrangements is agreements on future courses of action. If agreements can reduce unpredictability, the chance of conflict is diminished. Finally, process arrangements can reduce the opportunity for strategic behaviour that could harm the project while also disciplining the sponsor in its interpretation of information.

10.5 Wrap-up

This final section brings together a few overarching conclusions that can be drawn from the study, addressing implications for real-life project management.

10.5.1 Manageability dilemmas

Occurrences of bounded manageability and the management of uncertainty in the studied projects revolved around a few key dilemmas, as discussed above. Based on the literature, the case studies and the analyses, some general observations can be made on occurrences of bounded manageability in projects.

First, dilemmas occur at three levels: the project definition level, which concerns general strategy regarding uncertainties in relation to project ambitions; the pivotal organisational level, which concerns differentiation and interdependence features of project organisation strategies; and the level that concerns operational management, meaning the everyday processing of information and related to the attitudes of individual actors.

Second, trade-offs on dilemmas generally take place between two extremes: attempts to attain manageability by a multi-actor effort versus attempts to attain manageability by a solo effort of the principal (i.e. owner). Both strategies have upsides and downsides. A multi-actor effort enriches the project. It enables the project organisation to benefit most from diverse sources of knowledge and creates the best conditions for competing values. This is likely to produce optimal solutions, but with relatively limited control of manageability (cost and schedule). A solo effort concentrates power in the sponsor, which selects the values and input that will be included, therewith retaining all control. This is likely to make control over costs and schedule easiest, but with suboptimal outcomes on features and functionality.

Third, there is no right or wrong way to enter the dilemmatic trade-offs. No matter which direction is chosen, there will inevitably be upsides and downsides. Whether a certain direction leads to bounded manageability will depend on the mutual relations with other dilemmas. A balance between the two could work, without necessarily finding an equilibrium between the extremes, but instead compensating a strategy on one dilemma with that on another.

Fourth, the three levels are strongly interrelated. However, the implications of strategies and attitudes at one level for the other levels are seldom systematically considered. In project definition, when the focus is on scope maximisation and quality, the implications of decisions for manageability at the project execution level often go unconsidered. In the reverse direction, in day-to-day decisions at the project execution level, the focus on control is often strong. Here, however, the implications of decisions on the project's overall ability to meet its original drivers unwittingly become faint. Even between the organisational level and the project execution level, coherence in attitudes was not always evident. The political reality often had a stronger influence on segmentation, values and attempts to overcome information asymmetry than the effects such tactical choices would have at the project execution level.

10.5.2 Patterns connecting the three levels of dilemmas

The three dilemma levels are interrelated. The focus at the project definition level can ultimately influence the focus at the organisational and project execution levels. For example, if external demands push project sponsors toward scope and quality maximisation, this often makes a project more complex and challenging, increasing the uncertainty gap. At that point, typically in the early stages of the project (initiation, preparation), implications for project manageability do not play a dominant role in trade-offs. The levels seem to take different views on the potential and the need for control. The need for these is often unwittingly overcompensated in later phases and at other levels. Operational dilemmas occur when the complexity created in the early stages manifests in emerging developments and possibly conflict. The organisational dilemmas play a pivotal role here. The tendency to increase the complexity of a project at the front-end, creates a larger dependence on information processing, which ultimately takes place at the project execution level. So, higher-level dilemmas are set with little consideration for lower-level dilemmas. Lower-level dilemmas are set without understanding how higher-level dilemmas structure the choices available.

10.5.3 Recommendations to the sponsor or owner

All of the projects studied demonstrate the enormous influence of external factors on planning and engineering design. The Souterrain in The Hague evolved from a tram tunnel to a three-storey underground structure with a car park. The CA/T project was strongly influenced by social claims and mitigation promises. The Dortmund Stadtbahn Tunnel got an important addition in the preparation phase with a tube to the north, and so forth. This study shows that the effects of these factors extended all the way to operational decision-making. The addition of the car park to the Souterrain, for instance, made the implementation a lot more complex from a technical point of view, ultimately leading to design features that required difficult technical trade-offs, to disagreement between sponsor and contractor and ultimately to technical failure.

There are many links in the chain from political decision-making to operational project management. The impact that external factors – earlier identified using the PESTLE acronym – have at the highest level of political decision-making can be dealt with at the project definition and organisational levels, before they affect operational management. The uncertainty gap should be considered at the project definition level, as in the political decision-making external factors are most visible. A decision to reduce the uncertainty gap by decreasing the information required – i.e. toning down ambitions – would be a clear act to cope with external factors from a manageability viewpoint. Such acts in a situation where the choice has been made to increase the available knowledge and information at the project definition level, would require fundamental considerations at the organisational level, to make the project as manageable as possible at the project execution level.

In reality there appears to be a time factor in the implicit trade-off between quality and control. In the early phases of initiation and preparation, ambitions and political realities play the largest role. Here the realities of implementation, particularly the project execution level dilemmas, are far away and generally ignored. This results in a strong need for control in the implementation phase, at the project execution level. Here the political realities of the early phases will likely generate high technical complexity with manageability problems as a result, unless remedial measures are taken at the organisational level. Improvement can be achieved when considerations at the organisational level are made more explicit, and strategies at this level are developed with an eye on the implications of decisions at the project definition level for project execution.

An important message to sponsors of projects would therefore be to behave differently in the early phases of projects. Sponsors should stop pursuing ambitions without considering their implications for manageability at the project execution level. They must also keep in mind what high ambitions will require at the organisational level. This could first be done by making realistic trade-offs regarding the uncertainty gap upon project definition. Closing that gap is impossible, since inherent uncertainties always persist. But an acceptable level of uncertainty can be attained. Although it is difficult to gain a clear view of the size of the uncertainty gap, it is possible to determine the implications involved, by acquiring the knowledge and information to deal with the uncertainty. Public-private partnerships may be helpful, but it is unrealistic to expect very large transfers of risk to the private sector without clear gains for the private parties. In the largest and most complex projects, large private risk-bearing is unrealistic. Apart from consideration of the organisational dilemmas, reducing the uncertainty gap by adjusting project ambitions to capabilities instead of the other way around should be considered.

A hypothesis for future research could be that sponsors consider projects and their organisations in terms of management, rather than manageability. Management focuses on linking tasks to actors and the planning of work in terms of cost and schedules. Manageability is a more abstract concept and concerns the project organisation's capabilities to keep the project under control in the face of emerging developments and other uncertainties.

Appendix I: References

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Appendix II: Interviews and site visits

Name	Relevant affiliation
Chapter 5 Souterrain/Randstad Rail	
L. Alferink	Project director Projectgroep Tunnels Centrum, municipality of The Hague (from start until 1996)
M. van Asch van Wijk[1]	Coordinator switches and safety system Project Organisation Randstad Rail, municipality of The Hague
J. van Beek	Project manager Bouwdienst Rijkswaterstaat
H. Blaauw	Customer director Alstom Nederland
J. Bol	Project director Souterrain for TramKom (from Ballast-Nedam) until 2001, member of the board of directors of TramKom v.o.f. (2001-2004)
K. Brons	Geotechnical engineer for HBG, adviser to Allianz
J. Couvreur	Manager Infrastructure department HTM (public transport company)
F. Dissel	Business unit manager Siemens Nederland N.V.
J. van Dongen	Project director Souterrain for TramKom (from Van Hattum & Blankevoort) (2001-2004)
R. van Gelder	Project director Projectgroep Tunnels Centrum, municipality of The Hague (1996-2001)
T. Haan	Alderman of Zoetermeer
E. Heijers[2]	Project director Project Organisation Randstad Rail, municipality of The Hague
D. Hengeveld	Project manager electro-technical systems, Project Organisation Randstad Rail, municipality of The Hague
A. Hilhorst[3]	Head of Public Transport Department, Stadsgewest Haaglanden
B. Horvat	Director Horvat & Partners, em. professor of civil engineering at Delft University of Technology
C. Kruyt	Head of Urban Structures department (1995-1998), section director and deputy director City Management department (1998-2002), municipality of The Hague
D. Luger	Engineering consultant at Deltares (formerly GeoDelft and Grondmechanica Delft)
H.J. Meijer[4]	Alderman of Transport, municipality of The Hague (1989-2000)
S. Renzema[5]	Head of Public Transport department, Stadsgewest Haaglanden
S. de Ronde	Project director Souterrain for SAT Engineering
R. Sangen	Section head Transport, Stadsgewest Haaglanden
H. Schous[1]	Safety manager HTM
R. Sirks	Policy adviser Stadsgewest Haaglanden

W. van Spronsen	Project manager Transportation Systems Siemens Nederland N.V.
J. Terband	Project manager BAM Civiele Projecten
F. van Tol	Engineering consultant for Gemeentewerken Rotterdam, professor of civil engineering at Delft University of Technology
P. van der Tuin	Transport planner, municipality of Zoetermeer
H. Vergouwen	Project director Projectgroep Tunnels Centrum, municipality of The Hague (2001-2004)
E. Verroen[6]	Project manager conversion, testing and proofing period, Project Organisation Randstad Rail, municipality of The Hague
A. Verruijt	Em. professor of civil engineering at Delft University of Technology
J. van Vliet[3]	Project manager, Directorate General Passenger Transport, Ministry of Transport and Water Management (now Ministry of Infrastructure and the Environment).
E. Vols	Head of project implementation engineering bureau, municipality of The Hague
J. Wendrich[7]	Project manager Souterrain for SAT Engineering
P. van Woensel[3]	Alderman of Transport, municipality of The Hague (2006-2007)
G. Wolzak	Manager terms of reference Project Organisation Randstad Rail (from Movares)
J. Wortel	Director City Management department, municipality of The Hague (1998-2007)
R. de Zutter[1]	Safety manager Randstad Rail, Stadsgewest Haaglanden
Chapter 6 Central Artery/Tunnel Project	
M. Bertoulin[8]	Area manager for Bechtel/Parsons Brinckerhoff, Central Artery/Tunnel Project management
A. Fanton	Executive director Central Artery Environmental Oversight Committee
R. Garver	Boston Redevelopment Authority, City of Boston
J. Gillooly	Executive director Central Artery/Tunnel Project coordination team, deputy commissioner Boston Transportation Department, City of Boston
F. Johnson	Traffic coordinator, Boston Redevelopment Authority, City of Boston
M. Lewis	Project director Central Artery/Tunnel Project (2001-2005)
W. Lindemulder	Central Artery/Tunnel Management design and architecture department, Massachusetts Turnpike Authority
D. Luberoff	Professor Kennedy School of Government, Taubman Center for State and Local Government, executive director of Rappaport Institute, Harvard University
F. Moavenzadeh	Professor of Civil and Environmental Engineering, Massachusetts Institute of Technology
T. Nally	Planning director Artery Business Committee
T. Palmer	Reporter on the Central Artery/Tunnel Project for Boston Globe (1993-

	2001)
F. Salvucci	Secretary of Transportation of the Commonwealth of Massachusetts (1975-1978, 1983-1990), senior lecturer and senior research associate at Massachusetts Institute of Technology
W. Tuttle	Engineer Central Artery/Tunnel Project, for Massachusetts Turnpike Authority
R. Weinberg[9]	Chairman of the Massachusetts Port Authority (during Dukakis governorship, until 1991), co-founder of MoveMass
M. Wiley	Program manager Central Artery/Tunnel Project for Bechtel/Parsons Brinckerhoff
J. Wright	Deputy project director Central Artery/Tunnel Project
F. Yalouris	Director of design and architecture department, Central Artery/Tunnel Project
Chapter 7 Dortmund Stadtbahn	
A. Fischer	Project manager, Stadtbahnbauamt Dortmund
C. Genick[10]	Bezirksregierung Köln (on finance and oversight by Ministerium für Bau- und Verkehrwesen, Landesregierung Nordrhein-Westfalen)
J. Harmuth	Engineer Installations, Stadtbahnbauamt Dortmund
B. Herrmann	Manager Planning Department Stadtbahnbauamt Dortmund
H. Mämpel	Engineer Ingenieursbüro Maidl + Maidl
C. Peter	Engineer Ingenieursbüro Maidl + Maidl
R. Porwoll	Planner, Planning Department, Stadtbahnbauamt Dortmund
B. Sauerländer	Site engineer Stadtbahnbauamt Dortmund
B. Schaefer[11]	Engineer construction joint venture Ostentor (Wayss & Freytag)
A. Schmitz[11]	Construction manager construction joint venture Ostentor (Wayss & Freytag)
H. Sieberg	Manager Preparation Department, Stadtbahnbauamt Dortmund
W. Voβ	Manager Implementation Department, Stadtbahnbauamt Dortmund
Chapter 8	
Rijswijk railway tunnel	
K. Brons[12]	Geotechnical engineer for HBG
B. Keizer	Manager project communication, NS Railinfrabeheer
F. Lether[13]	Project manager Articon (now Arcadis)
A. den Ouden	Project director KSBN (Strukton)
K. Peters	Project leader Holland Railconsult (formerly consultancy department of Dutch Railways; now Movares)
F. van Tol[14]	Civil engineering consultant Gemeentewerken Rotterdam, professor of civil engineering, Delft University of Technology
G. Versteegh	Project leader municipality of Rijswijk

Post Office Square project Boston	
K. Maffucci	Manager Friends of the Post Office Square Trust
S. Muirhead	Boston Redevelopment Authority, City of Boston
R. Weinberg[15]	President Friends of the Post Office Square Trust
Herren Tunnel Lübeck	
J. Arndt	President Herrentunnel GmbH & Co. KG
M. Ehmsen[16]	Member of the executive of GTU Ingenieursgesellschaft
F. Matthias	Financial manager Herrentunnel GmbH & Co. KG
R. Otzisk[16]	Project engineering Emch + Berger Projekt- und Baumanagement GmbH

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- Railway tunnel Rijswijk: private visit during operation.
- Post Office Square: private visit during operation, 1 February 2004.
- Herren Tunnel: with M. Ehmsen and R. Otzisk during construction, 29 June 2004.

[1] Conducted by H. van der Voort.
[2] Interviewed twice, with J. Koppenjan.
[3] With J. Koppenjan
[4] Interviewed twice, once by telephone.
[5] Interviewed twice, once with J. Koppenjan.
[6] With W. Veeneman.
[7] By e-mail.
[8] Including site visit.
[9] Combined with interview for Chapter 8.
[10] By email.
[11] Including site visit.
[12] Combined with interview for Chapter 5.
[13] Interviewed twice.
[14] Combined with interview for Chapter 5.
[15] Combined with interview for Chapter 6.
[16] Including site visit.

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Reports, communications and legal documents

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Souterrain

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Executive summary

Bounded manageability (Chapter 1)

Many complex infrastructure construction projects appear difficult to manage, particularly if they have underground components. Research on the persistent problem of poorly performing infrastructure construction efforts has so far focused mainly on two areas: project appraisal and project management. The former considers poor performance (particularly cost overruns) to occur due to the strategic behaviour of parties with an interest in the projects being developed, such as politicians and engineers. The most prominent authors in this field even state that other explanations are invalid, as in every new infrastructure construction project improvement over time would be expected, which has not occurred. The latter focus, project management, proposes tools for better planning and controlling projects. This field has taken techniques from civil engineering (construction methods), economics and finance (net present value method, cost and schedule performance indices) and law (contract management) to improve the performance of projects. From this perspective it could be suggested – contrary to the conventions of the former field – that the time and cost performance of projects has not significantly improved because the challenges placed on managers by the increasing complexity of projects has sometimes outpaced managers' increased capability to deal with them; or at least kept a phase difference intact. This implies that there is an inherent difficulty in managing projects, which in this study is called *bounded manageability*. It has three typical features of which one or more can occur:

- *Limited monitorability*. This refers to managers' ability to understand what is going on. Do managers, for example, notice when deviances occur?
- *Limited predictability*. This is the extent that managers can foresee the effects of their actions. Do they have a full view on all the possible (possibly cascading) effects of a decision?
- *Limited controllability*. This regards managers' ability to steer developments. Will interventions have any effect and if so, will it be the intended effect?

To understand bounded manageability and consider possibilities for improving the inherent manageability of projects, it is important to understand why projects have limited monitorability, predictability and controllability. This results in the following research questions:

- What explains the apparent bounded manageability of many complex underground infrastructure construction projects?

- How does bounded manageability emerge?
- Why does bounded manageability emerge?

- What can be done to improve manageability?

Complexity (Chapter 2)

The first step of this research was to understand complexity in complex infrastructure construction projects. In essence, such projects are an interaction between an organisational system (e.g., sponsor, owner, contractors, engineers and consultants) and a technical system (the artefact to be created, as well as, e.g., abutting structures and the surrounding soil). The organisational system is where decisions are made on the development of the technical system. Complexity can then be defined as the level of differentiation and interdependence in the organisational and technical systems. The greater the differentiation and interdependence in the technical system to be developed, the greater typically the differentiation and interdependence of the organisational system. After all, for greater challenges, more specialist actors will be required to fulfil the tasks, and they will also be more dependent on each other's particular specialisms. Still, although the organisational system can grow in accordance with the technical system, this does not mean that bounded manageability can be entirely eliminated. There is a third dimension – one that that lies at the core of bounded manageability – which is the uncertainty that is inherent in projects. This uncertainty has been analysed further in chapter 3

Uncertainty (Chapter 3)

This research distinguished six types of uncertainty. These were categorised based on whether they are incognition-driven or interaction-driven. Among the incognition-driven uncertainties, a division was made between uncertainty that is ever-present and that which is potentially present, and whether uncertainties are knowable to the managers concerned. Table ES1 presents the six types of uncertainty.

Table ES1: The six types of uncertainty in complex projects.

	Incognition-driven uncertainty		Interaction-driven uncertainty
	Ever-present uncertainty	Potential uncertainty	
Knowable to manager	**Instability uncertainty** (aleatory uncertainty, i.e., stochastic uncertainty and parametric variability)	**Incompleteness uncertainty** (epistemic uncertainty as a result of incomplete information)	**Interpretation uncertainty** (sponsor-instigated deviations in assessment and decision-making)
Unknowable to manager	**Inscrutability uncertainty** (inscrutability uncertainty)	**Inconceivability uncertainty** (black swan events)	**Intention uncertainty** (strategic behaviour)

All these uncertainties represent, in essence, a gap that occurs between the information required to fulfil the tasks required to successfully complete the project and the information that is available to the project organisation. Attempts to keep a project manageable typically focus on acquiring more information. This strategy has limitations though. These relate to multi-actor interests and bounded rationality problems.

Empirical research (Chapter 4)

To understand the influence uncertainties have on the manageability (and ultimately the performance) of projects, explorative, inductive case-study research was carried out on actual infrastructure construction projects. The projects examined were, specifically, at least partly underground and executed in an intensively used environment. These criteria ensured that the projects studied had high levels of differentiation and interdependence, i.e. complexity, through for example, interfaces with the soil and the intensively used environment, such as abutting structures and heavy traffic. Three projects from three different countries were extensively studied: Randstad Rail/Souterrain in The Hague (the Netherlands), the Central Artery/Third Harbor Tunnel project in Boston (USA) and the East-West Stadtbahn Tunnel project/site S10 in Dortmund (Germany). Also, three smaller projects were studied: a railway tunnel in Rijswijk (the Netherlands), Post Office Square redevelopment in Boston (USA) and the Herren Tunnel in Lübeck (Germany). These latter studies aimed, in particular, to determine whether similar uncertainty and bounded manageability features could also be found in less complex projects and to explore how they were dealt with in these. The whole project trajectories were studied, from initiation and preparation to implementation, scheduling and finances. Some remarkable occurrences of (potential) bounded manageability were mapped based on project documentation and semi-structured interviews. The most influential events in the performance of these projects were described.

Souterrain-Randstad Rail, The Hague, the Netherlands (Chapter 5)

The Souterrain and Randstad Rail projects were functionally highly interrelated, but separately implemented. Both were owned and managed by local or regional public authorities; both were plagued with performance problems during execution. The Randstad Rail project aimed to convert existing rail systems (train, tram, metro) into a new light rail mode. It overran its original completion date and even after completion was plagued by disruptions and derailments. The Souterrain tunnel and car park was designed to accommodate the Randstad Rail's intersection in busy downtown The Hague. This structure experienced catastrophic flooding during construction, due to leakage in a grout layer that was supposed to prevent groundwater from flowing in. The most striking uncertainties found in these projects were the following:

- *Instability uncertainty*. Variability in the repetitive process of constructing the grout layer elements.
- *Incompleteness uncertainty*. Among other, configuration issues in Randstad Rail, requirements for a test-and-trial period for Randstad Rail, version control issues in the project terms of reference.
- *Inscrutability uncertainty*. The worries of the contractors' managers regarding schedule-affecting modifications in the Randstad Rail project and the design of the grout layer in the Souterrain.
- *Interpretation uncertainty*. The Souterrain sponsor's interpretation of input from its main contractor on the grout layer design and techniques for completing the project after occurrence of the leakage.
- *Intention uncertainty*. The possible strategic behaviour of contractors, in Randstad Rail to extend the time available to do the work and in the Souterrain to evade liability for a possible grout layer failure.

Central Artery/Tunnel project, Boston, USA (Chapter 6)

This project concerned construction of a third tunnel under Boston Harbor and reconstruction of the old Central Artery highway in central Boston. Public authorities were the owners of this project, and a project management consultant was hired to manage project preparation and implementation. Construction was plagued by skyrocketing cost overruns, and after completion a technical problem revealed itself when a drop-ceiling fixture gave way. The resulting ceiling collapse crushed a car, killing a passenger. The main uncertainties in this project were the following:

- *Instability uncertainty*. Inevitable variability in the repetitive installation process of the drop-ceiling fixtures.
- *Incompleteness uncertainty*. Epoxy specifications for ceiling fixtures were found to be inadequate and the ceiling fixture design was fallible.
- *Inscrutability uncertainty*. Engineers had expressed doubts about the drop-ceiling fixtures.
- *Inconceivability uncertainty*. The ceiling collapsed, though the managers had not considered this possible.
- *Interpretation uncertainty*. The owner's interpretation of input for decision-making was influenced by his focus on mitigation, despite numerous request for changes from (sub)contractors due to technical reasons.
- *Intention uncertainty*. The project management consultant oversaw its own designs and work.

Stadtbahn, Dortmund, Germany (Chapter 7)

This project concerned the phased construction of the underground sections of an urban rail system. The East-West Tunnel was the third and final main section. The S10 site was the final section of that third tunnel, completing the underground stretch in the centre of Dortmund. The project was managed by local authorities and built in phases to match the capacities of the sponsor department and the availability of budgets. The project went through a sizable change in its early phases: an additional tunnel branch was added and ultimately built by a different contractor than the one responsible for the original branch. Implementation, nonetheless, went rather smoothly, without major setbacks. The most important uncertainties were the following:

- *Instability uncertainty*. Minor leakages occurred.
- *Incompleteness uncertainty*. Exogenous developments in tram design were incorporated, meaning that completed platforms had to be rebuilt. Part of the trajectory had weak soil conditions, and engineering trade-offs had to be made regarding shotcrete composition.
- *Intention uncertainty*. The contract area for the original branch had to be divided from the branch added later. This created the potential for contractor conflict.

Reference projects (Chapter 8)

The Rijswijk railway tunnel, the Post Office Square reconstruction and Herren Tunnel projects were less complex, though still very challenging technical and organisational feats. Moreover, the sponsor organisations in these projects were well-equipped for their task, either because there was ample expertise in the client organisation (Rijswijk) or because the manager was a private entity, with a strong foothold in the construction business (Post Office Square and Lübeck). Uncertainties in these projects appeared to be much less influential; not just because the projects were less complex (they still had challenging features), but also predominantly because the gaps between the knowledge required and the knowledge available to the sponsor organisations were fairly small. Some observations on uncertainties can nonetheless be made:

- *Instability uncertainty*. Effects of variability could be neutralised in some cases because operations were included in the contract (Post Office Square and Lübeck).
- *Incompleteness uncertainty*. Innovative construction methods (Rijswijk), interdependence with abutting structures (Post Office Square) and tunnelling through an aquifer (Lübeck) were all managed successfully.
- *Inscrutability uncertainty*. The strong involvement of specialists in decision-making gave ample opportunity to make maximum use of their knowledge. All applications were successfully completed.

- *Interpretation uncertainty.* The sponsor role was, in all cases, rather close to engineering knowledge, limiting the potential for flawed interpretation of input.
- *Intention uncertainty*. There was little opportunity or need for strategic behaviour, due to knowledge parity between sponsor and contractor.

Manageability dilemmas (Chapter 9)

The case studies demonstrate that bounded manageability has a strong influence on project performance, as effects of uncertainties in the projects persisted despite attempts to close the uncertainty gap. At the core of each occurrence of complexity in which uncertainty played a role was a set of manageability dilemmas that seemed inherent to the occurrence. Below are some examples of how the occurrences of uncertainty relate to the defined dilemmas.

From uncertainties to manageability dilemmas

Instability uncertainty. Since stochastic uncertainty and parametric variability are inevitable features of projects, an "*uncertainty gap*" exists in every project: there is a gap between the knowledge and information available and the knowledge and information required. Likewise, the amount of *dynamics* may grow, which raises the question whether these should be accommodated. Typically, the greater the ambitions of a project, the larger the gap, because the amount of variability typically grows along with the size of the challenge. Occurrence of instability uncertainty is therefore strongly related to how a project is defined (its scope or functionality, the level of quality sought).

Incompleteness uncertainty. Like with stochastic uncertainty and parametric variability, the occurrence of discrete risk events is largely determined by the challenge that the project definition imposes on the project organisation (*uncertainty gap*). See also the dilemma in the previous paragraph. But in addition, incompleteness uncertainty can emerge during project implementation as a result of particular *dynamics*. Emergent developments can set new challenges for a project organisation. Managers may either be receptive to these emergent developments and change plans (e.g., addressing scheduling and cost control problems) or try to fend them off (rejecting potentially indispensable adjustments).

Inscrutability uncertainty. This type of uncertainty relates to knowledge implicitly available to parties in the project organisation, but only revealed on situational basis. When that happens, it is typically the most informed parties (usually contractors or other agents) that have exclusive access to it. This leads to three dilemmas. The first is *information asymmetry*, which is a typical phenomenon in project organisations; that is, availability of information and authority to make decisions are often vested in different roles in the project organisation. The dilemma concerns how to bring information and decision-making authority together. Furthermore, as tacit knowledge is typically revealed only on a situational basis, its asymmetry may not be explicitly addressed when considering ways to deal with information. Second, implicitly available knowledge is generally revealed when particular *dynamics* arise. Many developments emerge in the course of agents' work, and the agents closest to operations typically have the most knowledge and information on these developments (e.g., how to deal with diverging soil conditions where a contractor is working). The dilemma is whether to embrace these dynamics or to fend them off. The third dilemma is that this information is seldom objectifiable *(rationalisable)*. It concerns unwritten, not explicit knowledge and for that reason is easily disputed. The choice is then whether the decision-maker receiving input on the basis of tacit knowledge will accept it, or fend it off. The advantage the tacit knowledge owner has relative to the decision-maker can be used strategically. Therefore this uncertainty is often strongly related to intention uncertainty.

Inconceivability uncertainty. This type of uncertainty expresses the greatest loss of control, but was rather rare in the cases studied. Where it did occur, the typical *"I knew it all along"* reaction did not seem entirely uncalled-for. There were clues that engineers in agent positions doubted some of the technical solutions adopted, but they were overruled by higher-level managers, because receptivity to their doubts would have compromised other values, such as cost control. The root causes of inconceivability uncertainty lie in the way a project is defined and the primary trade-offs. As under instability uncertainty, these factors determine the size of the *uncertainty gap*; where the dilemma is whether to tailor knowledge to ambition or vice versa. Although one cannot plan on black swans, due to their specific nature, the uncertainty gap does determine to some extent the vulnerability and resilience with regard to black swans. They typically lead to a particular dynamics for responding to negative events in a project.

Interpretation uncertainty. This type of uncertainty results from the divide between the principal or main decision-maker and agents, which carry out the principal's policies. Delegation of tasks comes with a few dilemmas. First, how *segmented* will the project organisation be? High segmentation means that many specialisations and handovers will be needed. Both drive interpretation uncertainty. Second, and related to the first, how much *variety* will be allowed in attained *values*? Third, how will the principal deal with its knowledge and information disadvantage (*information asymmetry*) in relation to the agents? If the typically inevitable *dynamics* occur and the principal has to make trade-offs based on input from agents, it often tries to avoid emergent dynamics, because changes make it more difficult for managers to keep to schedules and budgets.

Intention uncertainty. The essence of intention uncertainty is the problem that agents may behave strategically; that is, in their own interest. This interest may be conflicting with the principal's. The core dilemma for the principal is then what to do about it. A whole series of dilemmas feed into this or relate to tactics for avoiding strategic behaviour: how much *segmentation* should be allowed(linked to the level of control in the hands of the principal), how much *value variety* should be allowed (including values pursued by the agent) and in what way the principal deals with its information deficiency (*information asymmetry*). There are also project-related *dynamics* in which actors pursue or are perceived by the principal as pursuing their own interests (change requests being used or perceived by the principal as an opportunity to claim additional costs); for which one has to decide whether or not to allow them into the project. Finally is the question of what to do with the type of information that is most likely to accommodate strategic behaviour on the basis of the degree to which it can be objectified (*rationalisation*). Fend off or absorb?

Patterns of manageability dilemmas

This study identified seven recurring key dilemmas (Table ES2). The dilemmas have the characteristic of "double binds"; that is, the options are typically dichotomatic, i.e. each with downsides that neutralise upsides. The case studies, moreover, suggest that trade-offs on the dilemmas are rarely made explicitly. More common is for a course of action to emerge without a formal decision having been made, let alone consideration of the dilemmas' interrelatedness. The interrelations between dilemmas result in chains of dilemmas. Courses of action taken in dilemmas can amplify or compensate for the adverse effects of others'. As a result, the level of manageability depends on the pattern of dilemmas that evolves in a project. The dichotomic choices can roughly be categorised based on whether managers pursue manageability as a multi-actor effort or predominantly as a principal's effort.

Table ES2 Manageability dilemmas, the uncertainties they relate to and the dichotomic options for decision policy.

Dilemma	Dilemmatic options	Dominant uncertain-ties	Manageability as multi-actor effort	Manageability as a principal's effort
1. Uncertainty gap	- Increase the information available to the project organisation - Reduce the information required (lowering ambitions)	**Instability** **Incompleteness** **Inconceivability**	**Reduce the information required** *Upside: Less uncertainty* *Downside: Downscaled ambitions or higher cost*	**Increase the information available** *Upside: Attainment of high ambitions* *Downside: Managers unaware of the uncertainty they face*

2. Segmentation	- Separate tasks (accepting handovers) - Integrate tasks (avoiding handovers)	**Interpretation** **Intention**	**Incorporate handovers** *Upside: Optimal use of specialisms* *Downside: Higher handover management and coordination effort and greater chance of conflict*	**Avoid handovers** *Upside: Conflict and liability issues avoided* *Downside: Greater dependence on fewer actors*
3. Value variety	- Accept multiple values - Attain singular values	**Interpretation** **Intention**	**Embrace value variety** *Upside: Checks and balances, substantial enrichment* *Downside: Increased chance of conflict*	**Avoid value variety** *Upside: Control; higher chance of success on that particular value* *Downside: Neglect of other important values*
4. Information asymmetry	Intertwinement - Integrate information ownership and decision-making authority	**Inscrutability** **Interpretation** **Intention**	**Integrate** *Upside: High-quality decisions* *Downside: Strong dependency*	**Separate with redundancy of information owner or decision-maker** *Upside: Diversified sources and countervailing power to decision-maker* *Downside: Loss of efficiency*
	Disentanglement - Transfer information to decision-maker - Transfer decision-making authority to information owner - Create redundancy of information owner - Create redundancy of decision-maker		**Transfer decision-making authority to information owner** *Upside: High-quality decisions* *Downside: Loss of control*	**Transfer information to decision-maker** *Upside: High-quality decisions* *Downside: Interpretation of input might be flawed*
5. Dynamics	- Be responsive to emergent developments - Be resistant to emergent developments	**Incompleteness** **Inscrutability** **Inconceivability** **Interpretation** **Intention**	**Receptivity to dynamics** *Upside: Optimisation* *Downside: Loss of control, higher vulnerability to strategic behaviour*	**Resistance to dynamics** *Upside: Control* *Downside: Inability to respond to emerging developments*
6. Strategic behaviour	- Be receptive to all input, including that which is potentially strategic - Be resistant to input that is potentially strategic	**Intention**	**Receptivity to potential strategic input** *Upside: Maximised information* *Downside: Vulnerability to strategic behaviour*	**Resistance to potential strategic input** *Upside: No possibility for strategic behaviour* *Downside: May exclude valuable input*
7. Rationali-sation	- Be receptive to all input, including non-objectifiable - Be resistant to non-objectifiable input	**Inscrutability** **Intention**	**Receptivity to unobjectifiable input** *Upside: Maximised information* *Downside: Vulnerability to strategic behaviour*	**Resistance to unobjectifiable input** *Upside: No possibility for strategic behaviour* *Downside: May exclude valuable input*

The empirical research suggested that the dilemmas occur at three levels: the project definition level, the project organisation level and the project execution level (Table ES3). Not recognising patterns across the dilemmas and levels can lead to bounded manageability. Trade-offs on each individual dilemma are then made without understanding how the dilemmas are related at the three levels. Setting ambitions particularly high at the project definition level, for instance, can create substantial challenges for management at the project execution level. To maintain control, operational managers may resist emergent developments and fend off non-objectifiable input, because these could lead to uncontrollable time and cost overruns. In doing so, however, they may fend off potentially indispensable input from other actors; throwing away the baby with the bathwater. Understanding these patterns can help project managers develop a manageability strategy. For instance, trade-offs on the dilemmas can be rendered more explicit, and the effects of one chosen course of action on the overall pattern can be considered.

Table ES3 Three levels of manageability dilemmas.

Dilemma	Manageability as multi-actor effort	Manageability as a principal's effort
	Project definition level	
Uncertainty gap	Reduce the information required	Increase the information available
	Project organisation level	
Segmentation	Incorporate handovers	Avoid handovers
Value variety	Embrace value variety	Avoid value variety
Information asymmetry	Integrate	Separate
	Transfer decision-making authority to information owner	Transfer information to decision-maker
	Project execution level	
Dynamics	Receptivity to emergent dynamics	Resistance to dynamics
Strategic behaviour	Receptivity to potential strategic input	Resistance to potential strategic input
Rationalisation	Receptivity to unobjectifiable input	Resistance to unobjectifiable input

A few observations can be made on the basis of the cases:

1. Trade-offs on project definition and operational issues are made at different levels. Hence, manageability-influencing events often occur at a different level than their causes. If managers do not recognise the overall interdependence of the dilemmas, they may not understand the origins of bounded manageability or the potential for bounded manageability to result from their choices.
2. The project organisation level is pivotal. Here is where organisational features can be fine-tuned to impact how trade-offs are made. But at this particular level,

trade-offs seem to be made mostly with within-level characteristics in mind, and without consideration of the interrelatedness with trade-offs at other levels.

3. In decision-making at the project definition level, there tends to be little consideration of the project execution level. At the project definition level, managers seek to match the desired scope, quality, budget and schedules to their ambitions, not to attainability of the conditions and the timeframe in which the project actually has to be implemented.
4. Managers at the project organisational level could address better potential problems at the project execution level. The attitudes of managers at the project execution level can be guided by the steering given to the project organisation regarding segmentation, value variety and the information/decision-making divide, but only if the expected effects at the project execution level are meticulously plotted.
5. The logic of tables ES2 and ES3, in combination with the observations from the cases, suggests that if a manageability pattern develops, the outcome will likely be one of two extremes: a very dominant focus on delivering scope and quality, which could lead to poor performance on budgets and schedules, or a very dominant focus on delivering the project on time and on budget, with a larger chance of poor performance on quality and possibly scope, if overruns have to be compensated for.
6. The lower one gets in the hierarchy, the stronger the focus tends to be on budget and schedule control, probably for the simple reason that these are the variables that are most visible and best measurable and this is what managers are often held accountable for.

Conclusions and recommendations (Chapter 10)

How does bounded manageability emerge?

Following the theoretical framework developed in this study, bounded manageability originates in events that can be categorised as the six uncertainties mentioned earlier. These concern both interaction-driven and incognition-driven uncertainties. Typical responses to uncertainty (the most common response is to acquire more information) do not always lead to greater manageability, because they create a number of dilemmas with a double-bind character. That is, each course of action leads to other dilemmas. While every pattern of response strategies may resolve some of the uncertainty, it also creates new uncertainties through the introduction of new double-bind dilemmas. Examination of these uncertainties in real-life cases led to formulation of seven key dilemmas. Bounded manageability develops as a pattern of manifestations of dilemmas, with dilemmas possibly even amplifying the downsides of other manageability dilemmas.

Why does bounded manageability emerge?

Bounded manageability emerges mainly because in trade-offs managers pay little attention to cross-level patterns of manageability dilemmas. For example, whereas higher levels of complexity and uncertainty may evoke emergent dynamics, they also motivate managers to adopt a stronger control focus, instead of adjusting to these dynamics. This can lead to poor assessments of input for decision-making, and it makes potential strategic behaviour problematic. The potential for strategic behaviour is an issue not just because of – indeed – the strategic behaviour itself, but also because the principal's fears of strategic behaviour determine its attitude in dealing with the uncertainties.

A chosen course of action on one dilemma influences other dilemmas, but these effects are not explicitly considered in the original trade-offs. Many trade-offs are themselves not made explicitly. They tend to occur more as emerging tactics than as conscious strategies. A typical tension here lies in matching information processing to decision-making, which happens in the seven manageability dilemmas identified. The dilemmas are interrelated and, as noted above, chosen courses of action create patterns through the three levels. The two extremes are trying to attain manageability as a solo effort by the principal and trying to attain it as a multi-actor effort. However, consistently pursuing one or the other puts manageability under strain.

The two typical dominant focuses are to maximise scope and quality and to control costs and schedules. At the higher management tiers, and early in a project, ambitions tend to be elevated, though the effects of these high ambitions on the ability to control costs and schedules during project implementation are still implicit at that stage. Trade-offs are rarely made with implementation at the project execution level in mind. During implementation, managers have to employ full sail to deliver on time and on budget.

What can be done to improve manageability?

Managers can improve manageability by taking a view on their project that goes beyond their own specified task. A scope that leads to a more manageable project is one that reflects not only the demands, but also the uncertainties during implementation at the project execution level. This applies particularly to the managers involved in project definition, as they are typically in a position to set conditions for the project organisation. The forces for balancing scope, quality, time and cost work in opposite directions at these two levels project definition and project organisation. The project organisation level, in the middle of the project hierarchy, should be the focal point for absorbing collisions that might occur despite the broader views taken of scope, quality, time and cost.

To compensate for a one-sided focus, more variety in trade-offs could be organised, by actively bringing countervailing powers into play. This way, a scope definition that might be too ambitious for controllable project implementation could be challenged; ideally by an actor unrelated to any of the project drivers or values. In addition, incentives should be carefully organised, particularly since trade-offs are often made implicitly. If, for instance, an agent has incentive to value the common good above its own individual interests, there is little need to be too selective with regard to the objectifiability of input. The project organisation level, with segmentation of the project organisation, value variety and information asymmetry as the main manageability dilemmas, is the pivotal level in the chain of dilemmas. Both countervailing powers and incentives can be organised here. Process arrangements can then work to minimise surprise behaviour by other actors. They could, for instance, come in the form of pre-defined courses of action to take in case of for instance an engineering dispute. This would prevent actors from being swayed by the issues of the day.

Samenvatting

Beperkte beheersbaarheid (hoofdstuk 1)

Veel complexe infrastructuurprojecten blijken moeilijk te managen; vooral als delen ondergronds zijn. Onderzoek naar het hardnekkige probleem van slecht presterende infrastructuurprojecten is vooralsnog vooral gericht geweest op twee gebieden: besluitvorming over projecten en projectmanagement. In het eerste gebied wordt slecht presteren (vooral kostenoverschrijdingen) vooral toegeschreven aan strategisch gedrag van partijen die belang hebben bij de daadwerkelijke ontwikkeling van die projecten, zoals politici en ingenieurs. De belangrijkste auteurs in dit onderzoeksgebied stellen zelfs dat andere verklaringen niet valide zijn, omdat anders naarmate de tijd voortschrijdt verbetering verwacht zou mogen worden. Die heeft zich echter niet voorgedaan. Het tweede onderzoeksgebied, project management, richt zich op de ontwikkeling van instrumenten voor betere planning en controle van projecten. Dit terrein heeft zich toegelegd op ontwikkelingen in zowel de civiele techniek (bouwmethoden), economie en financiën (netto contante waarde, richtlijnen voor kosten- en uitvoeringstijd etcetera) en recht (contractbeheersing) om de prestaties van projecten te verbeteren. Vanuit deze invalshoek kan, in tegenstelling tot de aannames uit de eerste invalshoek, worden gesteld dat prestaties op het gebied van kosten en tijdsbesteding niet significant verbeterd zijn vanwege de uitdagingen waarvoor projectmanagers zich geplaatst zien. Hun groeiende vermogen om met de complexiteit om te gaan, heeft geen gelijke tred gehouden met de toenemende complexiteit van de projecten. Ofwel: het faseverschil tussen beide is intact gebleven. Dit impliceert dat er een inherente moeilijkheid zit in het managen van projecten, die in deze studie *bounded manageability*, of “beperkte beheersbaarheid” wordt genoemd. Het heeft drie belangrijke kenmerken, waarvan er zich één of meer in een project kunnen voordoen:

- *Beperkte controleerbaarheid*. Dit betreft het vermogen van managers om te begrijpen wat er in een project gebeurt. Hebben managers het bijvoorbeeld door als er zich afwijkingen voordoen?
- *Beperkte voorspelbaarheid*. Dit betreft de mate waarin managers de gevolgen van hun handelen kunnen overzien. Hebben ze volledig zicht op al de mogelijke (eventueel trapsgewijze) gevolgen van een besluit?
- *Beperkte stuurbaarheid.* Dit betreft het vermogen van managers om ontwikkelingen sturen. Zullen interventies effect hebben en zo ja, is dat ook het bedoelde effect?

Om beperkte beheersbaarheid te begrijpen en mogelijkheden voor verbetering van de beheersbaarheid te kunnen overwegen, is het belangrijk om te begrijpen waarom projecten een beperkte controleerbaarheid, voorspelbaarheid stuurbaarheid hebben. Dit resulteert in de volgende vragen:

- Wat verklaart de klaarblijkelijke beperkte beheersbaarheid van veel complexe ondergrondse infrastructuurprojecten?
    - Hoe ontstaat beperkte beheersbaarheid?
    - Waarom ontstaat beperkte beheersbaarheid?
- Wat kan er worden gedaan om de beheersbaarheid van deze projecten te verbeteren?

Complexiteit (hoofdstuk 2)

De eerste stap in dit onderzoek was om de complexiteit van infrastructuurprojecten te begrijpen. In essentie zijn deze projecten een interactie tussen een organisatorisch systeem (bijvoorbeeld projectsponsor, opdrachtgever, opdrachtnemers, ingenieurs en consultants) en een technisch systeem (het artefact dat moet worden gecreëerd, evenals bijvoorbeeld omliggende bebouwing en de omringende bodem). In het organisatorische systeem worden beslissingen genomen over de ontwikkeling van het technische systeem. Complexiteit kan dan worden gedefinieerd als het niveau van differentiatie en interdependentie in de organisatorische en technische systemen. Hoe groter de differentiatie en interdependenties in het technisch systeem dat moet worden ontwikkeld, hoe groter veelal de differentiatie en interdependentie in het organisatorisch systeem. Voor grotere uitdagingen zijn immers doorgaans meer specialisten nodig om taken te vervullen en ze zullen sterker van elkaars specialisme afhankelijk zijn. Desondanks kan, ondanks dat het organisatorisch systeem kan meegroeien met de complexiteit van het technisch systeem, de beperkte beheersbaarheid niet geheel worden weggenomen. De kern van beperkte beheersbaarheid ligt namelijk in de onzekerheid die inherent is aan het doen van projecten. Deze onzekerheid is in hoofdstuk 3 verder geanalyseerd.

Onzekerheid (hoofdstuk 3)

In het onderzoek zijn er zes verschillende onzekerheden in projecten geïdentificeerd. Ze zijn gecategoriseerd op basis van of ze worden veroorzaakt door onwetendheid of door interactie tussen opdrachtgever en opdrachtnemer. Binnen de door onwetendheid veroorzaakte onzekerheden is een verder onderscheid gemaakt tussen onzekerheid die altijd aanwezig is en onzekerheid die enkel in potentie aanwezig is.

Tabel S1: De zes typen onzekerheid in complexe projecten

	Door onweetbaarheid veroorzaakte onzekerheid		Door interactie veroorzaakte onzekerheid
	Altijd aanwezige onzekerheid	**Potentiële onzekerheid**	
Kenbaar voor de manager	Onzekerheid door onbestendigheid (aleatorische onzekerheid (bv. stochastische onzekerheid en parametrische variabiliteit)	Onzekerheid door onvolledigheid (epistemische onzekerheid vanwege incomplete informatie)	Onzekerheid door interpretatie (door opdrachtgever geïnitieerde afwijkingen in oordeelsvorming en besluitvorming)
Niet-kenbaar voor manager	Onzekerheid door ondoorgrondelijkheid (Impliciete kennis)	Onzekerheid door onkenbaarheid ("black swan"-gebeurtenissen)	Onzekerheid door intentie (strategisch gedrag)

Al deze onzekerheden representeren in essentie het gat dat bestaat tussen de informatie benodigd om de vereiste taken uit te voeren die nodig zijn om het project succesvol te voltooien en de informatie die de projectorganisatie beschikbaar heeft. Inspanningen om een project beheersbaar te houden richten zich veelal op het verkrijgen van meer informatie. Deze strategie heeft echter beperkingen. Deze hebben te maken met multi-actorbelangen en problemen die verband houden met beperkte rationaliteit.

Empirisch onderzoek (hoofdstuk 4)

Om de invloed te begrijpen die onzekerheden hebben op de beheersbaarheid (en uiteindelijk het succes) van projecten, is een explorative, inductieve case study gedaan naar bestaande infrastructuurprojecten. De onderzochte projecten waren op zijn minst ten dele ondergronds en werden gerealiseerd in een intensief gebruikte omgeving. Deze criteria zorgden ervoor dat de bestudeerde projecten hoge niveaus van differentiatie en interdependentie kenden; dat wil zeggen; complexiteit als gevolg van bijvoorbeeld raakvlakken met de bodem en bijvoorbeeld met omliggende bebouwing en grootschalig verkeer. Drie projecten uit drie verschillende landen zijn uitgebreid onderzocht: Randstad Rail/Souterrain in Den Haag (Nederland), het Central Artery-/Derde Haventunnelproject in Boston (Verenigde Staten) en de Oost-west Stadtbahntunnel/S10-sectie in Dortmund (Duitsland). Er zijn ook drie kleinere projecten bestudeerd: een spoortunnel in Rijswijk (Nederland), de herstructurering van Post Office Square in Boston (Verenigde Staten) en de Herrentunnel in Lübeck (Duitsland). Deze waren er vooral op gericht om vast te stellen of vergelijkbare onzekerheid en beperkte-beheersbaarheidskenmerken ook gevonden konden worden in minder complexe projecten en om te verkennen hoe er in deze projecten mee werd omgegaan. Het hele verloop van de projecten is bestudeerd, van initiatie, voorbereiding en uitvoering tot planning en financiën. De meest opmerkelijke gevallen van (potentiële) beperkte beheersbaarheid zijn in kaart gebracht op basis van projectdocumentatie en semi-gestructureerde interviews met betrokkenen. De gebeurtenissen in de uitvoering van deze projecten die het meest invloed hebben gehad op beheersbaarheid zijn beschreven.

Souterrain-RandstadRail, Den Haag, Nederland (hoofdstuk 5)

De projecten Souterrain en Randstad Rail zijn functioneel sterk aan elkaar verbonden (het Souterrain is onderdeel van RandstadRail), maar werden los van elkaar uitgevoerd. Beide werden beheerd en uitgevoerd door lokale of regionale overheden. Beide werden gekenmerkt door uitvoeringsproblemen. De bedoeling van Randstad Rail was om bestaande spoorsystemen (trein, tram en metro) om te bouwen tot een nieuw lightrailsysteem. De oplevering was vertraagd en na opening werd het systeem geplaagd door storingen en ontsporingen. De Souterraintunnel en parkeergarage werden ontworpen om de doorsnijding van het centrum van Den Haag door Randstad Rail in te passen. Dit bouwwerk stroomde vol water tijdens de bouw als gevolg van een ernstige lekkage in een groutlaag die moest voorkomen dat grondwater de tunnel in stroomde tijdens de bouw. De meest in het oog springende onzekerheden waren de volgende:

- *Onzekerheid door onbestendigheid*. Variabiliteit in het repetitieve karakter van het bouwproces van de groutlaagelementen.
- *Onzekerheid door onvolledigheid*. Onder andere configuratieproblemen in Randstad Rail, onduidelijke eisen aan de proefperiode voor het vervoer op Randstad Rail en versiecontrole van het programma van eisen van Randstad Rail.
- *Onzekerheid door ondoorgrondelijkheid.* Zorgen van managers aan opdrachtnemerskant over wijzigingen in Randstad Rail die de tijdsplanning onder druk zetten en over het ontwerp van de groutlaag in het Souterrain.
- *Onzekerheid door interpretatie.* Interpretatie door de opdrachtgever van het Souterrain van input afkomstig van de hoofdaannemer over het ontwerp van de groutlaag en over de technieken voor voltooiing van het project na de lekkage.
- *Onzekerheid door intentie.* Mogelijk strategische gedrag van aannemers in Randstad Rail om de beschikbare uitvoeringstijd op te rekken en in het Souterrain om aansprakelijkheid uit de weg te gaan voor eventueel falen van de groutlaag.

Central Artery/Derde Haventunnel, Boston, VS (hoofdstuk 6)

Dit project betrof de bouw van een derde tunnel onder Boston Harbor en de herstructurering van de Central Artery-snelweg in het centrum van Boston. De staat Massachusetts was opdrachtgever van het project en een consultant werd ingehuurd om de voorbereiding en uitvoering te managen. De realisatie werd gekenmerkt door enorme kostenoverschrijdingen en na voltooiing openbaarden zich technische problemen toen de bevestiging van plafondplaten in één van de tunnels losliet. Deze vielen op een auto, hetgeen een passagier het leven kostte. De belangrijkste onzekerheden waren de volgende:

- *Onzekerheid door onbestendigheid*. Onvermijdelijke variabiliteit in het repetitieve installatieproces van de bevestiging van de plafondplaten.
- *Onzekerheid door onvolledigheid*. De specificaties van epoxy dat werd gebruikt voor de plafondplaatbevestiging bleken verkeerd en ontwerp van de plafondplaatbevestiging was feilbaar.
- *Onzekerheid door ondoorgrondelijkheid*. Ingenieurs hebben twijfels over de plafondplaatbevestiging geuit.
- *Onzekerheid door onkenbaarheid.* Managers konden zich niet voorstellen dat de plafondplaten los konden laten.
- *Onzekerheid door interpretatie.* Interpretatie van input voor besluitvorming werd beïnvloed door de opdrachtgevers eigen focus op mitigerend beleid voor de projectomgeving, ondanks vele veranderingsverzoeken van aannemers om veelal technische redenen.
- *Onzekerheid door intentie.* De projectmanagementconsultant controleerde zijn eigen werk.

Stadtbahn Dortmund, Duitsland (hoofdstuk 7)

Dit project betrof de gefaseerde bouw van de ondergrondse delen van een stedelijk railtransportsysteem in het Duitse Dortmund. De Oost-westtunnel was het derde en laatste deel. De S10-sectie was het laatste deel van de derde tunnel, waarmee het ondergrondse deel in het centrum van Dortmund was voltooid. Het project werd door de lokale overheid gemanaged en werd gebouwd in fases om het werk te laten aansluiten bij de capaciteit van de verantwoordelijke afdeling van de opdrachtgever en de beschikbaarheid van budgetten. Het project kende al vroeg een belangrijke wijziging toen een extra vertakking aan de tunnel werd toegevoegd, die uiteindelijk door een andere aannemer werd gebouwd dan die van de oorspronkelijk ontworpen tunnel. De uitvoering verliep desondanks vrij voortvarend en zonder grote tegenvallers. De belangrijkste onzekerheden waren de volgende:

- *Onzekerheid door onbestendigheid*. Er deden zich enkele relatief kleine lekkages voor.
- *Onzekerheid door onvolledigheid*. Exogene ontwikkelingen in tramontwerp werden alsnog meegenomen, wat tot gevolg had dat voltooide perrons moesten worden verlaagd. In een deel van het traject was er ook sprake van een zwakke bodem en er moesten ingewikkelde afwegingen worden gemaakt over de toepassing van spuitbeton.

- *Onzekerheid over intentie*. Het contractgebied van de oorspronkelijk ontworpen tunnel moest worden gescheiden van de vertakking die later werd toegevoegd. Het creëerde een potentieel voor conflict tussen aannemers.

Referentieprojecten (hoofdstuk 8)

De spoortunnel in Rijswijk, de reconstructie van Post Office Square en de Herrentunnel waren minder complexe projecten, hoewel ze wel allemaal hun specifieke technische en organisatorische uitdagingen kenden. Bovendien waren de opdrachtgevende instanties goed toegerust voor hun taak, ofwel omdat er voldoende kennis in de opdrachtgevende organisatie aanwezig was (Rijswijk), ofwel omdat de manager aan opdrachtgeverskant een gespecialiseerde private organisatie was, met een vaste voet in de bouwindustrie (Post Office Square en Lübeck). Onzekerheden in de projecten bleken minder invloedrijk; niet alleen omdat de projecten minder complex waren (ze kenden nog steeds hun specifieke technische uitdagingen), maar ook, en vooral, omdat de gaten tussen vereiste kennis en kennis beschikbaar voor de opdrachtgeversorganisaties relatief klein waren. Er kunnen desondanks enkele observaties worden gemaakt over onzekerheden:

- *Onzekerheid door onbestendigheid*. De gevolgen van variabiliteit in tijd en kosten konden in sommige gevallen worden geneutraliseerd doordat exploitatie van de infrastructuur in het contract werden meegenomen (Post Office Square en Lübeck).
- *Onzekerheid door onvolledigheid.* Er was sprake van innovatieve bouwmethoden (Rijswijk), raakvlakken met omliggende bebouwing (Post Office Square) en tunnelen door een (drink)waterhoudende bodemlaag (Lübeck). Deze werden alle succesvol gemanaged.
- *Onzekerheid door ondoorgrondelijkheid.* De sterke betrokkenheid van specialisten in besluitvorming gaf ruime gelegenheid om maximaal van hun kennis gebruik te maken. Alle technische uitdagingen werden succesvol voltooid.
- *Onzekerheid door interpretatie.* De opdrachtgeversrol stond in alle gevallen relatief dicht bij ingenieurskennis, wat het potentieel voor verkeerde interpretatie verminderde.
- *Onzekerheid door intentie.* Er was weinig gelegenheid of noodzaak tot strategisch gedrag vanwege relatieve gelijkwaardigheid van kennis tussen opdrachtgevers en opdrachtnemers.

Beheersbaarheidsdilemma's (hoofdstuk 9)

De case studies tonen dat beperkte beheersbaarheid sterke invloed heeft op het projectresultaat, aangezien de effecten van onzekerheid aanhielden, ondanks pogingen om het "onzekerheidsgat" te dichten. In de kern van elk geval van complexiteit waarin onzekerheid een rol speelde, lag een reeks beheersbaarheidsdilemma's die inherent schenen aan het geval. Hieronder staan enkele voorbeelden van hoe het zich voordoen van onzekerheid verband houdt met de gevonden dilemma's.

Van onzekerheid naar beheersbaarheidsdilemma's

Onzekerheid door onbestendigheid. Omdat stochastische onzekerheid en parametrische variabiliteit onvermijdelijke kenmerken zijn van projecten, bestaat er een *"onzekerheidsgat"* in elk project: er is een gat tussen beschikbare kennis en informatie en benodigde kennis en informatie. Hoe hoger de ambities van een project, hoe groter normaalgesproken het gat, omdat de hoeveelheid variabiliteit normaalgesproken parallel aan de omvang van de uitdaging groeit. Ook de hoeveelheid *dynamiek* kan hierdoor groeien, waarbij de vraag is of daarin moet worden meegegaan. Het zich voordoen van onzekerheid door onbestendigheid is daardoor sterk gerelateerd aan hoe het project is gedefinieerd (de scope of functionaliteit, de verwachte kwaliteit). Het dilemma is hier of de beschikbare kennis moet worden vergroot, of de benodigde kennis verminderd (bijvoorbeeld door het bijstellen van ambities).

Onzekerheid door onvolledigheid. Evenals bij stochastische onzekerheid en parametrische variabiliteit, wordt het zich voordoen van discrete risico's voor een groot deel bepaald door de uitdaging die door de projectdefiniëring aan de projectorganisatie wordt opgelegd (*onzekerheidsgat*). Zie ook het dilemma hierboven. Maar daarnaast kan onzekerheid door onvolledigheid zich voordoen tijdens de uitvoering door bepaalde *dynamiek*. Emergente ontwikkelingen kunnen de projectorganisatie voor nieuwe uitdagingen stellen. Managers kunnen ontvankelijk zijn voor deze ontwikkelingen en de plannen aanpassen (bijvoorbeeld problemen in de controle over tijdsplanning en kosten adresseren) of ze afweren (afwijzen van aanpassingen die mogelijk noodzakelijk zullen blijken).

Onzekerheid door ondoorgrondelijkheid. Dit type onzekerheid houdt verband met kennis die impliciet beschikbaar is voor partijen in een projectorganisatie, maar die slechts op situationele basis tevoorschijn komt. Als dat gebeurt, zijn het meestal de best geïnformeerde partijen (meestal aannemers of andere opdrachtnemers) die exclusief toegang hebben tot die informatie. Dit leidt tot drie dilemma's. De eerste is *informatieasymmetrie*; een typisch fenomeen in projectorganisaties. Dit wil zeggen dat beschikbaarheid van informatie en beslissingsbevoegdheid vaak bij verschillende rollen in de projectorganisatie horen. Het dilemma is hier hoe informatie en beslissingsbevoegdheid bij elkaar moeten worden gebracht. Bovendien, omdat impliciete kennis zich normaalgesproken slechts op situationele basis toont, wordt de asymmetrie wellicht niet expliciet meegenomen als overwogen wordt hoe met informatie moet worden omgegaan. Ten tweede, impliciet beschikbare informatie komt doorgaans aan de oppervlakte wanneer zich *dynamiek* voordoet. Veel ontwikkelingen ontstaan gedurende de werkzaamheden van de opdrachtnemers en de opdrachtnemers die het dichtst bij de uitvoering staan hebben doorgaans de meeste kennis en informatie over die ontwikkelingen (bijvoorbeeld hoe om te gaan met de bodemgesteldheid). Het dilemma is of de projectorganisatie mee moet gaan met deze dynamiek, of hem moet afweren. Het derde dilemma heeft te maken met dat deze informatie zelden objectiveerbaar is (*rationalisatie)*. Het betreft onbeschreven, niet-expliciete kennis en die is daarom gemakkelijk te betwisten. De keuze is hier dan of de besluitvormer, die input op basis van impliciete kennis ontvangt, deze input accepteert of zal afweren. Het voordeel dat de impliciete-kenniseigenaar ten opzichte van de besluitvormer heeft, kan strategische worden gebruikt. Daarom is deze onzekerheid vaak sterk verbonden met onzekerheid door intentie.

Onzekerheid door onkenbaarheid. Dit type onzekerheid behelst het grootst mogelijke verlies van controle, maar het was vrij zeldzaam in de onderzochte cases. Waar het zich voordeed, bleek de typische *"ik heb het altijd al gezegd"*-reactie niet altijd ongefundeerd. Er waren aanwijzingen dat ingenieurs aan opdrachtnemerskant twijfels hadden over sommige technische oplossingen, maar deze werden verworpen door hoger geplaatste managers, omdat ontvankelijkheid voor hun twijfels andere waarden, zoals kostenbeheersing, onder druk zou hebben gezet. De oorzaken van onzekerheden door onkenbaarheid liggen in de manier waarop een project is gedefinieerd en de fundamentele afwegingen daarbij. Evenals bij onzekerheid door onbestendigheid bepalen deze factoren de omvang van het *onzekerheidsgat*. Hoewel in beginsel niet op *black swans* valt te plannen, kan het onzekerheidsgat wel tot op zekere hoogte de kwetsbaarheid en veerkracht met betrekking tot black swans bepalen. Daarmee wordt het dilemma weer of de kennis moet worden afgestemd op de ambities of andersom. Ze leiden veelal tot reacties op negatieve ontwikkelingen in een project.

Onzekerheid door interpretatie. Dit type onzekerheid komt voort uit de scheidslijn tussen de "principal", of centrale besluitvormer, en "agents", de uitvoerders van het beleid van de principal. Overdracht van taken gaat gepaard met enkele dilemma's. Ten eerste: hoe *gesegmenteerd* zal de projectorganisatie zijn? Een hoge mate van segmentatie betekent dat veel specialisaties en overdrachten nodig zullen zijn. Beide dragen bij aan onzekerheid door interpretatie. Ten tweede, en gerelateerd aan de eerste, hoeveel *variëteit* wordt toegestaan in de *waarden* die een plaats krijgen in het proces? The derde: hoe gaat de principal om met zijn kennis- en informatieachterstand (*informatieasymmetrie*) in relatie met de agents? Als de doorgaans onvermijdelijke *dynamiek* zich voordoet en een principal een afweging moet maken op basis van input van agents, zal hij veelal dynamiek uit de weg proberen te gaan, omdat veranderingen het moeilijk maken voor managers om tijdsplanningen en budgetten te handhaven.

Onzekerheid over intentie. De essentie van onzekerheid over intentie is het probleem dat agents zich strategisch kunnen gedragen; dat wil zeggen, hun eigen belang volgend. Dit belang is ten dele tegengesteld aan dat van de principal. Het kerndilemma voor de principal is dan wat daaraan te doen. Een hele reeks andere dilemma's komt hier samen of vloeit voort uit tactieken om strategisch gedrag uit de weg te gaan: hoeveel *segmentatie* staat men toe (verbonden aan de mate van controle waarover de principal beschikt), hoeveel *waardenvariëteit staat men toe* (het al dan niet betrekken van waarden die door de agent worden nagestreefd) en op welke manier gaat de principal om met zijn informatiegebrek (*informatieasymmetrie)*. Er is ook project-gerelateerde *dynamiek* waarbij actoren hun eigen belangen nastreven of er door de principal van worden verdacht dat ze dat doen (verzoeken voor wijzigingen die worden gebruikt om meerkosten te claimen, of die op die manier door de principal worden gepercipieerd); waardoor afweging wordt of al dan niet die dynamiek moet worden toegestaan. Tenslotte is er de vraag wat te doen met het soort informatie dat het meest waarschijnlijk is om op een strategische manier te worden gebruikt, op basis van de mate waarin deze kan worden geobjectiveerd *(rationalisatie)*. Afweren of toelaten?

Patronen van beheersbaarheidsdilemma's

Dit onderzoek heeft zodoende zeven geregeld terugkerende hoofddilemma's opgeleverd (tabel S2). De dilemma's hebben een *"double bind"*-karakter; dat wil zeggen dat de opties dichotoom zijn, waarbij beide opties voor- en nadelen hebben die elkaar uitvlakken. De onderlinge verbanden tussen dilemma's resulteren in ketens van dilemma's. Handelswijzen als gevolg van dilemma's kunnen de effecten van andere dilemma's versterken of compenseren. Bovendien suggereren de case studies dat afwegingen zelden expliciet worden gemaakt. Het komt meer voor dat een handelswijze ontstaat zonder voorafgegaan te worden door een formeel besluit, laat staan een overweging van het onderlinge verband tussen dilemma's, waardoor het management van een project in een soort patroon terechtkomt. Het niveau van beheersbaarheid hangt af van het patroon van dilemma's dat in een project ontstaat. De dichotome keuzes kunnen grofweg gecategoriseerd worden op basis van of managers beheersbaarheid nastreven als een multi-actor onderneming of overwegend als een onderneming van de principal zelf.

Tabel S2: Beheersbaarheidsdilemma's, de onzekerheden waar ze uit voortkomen en de dichotome opties voor afwegingen

Dilemma	Dilemmatische opties	Dominante onzeker-heden	Beheersbaarheid als multi-actor onderneming	Beheersbaarheid als onderneming van de principal
1. Onzeker-heidsgat	- Beschikbare kennis project-organisatie vergoten - Benodigde kennis verminderen (ambities verlagen)	**Onbesten-digheid** **Onvolledig-heid** **Onken-baarheid**	**Benodigde informative verminderen** *Voordeel: Minder onzekerheid* *Nadeel: Verlaging ambities of hogere kosten*	**Beschikbare kennis vergroten** *Voordeel: Hoog ambitieniveau kan worden aangehouden* *Nadeel: Managers zijn zich niet bewust van de onzekerheid waarmee ze te maken krijgen*
2. Segmentatie	- Taken opsplitsen (accepteren van overdrachten) - Taken integreren (overdrachten uit de weg gaan)	**Interpretatie** **Intentie**	**Overdrachten** *Voordeel: Optimaal gebruik van specialismen.* *Nadeel: Grotere inzet nodig voor management van overdrachten en coördinatie en grotere kans op conflict*	**Geen overdrachten** *Voordeel: Conflict en aansprakelijkheidskwesties worden uit de weg gegaan* *Nadeel: Grotere afhankelijkheid van minder actoren*
3. Waarden-variëteit	- Waardenvariëteit omarmen - Waardenvariëteit afwenden	**Interpretatie** **Intentie**	**Waardenvariëteit aanvaarden** *Voordeel: Checks and balances, inhoudelijke verrijking* *Nadeel: grotere kans op conflict*	**Waardenvariëteit uit de weg gaan** *Voordeel: Controle; grotere kans op succes op die specifieke waarde.* *Nadeel: Veronachtzaming van andere belangrijke waarden*
4. Informatieasymmetrie	*Vervlechting* - Integreren van informatiebezit en besluitvormings-bevoegdheid	**Ondoorgron-delijkheid** **Interpretatie** **Intentie**	**Integreren** *Upside: High-quality decisions* *Downside: Strong dependency*	**Scheiden met redundantie van informatiebezit of besluitvormingsbe-voegdheid** *Voordeel: Gediversificeerde bronnen en tegenwicht tegen de besluitvormer* *Nadeel: efficiëntieverlies*
	Ontwarring - Informatieover-dracht aan besluitvormer - Overdracht van besluitvormings-bevoegdheid aan informatiebezitter - Redundant informatiebezit organiseren - Redundante besluitvormings-bevoegdheid organiseren		**Besluitvormingsbe-voegdheid overdragen aan informatiebezitter** *Voordeel: Hoge kwaliteit van besluiten* *Nadeel: verlies van controle*	**Informatieoverdracht aan besluitvormer** *Voordeel: Hoge kwaliteit besluiten* *Nadeel: Interpretatie van input kan verkeerd zijn*

5. Dynamiek	- Ontvankelijk zijn voor opkomende ontwikkelingen - Opkomende ontwikkelingen afwenden	**Onvolledig-heid** **Ondoorgron-delijkheid** **Onkenbaar-heid** **Interpretatie** **Intentie**	**Ontvankelijkheid voor dynamiek** *Voordeel: Optimalisatie* *Nadeel: Verlies van controle, grotere kwetsbaarheid voor strategisch gedrag*	**Weerstand tegen dynamiek** *Voordeel: Controle* *Nadeel: Onvermogen om op opkomende ontwikkelingen te reageren*
6. Strategisch gedrag	- Ontvankelijk zijn voor alle input, inclusief input die potentieel strategisch is - Potentieel strategisch verstrekte input afweren	**Intentie**	**Ontvankelijkheid voor potentieel strategische input** *Voordeel: Maximaliseren van informatie* *Nadeel: Kwetsbaarheid voor strategisch gedrag*	**Potentieel strategische input afweren** *Voordeel: Geen mogelijkheid voor strategisch gedrag* *Nadeel: Waardevolle input zou buiten beschouwing kunnen blijven*
7. Rationalisatie	- Ontvankelijk zijn voor alle input, inclusief niet-objectiveerbare - Niet-objectiveerbare input afweren	**Ondoorgron-delijkheid** **Intentie**	**Ontvankelijkheid voor onobjectiveerbare input** *Voordeel: Maximaliseren van informatie* *Nadeel: Kwetsbaarheid voor strategisch gedrag*	**Weerstand tegen onobjectiveerbare input** *Voordeel: Geen mogelijkheid voor strategisch gedrag* *Nadeel: Waardevolle input zou buiten beschouwing kunnen blijven*

Het empirisch onderzoek suggereert dat de dilemma's zich op drie niveaus voordoen: projectdefinitieniveau, projectorganisatieniveau en projectuitvoeringsniveau (tabel S3). Het niet herkennen van patronen die zich over de drie niveaus uitspannen, kan leiden tot beperkte beheersbaarheid. Afwegingen in ieder afzonderlijk dilemma worden dan gemaakt zonder besef van hoe de dilemma's op de drie niveaus met elkaar samenhangen. Een hoog ambitieniveau aanhouden op projectdefinitieniveau kan de managers op projectuitvoeringsniveau bijvoorbeeld voor grote uitdagingen stellen. Om controle te behouden zouden managers op projectuitvoeringsniveau bijvoorbeeld opkomende ontwikkelingen kunnen tegenhouden en onobjectiveerbare input kunnen afwijzen, omdat deze zouden kunnen leiden tot onbeheersbare tijds- en kostenoverschrijdingen. Zo doende zouden ze echter wel eens onmisbare input van andere actoren af kunnen weren en daarmee het kind met badwater weggooien. Begrip van deze patronen kan managers helpen een beheersbaarheidsstrategie te ontwikkelen. Afwegingen in dilemma's zouden bijvoorbeeld explicieter kunnen worden gemaakt en de gevolgen van een gekozen handelswijze op het gehele patroon kunnen zo inzichtelijk worden gemaakt.

Tabel S3: Drie niveaus van beheersbaarheidsdilemma's

Dilemma	Beheersbaarheid als multi-actor verrichting	Beheersbaarheid als verrichting van de principal
	Projectdefinitieniveau	
Onzekerheidsgat	Verminder benodigde informatie	Vergroot beschikbare informatie
	Projectorganisatieniveau	
Segmentatie	Taken integreren	Taken splitsen
Waardenvariëteit	Waardenvariëteit omarmen	Waardenvariëteit afwenden
Informatie-asymmetrie	Integreren	Segregeren
	Besluitvormingsbevoegdheid overdragen aan informatiebezitter	Informatie overdragen aan besluitvormer
	Projectuitvoeringsniveau	
Dynamiek	Ontvankelijkheid voor opkomende ontwikkelingen	Afwenden van opkomende ontwikkelingen
Strategisch gedrag	Ontvankelijkheid voor potentieel strategische input	Afweren van potentieel strategische input
Rationalisatie	Ontvankelijkheid voor onobjectiveerbare input	Afweren van onobjectiveerbare input

Op basis van de cases kunnen enkele observaties worden gemaakt:

1. Afwegingen over projectdefinitie- en uitvoeringsissues worden op verschillende niveaus gemaakt. Daardoor vinden gebeurtenissen die de beheersbaarheid beïnvloeden vaak plaats op een ander niveau dan hun oorzaak. Als managers de onderlinge afhankelijkheid van dilemma's niet herkennen, kan het zijn dat ze de oorzaken van beperkte beheersbaarheid of het potentieel voor beperkte beheersbaarheid die uit hun keuzes voortvloeit niet begrijpen.
2. Het projectorganisatieniveau is een spil. Hier kunnen organisatorische kenmerken die invloed hebben op hoe afwegingen worden gemaakt, worden afgesteld. Maar op dit niveau lijkt het erop dat afwegingen vooral worden gemaakt met de kenmerken binnen het niveau in gedachte en zonder overweging van de verbanden met afwegingen op andere niveaus.
3. In de besluitvorming op projectdefinitieniveau is er de neiging weinig aandacht te schenken aan het projectuitvoeringsniveau. Op projectdefinitieniveau proberen managers de gewenste scope, kwaliteit, tijdsplanning en kosten af te stemmen op hun ambities en niet op de haalbaarheid van de voorwaarden waaronder het project moet worden uitgevoerd.
4. Managers op het projectorganisatieniveau kunnen het potentieel voor problemen op projectuitvoeringsniveau beter adresseren. De houding van managers op projectuitvoeringsniveau kan richting worden gegeven door te

sturen op segmentatie, waardenvariëteit en de scheiding tussen informatie en besluitvormingsbevoegdheid, maar alleen als de te verwachten effecten op uitvoeringsniveau nauwkeurig in kaart worden gebracht.

5. De bevindingen in de tabellen S2 en S3, in combinatie met de observaties uit de cases suggereren dat als zich een beheersbaarheidspatroon ontwikkelt, de uitkomst waarschijnlijk één van twee uitersten is: ofwel een zeer dominante focus op het leveren van scope en kwaliteit, wat kan leiden tot een slechte prestatie op het gebied van kosten en uitvoeringstijd, of een dominante focus op het op tijd en binnen budget opleveren van het project, met een grotere kans op slechte prestatie op het gebied van kwaliteit, en mogelijk scope als overschrijdingen moeten worden gecompenseerd.
6. Hoe lager men in de hiërarchie van het project komt, hoe sterker de focus lijkt te zijn op beheersing van kosten en tijdsplanning, waarschijnlijk om de eenvoudige reden dat dit de meest zichtbare en meetbare variabelen zijn en managers er voor verantwoordelijk worden gehouden.

Conclusies en aanbevelingen (hoofdstuk 10)

Hoe ontstaat beperkte beheersbaarheid?

Volgens het theoretisch raamwerk dat in deze studie is opgezet ontstaat beperkte beheersbaarheid in gebeurtenissen die kunnen worden gecategoriseerd in de hierboven genoemde zes onzekerheden. Dit betreft zowel onzekerheden die worden veroorzaakt door onwetendheid als onzekerheden die worden veroorzaakt door interactie. Typische responsen op onzekerheid (de meest voorkomende respons is het verwerven van meer informatie) leiden niet altijd tot hogere beheersbaarheid, omdat ze een reeks dilemma's veroorzaken met een *"double bind"*-karakter. Dat houdt in dat elke handelswijze tot andere dilemma's leidt. Hoewel elk patroon van responsstrategieën wellicht een deel van de onzekerheid kan oplossen, creëert het ook nieuwe onzekerheden door de introductie van nieuwe double-bind-dilemma's. Onderzoek naar deze onzekerheden in bestaande cases heeft geleid tot het formuleren van zeven hoofddilemma's. Beperkte beheersbaarheid ontwikkelt zich als een patroon van manifestaties van aan onzekerheid gerelateerde dilemma's, waarbij dilemma's zelfs de nadelen van de keuzeopties van andere beheersbaarheidsdilemma's kunnen versterken.

Waarom ontstaat beperkte beheersbaarheid?

Beperkte beheersbaarheid ontstaat vooral doordat managers in afwegingen weinig aandacht schenken aan niveau-overstijgende patronen van beheersbaarheidsdilemma's. Waar hogere complexiteit en onzekerheid bijvoorbeeld dynamiek oproepen, motiveren ze managers ook om een sterkere controlefocus aan te nemen, in plaats van zich aan deze dynamiek aan te passen. Dit kan leiden tot slechtere beoordeling van input voor besluitvorming en het maakt potentieel strategisch gedrag problematisch. Het potentieel voor strategisch gedrag is namelijk niet alleen een mogelijk probleem vanwege dat strategisch gedrag zelf, maar ook omdat de angst van de principal voor strategisch gedrag zijn houding bepaalt in het omgaan met onzekerheden.

Een gekozen handelswijze bij één dilemma heeft invloed op andere dilemma's, maar effecten worden niet expliciet meegenomen in de oorspronkelijke afweging. Veel van die oorspronkelijke afwegingen worden zelf niet eens expliciet gemaakt. Ze ontstaan meer als opkomende tactieken dan als bewuste strategieën. Hier bestaat een typische spanning in het in overeenstemming brengen van informatieverwerking en besluitvorming, wat plaatsvindt in de zeven geïdentificeerde beheersbaarheidsdilemma's. Zoals hierboven aangegeven, hangen de dilemma's met elkaar samen en creëren gekozen handelswijzen patronen door de drie managementniveaus heen. De twee extreme patronen behelzen de poging tot handhaving van beheersbaarheid als individuele verrichting door de principal en de poging tot handhaving van beheersbaarheid als multi-actorverrichting. Echter, het consistent navolgen van óf de één, óf de ander zal juist de beheersbaarheid onder druk zetten.

De twee typische dominante focussen zijn om scope en kwaliteit te maximaliseren of om kosten en uitvoeringstijd onder controle te houden. In de hogere managementlagen, en vroeg in het project, worden ambities veelal naar boven bijgesteld, terwijl de gevolgen van deze hoge ambities op het vermogen om kosten en uitvoeringstijd onder controle te houden tijdens de projectuitvoering op dat moment nog impliciet zijn. Afwegingen worden zelden gemaakt met de praktijk op uitvoeringsniveau in gedachte. Tijdens de uitvoering moeten managers daardoor alle zeilen bijzetten om op tijd en binnen budget te kunnen opleveren.

Wat kan er worden gedaan om beheersbaarheid te verbeteren?

Managers kunnen de beheersbaarheid verbeteren door bewustzijn dat hun project hun individuele taken overstijgt en beheersbaarheid daarmee ook. Een scope die tot beter beheersbare projecten leidt, is een scope die niet alleen de wensen reflecteert, maar ook de onzekerheden gedurende de projectuitvoering. Dit gaat vooral op voor managers op projectdefinitieniveau, omdat zij vaak in de positie zijn om de randvoorwaarden voor de projectorganisatie te bepalen. De krachten om scope, kwaliteit, tijd en kosten in balans te brengen, werken tegengestelde kanten op op projectdefinitie- en projectorganisatieniveau. Het projectorganisatieniveau, in het midden van de projecthiërarchie, zou het aandachtspunt moeten zijn voor het absorberen van botsingen die zich, ondanks een wijdere blik op scope, kwaliteit, kosten en tijd kunnen voordoen.

Om een eenzijdige focus te compenseren, zou meer variëteit in afwegingen kunnen worden georganiseerd door actief tegengestelde krachten in stelling te brengen. Op die manier kan een scopedefinitie die te ambitieus zou kunnen zijn voor beheersbare projectuitvoering ter discussie kunnen worden gesteld; idealiter door een actor die los staat van de projectwaarden. Daarnaast moeten zorgvuldig gedragsprikkels worden georganiseerd; juist omdat afwegingen vaak impliciet worden gemaakt. Als bijvoorbeeld een agent een prikkel heeft om het algemeen belang boven zijn individuele belangen te stellen, is er weinig noodzaak tot het zeer selectief omgaan met objectiveerbaarheid van input. Het projectorganisatieniveau, met segmentatie van de projectorganisatie, waardenvariëteit en informatie-asymmetrie als de belangrijkste beheersbaarheidsdilemma's, is als gezegd de spil in de keten van dilemma's. Op dit niveau kunnen zowel tegengestelde krachten als gedragsprikkels worden georganiseerd. Dan kunnen er nog procesarrangementen worden vastgesteld om onvoorspelbaarheid in het gedrag van betrokkenen te minimaliseren. Die zouden bijvoorbeeld in de vorm kunnen worden gegoten van van tevoren vastgelegde handelswijzen in het geval van bijvoorbeeld onenigheid over een technische kwestie. Dit kan voorkomen dat betrokkenen worden geleid door de waan van de dag.

Curriculum vitae

Martijn Leijten was born August 4th, 1977, in Uden (the Netherlands). In 2001, he earned a spatial planning degree at the Nijmegen School of Management, Faculty of Policy Sciences, Katholieke Universiteit Nijmegen (now Radboud University). After an internship and work for two INTERREG projects of the European Commission at the Province of South Holland in The Hague, he became a researcher and teacher at Delft University of Technology's Faculty of Technology, Policy and Management. He is currently assistant professor in that faculty, and teaches project management and process management for the Construction Management and Engineering master's programme. In addition, he is a member of the teaching staff for the Essentials of Project Delivery course of the Shell Project Academy, Royal Dutch Shell.

Leijten has previously been involved in courses on governance, the politics of multi-actor systems and policy analysis. He has contributed to research for the Parliamentary Investigation on Infrastructure Projects of the House of Representatives of the Dutch Parliament and in carrying out an independent evaluation of the development of the Randstad Rail transport system for the Haaglanden Regional Authorities.