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UNIVERSITY OF TWENTE.

Organisation of a Test & Commissioning phase in light rail projects

Master Thesis v.2.0

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Preface

This master thesis is the final result of my research on the 'Organisation of a Test & Commissioning phase in light rail projects'. It is the final piece to successfully conclude my Master of Science in 'Construction Management and Engineering' with a specialisation in 'Markets & Organisation of Construction' at the University of Twente. This research is executed with the collaboration of Mott MacDonald Netherlands.

First of all, I want to express my firm gratitude to my graduation committee, Leentje Volker and Hans Boes. They gave me valuable guidance as well as the freedom to solve problems myself.

I want to thank my supervisors at Mott MacDonald, Martijn Donders and Janneke Tax for their valuable feedback, direction, and support during these six months. Furthermore, I would like to thank Ido Croese and Joost Bolck for welcoming me as a graduate intern, and the other colleagues for the interesting conversations and reflections.

Also, I would like to thank all the interviewees who were willing to discuss this intriguing topic and helped me with my research. It provided me with vast knowledge on light rail projects and gave insight into the potential organisational structures.

Finally, I would like to thank my parents, friends, and girlfriend for their patience and support during my research study.

Enjoy your reading!

Thom Broersen

Utrecht, September 2019

Executive summary

The mobility needs in the Netherlands are increasing while the capacity of existing transport is limited. This leads to congestions, travel delays and an increase in emission gasses. Especially within densely populated cities, the availability of reliable and fast transportation modes become problematic. Light rail is a transportation solution with high capacity and significant commercial speed. However, its implementation in cities leads to different problems. One of these problems is that different approaches for organising a Test & Commissioning phase for light rail projects lead to different outcomes, which can contribute to delays and an increase in costs. To improve this situation, the following research objective has been set; *Determine how a Test & Commissioning phase can be organised for light rail projects*.

A conceptual model has been created to achieve this objective, which allows the identification of the four research questions. The influence of the involved stakeholders (Client / Suppliers / Operator / Knowledge centres) & project characteristics on the procurement strategy has been researched. The procurement strategy describes the organisational structure & conditions for successful implementation. The influence of the procurement strategy on the Test & Commissioning phase has been researched, see figure 1.

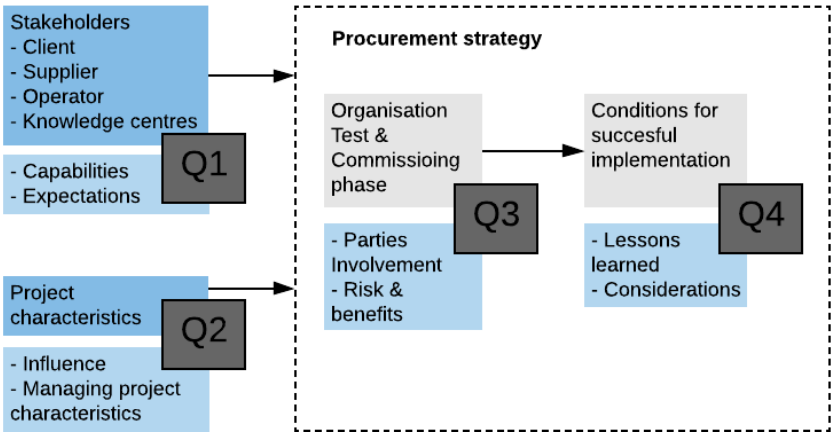

Figure 1 Conceptual model

The required capabilities of the involved parties within a light rail project (literature study) and during the Test & Commissioning phase (interviews) have been researched. The outcome found in the literature differs from what was found during the interviews. The literature describes the role of the client strictly from a managerial perspective. While the interviews show that both adequate size and experience, are required to manage the involved parties actively. This is especially so, when there are interfaces with other projects and processes. The role of the supplier focusses on coordinating the construction project on time, cost, quality and safety standards. For a Test & Commissioning phase, however, it appears more important to collaborate with other parties and perform system integration, as stated in the interviews. Moreover, one-third of the interviewees mentioned that the operator should be involved earlier during the Test & Commissioning phase. This could increase the success of the handover when the project moves to operation. The knowledge centres must possess the relevant technical and legal capabilities as was both found in literature and during the interviews.

The second aspect which could influence the procurement strategy, are the project's characteristics. A list of 18 project characteristics have been set up and researched. A few

examples of these characteristics are technical complexity and scale of the project. The interviewees have different opinions on who should carry the responsibilities in case one of these project characteristics occurs. The project characteristics are treated individually, although it has been discovered that they are often interrelated. The project characteristic most frequently mentioned is the technical complexity. The opinions of the interviewees differed, on whether the client or main contractor should bear more responsibilities in case of a technically complex project. For other factors, like the interface with other projects and processes, the interviewees were more single-minded. Almost all agreed on the fact that the client should bear more responsibility when the project has a lot of interfaces with other projects and processes.

In this research, four types of organisational structures regarding the responsibility of testing and commissioning were found, as displayed in figure 2. The responsibilities between the parties change over these structures. In the first option (Design-Build), the main contractor is authorised to execute the design and construction phase (without any coordination on Test & Commissioning). In the second option, the contractor would coordinate half of the test phase and has to perform system integration. The other part of the test phase is executed by the project organisation to satisfy the operator. In the third organisational structure, the contractor is coordinating the whole test phase and is handing over the project to the project organisation at the trial phase. The last organisational structure is a fully integrated Design-Build-Finance-Maintenance-Operate (DBFMO) contract where the contractor would perform design, build, Test & Commissioning, finance, maintenance and operation. Depending on the project, one of these alternatives could be chosen.

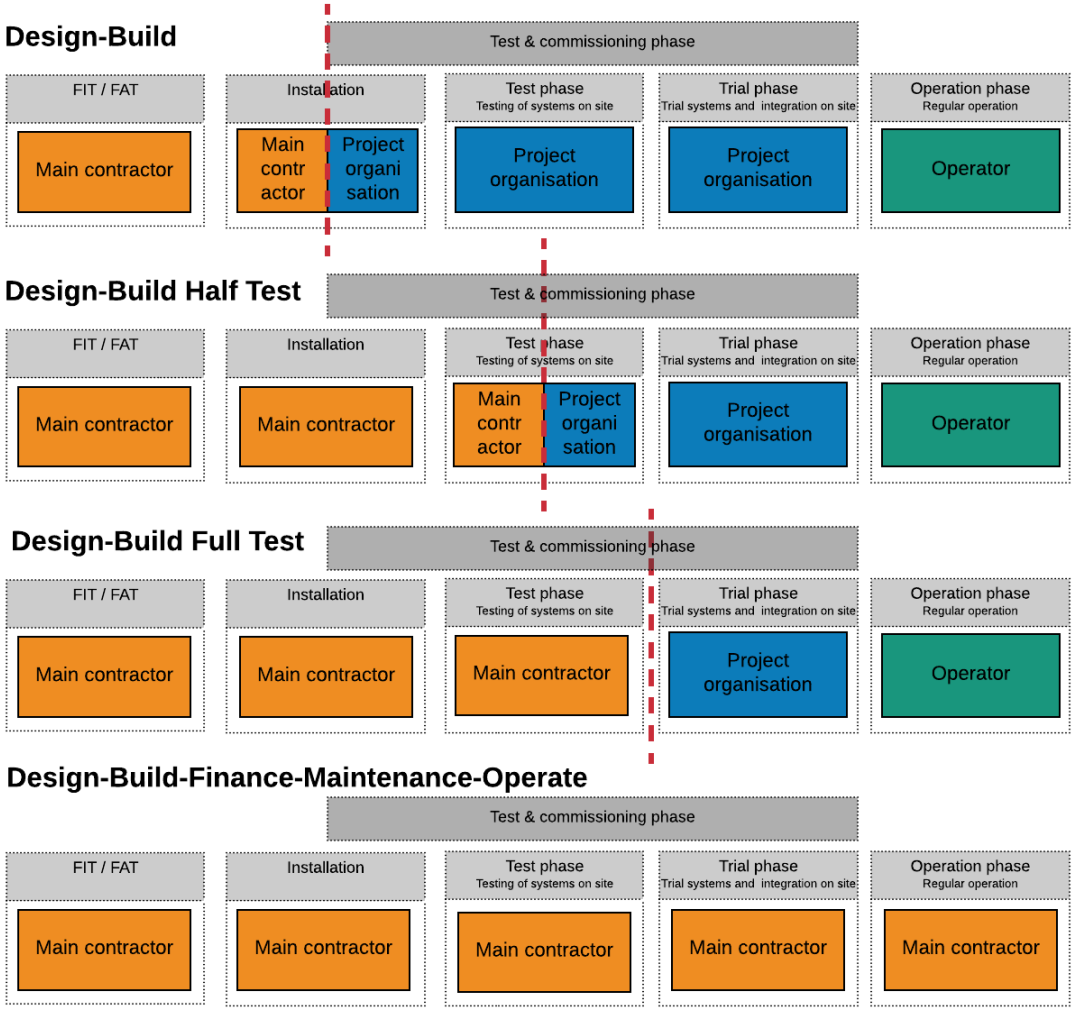

Figure 2 Four types of organisational structures

There was a difference in the attitude of people who worked on specific projects. Namely, 4 out of the 5 people who worked on the Uithoflijn were positive about the coordinating role of the contractor during the test phase (Design-Build Full Test). The persons who worked on the Hoekselijn & North-South Line were less positive about having the main contractor as coordinator and system integrator during the test phase. In the case of the North-South Line, the client pulled more responsibilities towards itself throughout the project. Furthermore, multiple interviewees mentioned that for a project as big as the North-South Line, the client should take more responsibilities during the Test & Commissioning phase.

It can be concluded that the interviewees have different opinions on the project characteristics. The attitude towards responsibilities for the parties did not differ for client, supplier, operator and knowledge centres. Thus, the clients did not suggest that the supplier should always execute the Test & Commissioning phase, or vice versa. Moreover, the organisational structure appears to be dynamic, such as for the North-South line. When an organisational structure has been chosen, this can change throughout the project. Depending on the project, the client can take on more or fewer responsibilities during the project. This implies that certain flexibility is required by the other parties.

This research mainly focused on the capabilities of the parties, the project characteristics, and its subsequent organisational structures. Multiple interviewees, however, mentioned that the success of the Test & Commissioning phase did not strictly depend on the organisational structure. The collaboration between the parties seems more important than determining who is formally responsible for certain activities. It is especially crucial that:

1. Parties know what to expect from each other
2. Client and contractor cooperate in the project team

The parties must align their work and interfaces, appreciate one another, and collaborate. The collaboration could be enhanced by an umbrella party who focusses on the project interest and solves disputes. Collaboration agreements, (Dutch: Bouwteam) in which the contractor and other parties are early involved, were a possible solution mentioned during the interviews. Parties should prevent involving their lawyers formally in the process because then the project deteriorates (Source; 2 clients, 2 project organisation, 1 operator, 1 knowledge centre).

The qualitative research showed that there are multiple forms of organisational structures for the Test & Commissioning phase within light rail projects. The interviewees had different opinions on the specific project characteristics that would lead to an organisational structure. Others thought that the organisational structure was not critical for a successful Test & Commissioning phase. The cooperation between parties seems essential. It was not possible to match the capabilities and project characteristics with a specific organisational structure.

The conditions for successful implementation of the organisational structure did differ. For a Design-Build form, the reduction of self-interest of the suppliers is critical. For the Design-Build Half Test and Design-Build Full Test a collaboration agreement could turn out positive. For the Design-Build Full Test and DBFMO contract it is essential that all parties, especially the operator, are early involved.

Furthermore, it is crucial that the agreements are clear for all parties. The client cannot organise everything perfectly in the initiation phase. A project always undergoes changes throughout the duration. Thus, the organisation should be dynamic, and parties should be flexible to adapt to changes. Finally, a culture must be created where the parties trust each other in order to collaborate.

Contents

Glossary and abbreviations

Bouwteam	A Bouwteam is a project-based collaboration between a client and one expert or several experts who, in a coordinated context, work together on the design, the engineering of the design and the construction.
Capabilities	Measure of the ability of a party to achieve its objectives.
Client	Usually, a governmental organisation which gives the order for a light rail project.
DB	Design-Build contract, integrated contract where the design and build components are executed by the main contractor.
DBB	Design Bid Build, traditional contract in which design and build are separated.
DBFMO	Design-Build-Finance-Maintenance-Operation, contract includes all components.
FAT/FIT	The Factory Acceptance Test (FAT) is used for equipment to be tested separately in the factory, thereafter some elements can be integrated in the factory during the Factory Integration Test (FIT).
Knowledge centre	Provide specific knowledge which is not in-house for client or supplier.
Light rail	Light rail is a rail-bound mode of public transport for cities and urban regions and it is able to be integrated within public realm, sharing public space with other traffic.
Operator	Provides the operating service for a light rail project.
PPP	Public Private Partnership
Procurement strategy	Process of purchasing goods or services with long-term objectives.
Project characteristics	Typical feature that can differ for every light rail project.
Supplier	Supplier of equipment/systems, for instance, contractor or manufacturer.
T&C phase	Test & Commissioning phase in which the system is tested, focussing on technique and operations.
Test phase	The test phase is a period in which infrastructure and vehicles are integrated and tested on the site location.
Trial phase	In the trial phase, the operator and administrator must prove that the light rail system can achieve the pre-defined requirements within the operational context.

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1 Introduction

1.1 Research context

Too much traffic, too much air pollution, and too little green spaces are problems every large city is dealing with. Today, 55% of the world's population is living in urban areas; for the developed world, this accounts for 80% (United Nations, 2018). This number is expected to keep increasing. Rapid population growth poses new challenges for cities and their infrastructure.

For instance, the impact it has on the quality of life for all residents in the city. With the increase of greenhouse gas emissions and the impact on climate and air quality, cities must anticipate and take measures. This can be in the form of car-free zones, an increase of bicycle lanes or improved public transport. Cities in the Netherlands are legally required to commit themselves to the climate goals for 2030 since the government signed the Paris Agreement.

Cities must not only take measures because they are legally bounded. Citizens expect high-quality levels of mobility and thus demand a properly functioning public transportation network. Within such a network, the use of light rail fits well. Light rail is a rail-bound public transport system, where vehicles share public space with other traffic. Large cities are well suited to develop this relatively new form of public transportation. It has a high capacity, a significant commercial speed, it is attractive to car users and can share the road with other users.

However, light rail projects have been implemented both successfully and non-successfully in cities around the world. The failed projects had numerous reasons such as technical, political and economic difficulties. The uncertainty on how to successfully implement a light rail project can concern cities and make them devious. More knowledge on this topic could make them favour the choice for light rail.

1.2 Problem statement

There is an increased demand for mobility in major cities. Municipalities need to facilitate these demands by providing adequate transportation solutions. These solutions must contribute to a decrease in congestion and emission gasses and an increase in public transport and bike and walking routes. There is a need for a sustainable transportation solution.

Municipalities are observant of new alternatives in the field of modes of transport. Bus networks are the backbone of public transport systems for cities all over the world. However, busses account for a substantial part of the harmful greenhouse gases. Moreover, the capacity, commercial speed and attractiveness to car users are lower than it is for light rail. (Kühn, 2002).

Therefore, light rail could be a solution in highly populated urban areas. Light rail is a rail-bound form of public transport. In contrast to train and metro, light rail is suitable for integration in public space and operates at a higher capacity (Bijl, Bukman, & Oort, 2015). Light rail systems are increasingly developed in both major and provincial cities across the globe (Ferbrache & Knowles, 2016). It is popular due to relatively low capital costs and increased reliability compared with heavy rail systems.

Unfortunately, not all light rail projects achieved a favourable outcome. In recent studies from Bijl et al. (2015) multiple light rail projects were not successful in terms of time and budget or even failed. Some after years of planning and others right after the start of the tendering process. Multiple research projects have been conducted on the importance of light rail projects as an efficient means of transport. But for successful implementation, it is essential to know the best approach for organising a light rail project. In practice, different approaches to the organisation of light rail projects have led to various outcomes. This research is focused on the organisation of the Test & Commissioning (T&C) phase for light rail projects. In the Test & Commissioning phase, all systems are integrated and tested before moving over to operation. This is required to ensure that the systems are safe and meet the design requirements.

The approach for organising a Test & Commissioning phase is different for every project. Beforehand, it is unknown whether the applied approach is the right choice, although it can have a significant impact on the result of the project. This research contributes to the knowledge of organising a Test & Commissioning phase for light rail projects.

Problem Statement

The different approaches for organising a Test & Commissioning phase for light rail projects lead to different outcomes which can contribute to delays and an increase of costs

1.3 Research objective

The research objective has been formulated within the project context and with consideration of the problem statement. It has been formulated as follows:

Research objective

Determine how a Test & Commissioning phase can be organised for light rail projects

This research is aimed at determining the possible organisational structures for a Test & Commissioning phase within light rail projects. At the end of the research, recommendations are proposed for organisational structures depending on certain project characteristics. This contributes to the understanding of organisational structures within light rail projects for public clients in the Dutch construction industry.

1.4 Research framework

The research framework represents the internal logic of the research. The research framework itself is a schematic representation of the research objective, and the actions need to be taken for achievement. It shows how the different phases of the research are interconnected and how the theoretical background is established. (Verschuren & Doorewaard, 2010)

As visualised in figure 3, the client (often governmental body) is deciding on the type of procurement. The client can determine the procurement strategy on their own or together with suppliers in a market consultation (see dotted line). Possibly they ask an external consultant for advice on the procurement method. In all phases of the project, decisions are made regarding the contract and the project. But in the initiation and planning phase, the specifications of the contract are identified.

After the client puts out a tender, it is up to the suppliers to respond. If multiple suppliers submit a bid, then the winner is chosen based on pre-announced award criteria. From the planning phase, the process moves over to realisation. After the construction is completed, all components such as trams and electronic systems need to be integrated and cooperate successfully. This can be the responsibility of the main supplier, client, operator, or a third party who gets contracted.

However, if the supplier does not observe a positive perspective for a profitable project, they will not submit a bid. In that case, the client can consult the market again before launching a new procurement procedure, as displayed in figure 3. Another option is to procure the project again without a market consultation.

The project characteristics that determine the organisational structure have been analysed. Recent projects are evaluated, and the lessons learned are used for future projects. This way, the client knows which project characteristics are vital. Subsequently, he can set out an appropriate procurement strategy. Expected is that the procurement strategy determines the organisational structure for a Test & Commissioning phase within a light rail project. However, the project characteristics that determine the suitability are yet unknown.

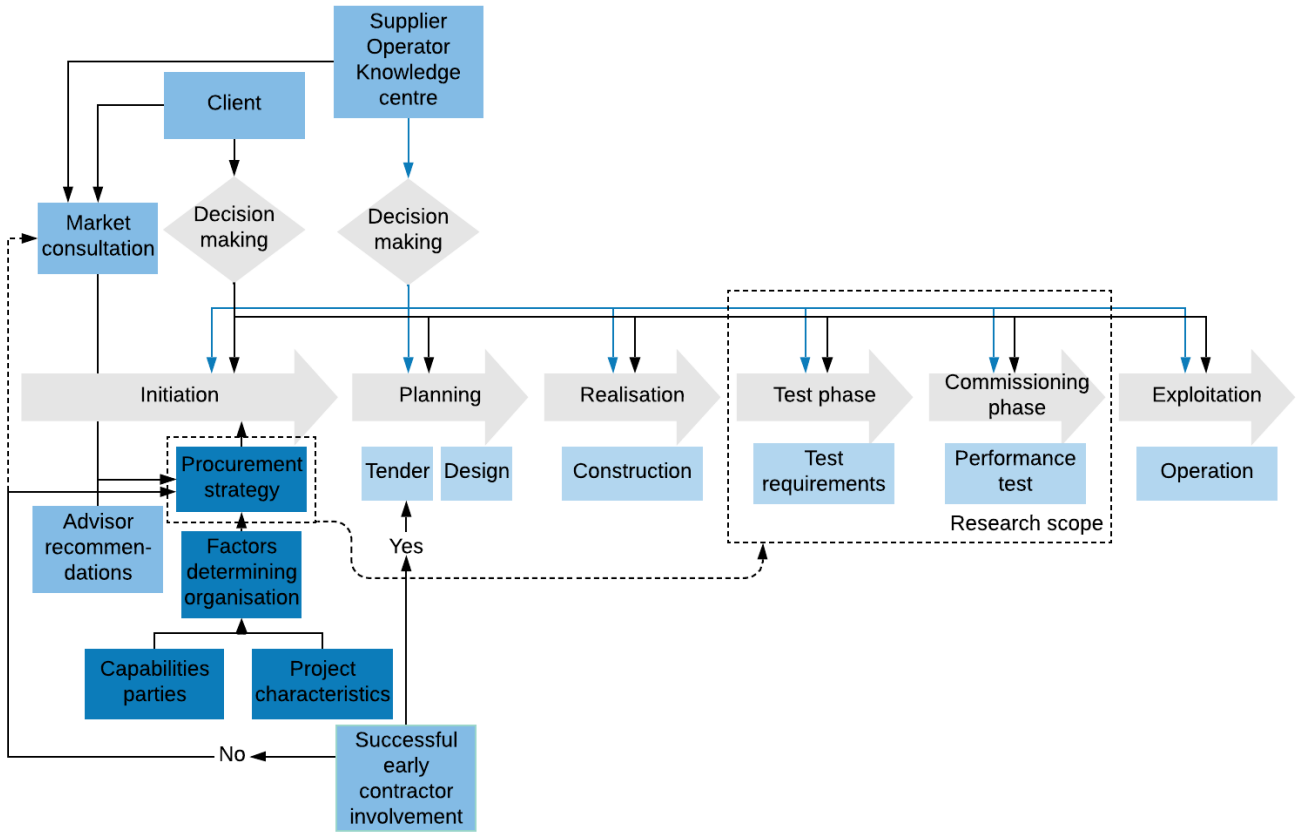

Figure 3 Research framework

The early decisions have high consequences on the total costs for the project (Winch, 2017, pp. 257-258). Therefore, it is essential to consider the consequences of early choices in the project. The procurement strategy substantially influences the final costs.

In conclusion, the research scope is set out between the procurement strategy and the Test & Commissioning phase. This implies the research is focussing on the relation between the choices made in the procurement strategy and the consequences for the Test & Commissioning phase.

1.5 Research questions

Multiple research questions have been created to accomplish the research objective; *Determine how a Test & Commissioning phase can be organised for light rail projects*

As stated in the research framework, a lot of the final project costs are determined by decisions early in the process. It is essential to know which way a Test & Commissioning performs most successfully in the project. As visualised in the research framework, this research focusses on the link between the procurement strategy and the Test & Commissioning phase. In figure 4, the conceptual model is visualised.

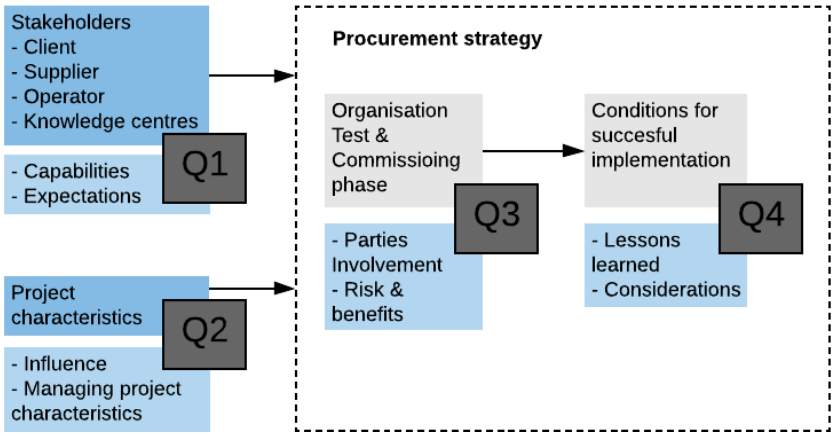

Figure 4 Conceptual model

Research questions

How can a Test & Commissioning phase be organised for light rail projects?

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1. Which capabilities of the stakeholders involved in light rail are essential for the success of the test and commissioning phase?
    a. What capabilities are required by the client, supplier, operator, and knowledge centers according to literature?
    b. What do the client, supplier, operator, and knowledge centers expect from each other in practice?

2. What project characteristics affect the organisation of a Test & Commissioning phase?
    a. Which project characteristics influence the organisational structure?
    b. Which party could manage these project characteristics the best way?

3. What are the potential organisational structures for light rail projects?
    a. Which parties must be involved?
    b. In which phase should these parties be involved?
    c. What are the potential risks and benefits for different organisational structures?

4. What are conditions for a successful implementation of the organisational structure?
    a. How can be learned from past light rail projects?
    b. Which aspects should be considered during the procurement strategy?

First, the report focusses on the required capabilities of the involved parties needed during the Test & Commissioning phase (Q1). Besides the capabilities of the parties, the project characteristics play a role as well. Therefore, the project characteristics that impact the organisation and by whom these

should be managed is outlined (Q2). The involved parties and project characteristics influence the procurement strategy. The procurement strategy has been split into the organisational and juridical aspects. The organisational structure describes which parties are involved in light rail projects, when they are involved and the risks and responsibilities they have (Q3). Logical organisation forms are the concession and the traditional and integration form. The report elaborates on forms that have already been used in light rail projects, as well as forms from other civil engineering disciplines that could be applicable for light rail projects. Then, the conditions for a successful implementation of the organisational structure have been researched (Q4). Finally, when all these questions have been answered, an answer to the main research question has been formulated. The research questions are further elaborated on the next page.

1.6 Relevance of the research project

Societal relevance

Citizens demand a clean environment, and this implies a decrease in pollution and greenhouse gasses and an increase of liveability. Policymakers such as the county council and municipalities must accomplish these changes together with their citizens. Developing the effectiveness of mobility in cities is a way of increasing liveability. Light rail is a highly efficient way to transport people through and to surrounding cities. Investments in public transport can be justified on the grounds of several considerations. Often mentioned are the three P's: Profit, Planet, and People. The social aspect in People is equity for society. Light rail is crucial for social cohesion and prevents social insulation for people who live just outside of the city. (Bijl, Bukman, & Oort, 2015)

If the design and project are worked out well, light rail can be a great solution. Therefore, it is important that lessons are learned from past projects. By learning from these projects, future projects can be lower on costs and higher in quality. Eventually, the taxpayers fund the light rail project, and they want value for money. Therefore, research on this topic must be enriched.

Scientific relevance

Research on light rail has steadily gained more support in recent years by looking at the amount of available literature. Among others, Dr. van der Bijl and Dr. van Oort evaluated 61 cases and wrote multiple books and publicised articles about their findings.

However, little is documented on the most appropriate type of organisation for light rail projects. There is a gap in the literature on the suitability for a Test & Commissioning phase for an integrated contract. Moreover, scientific research is absent on how a Test & Commissioning phase could be best organised and how the responsibilities should be distributed. One of the options is a traditional contract such has been applied in many light rail projects. However, the Uithoflijn showed the possibility to apply an integrated contract in which a test phase is included. This made the contractor responsible for the design, construction and test phase. By performing scientific research and analysing recent projects more knowledge is available on the most appropriate way of procuring light rail projects.

Managerial relevance

This research is executed with the collaboration of Mott MacDonald Netherlands. Mott Macdonald is a consultancy firm with its headquarters in London, United Kingdom. They employ 16,000 staff in 150 countries focusing on six sectors; advisory, built environment, energy, international development, transport, and water.

Mott Macdonald established its first company in the Netherlands in 2004. Currently, there are offices in Arnhem and Utrecht that employ around 100 employees. The department related to this research has around 30 employees. In the Netherlands, they provide consultancy services to public and private sector clients in sectors ranging from transport, infrastructure and buildings, to energy and environment. Key projects include the Uithoflijn in Utrecht, HTM in The Hague and North-South line in Amsterdam.

Light rail projects are large infrastructural projects in which Mott MacDonald participates. Delivering value to their customers is achieved by creating knowledge on the projects they work on. An extension of knowledge on the organisational structures of light rail projects makes them a better suitable partner and provides the opportunity to outperform others in the market.

1.7 Reading guide

The first chapter is the introduction of this research report. It describes the problem statement, research objective, research framework, research questions, and the societal and scientific relevance.

Chapter 2 provides the research strategy and research phases. In the research strategy, the methodology is described.

Chapter 3 includes background information and theory on what a Test & Commissioning phase is for light rail projects. Moreover, it provides the reader with the theoretical scope of the research.

Chapters 4, 5 and 6 are used for the analysis & synthesis of the interview results. The capabilities, project characteristics, organisational structures, and conditions for successful implementation are provided in these chapters.

After the data has been analysed in the previous chapters, conclusions are drawn in chapter 7. The discussion is given in chapter 8. This chapter includes the limitations and recommendations for further research. The structure has been visualised in figure 5.

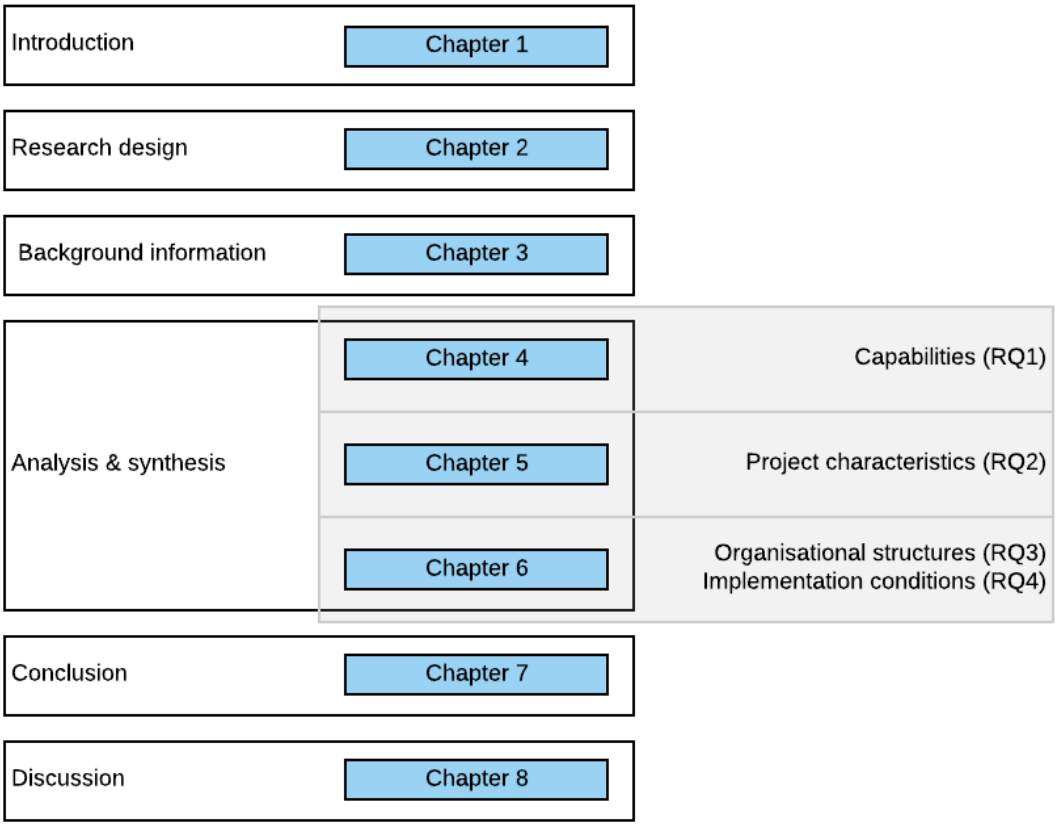


Figure 5 Research structure

2 Research design

The research design is created to find an answer to the research questions and the research objective. The first step in the research design describes the strategy for approaching the research objective. The research is divided into phases as specified in paragraph 2.2. The methodology is described comprehensively in the last paragraph of this chapter.

2.1 Research strategy

In view of the nature of the problem, this research opts for a practice-oriented project. A practice-oriented project is meant to provide knowledge and information that can contribute to a successful intervention to change an existing situation (Verschuren & Doorewaard, 2010, p. 45).

In this practice-oriented research, the problem has been identified in the problem statement. The market parties are aware of the difficulties with the organisation of the Test & Commissioning phase. Since every project is unique, new forms of organisations have been applied over the years. The best manner of organising a Test & Commissioning phase is still unknown. This is problematic since unsuccessful testing and commissioning can cause significant delays and an increase in costs. The research plan visualised in figure 6 is developed to find solutions for the problem.

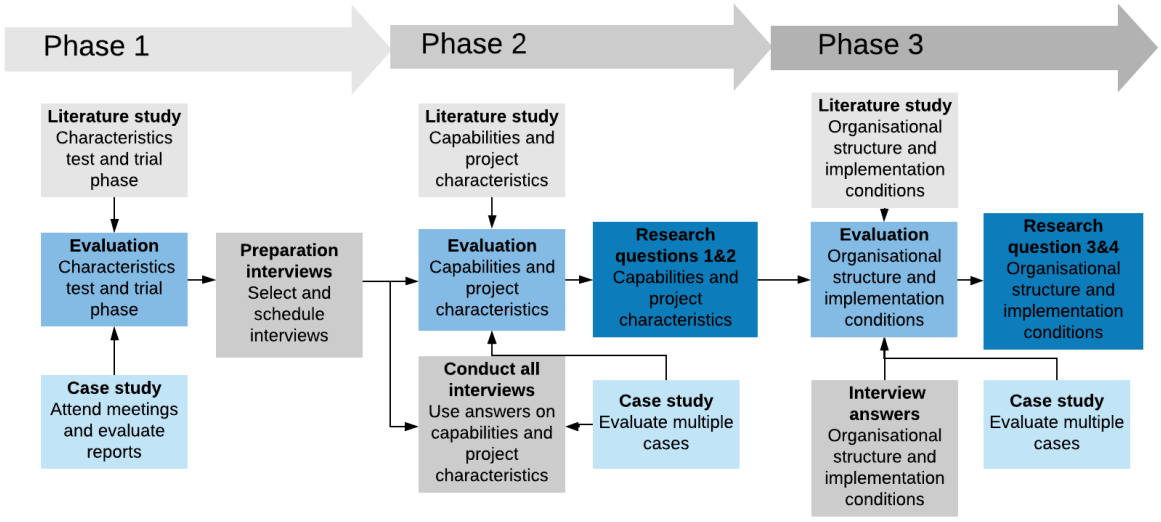


Figure 6 Research plan

2.2 Research phases

Phase 1

Phase 1 started off with a literature study. Literature provided good inside on the activities that are included in a Test & Commissioning phase. The case study compares the literature to practical experience. Multiple national and international cases are used to evaluate the data found in the literature. Moreover, meetings have been attended, and reports have been assessed. From these meetings and reports, the purpose of a Test & Commissioning phase came forward. The results from the literature study and case study have been evaluated to provide input for the interviews.

Phase 2

Phase 2 focused on the required capabilities of the parties involved during the project. Furthermore, the project characteristics of light rail project have been studied. The influence of the capabilities and project characteristics on the procurement strategy has been researched. These two aspects; capabilities and project characteristics, are treated separately.

The first half of the second phase focused on the parties involved in the project, such as client, supplier, operator and knowledge centres. The literature study has been used to get a sense of the responsibilities and capabilities of the parties (question 1a). The interviews focussed on the capabilities required explicitly during the Test & Commissioning phase (question 1b).

The second half of the second phase focused on the project characteristics. Expected is that project characteristics determine the manner in which a project is organised. The influence the project characteristics have on the organisational structure for a Test & Commissioning phase has been researched (question 2a). A list of 18 project characteristics has been made, and these were validated during the interviews to determine their influence. The interviewees were asked which party should bear more responsibilities during the Test & Commissioning phase in case a project has one of these characteristics (question 2b).

Phase 3

The last phase focused on two often related aspects of the procurement strategy. These are the organisational structure and contractual support. The literature study executed in phase 1 focused on both subjects to see what forms of organisations are applied in construction projects. This gave a broad overview which can then be translated to light rail projects. The usefulness for light rail projects has been assessed since not all organisational structures are directly applicable. First, there has been looked at the parties involved in light rail projects (question 3a). The phase of the project in which the parties are involved has also been assessed (question 3b). Any recommendations on which and when these parties should be involved for future projects has also been discussed. Moreover, the risks and responsibilities of these parties come to light (question 3c).

The conditions for a successful implementation of the organisational structure has been researched in the last research question. The lessons learned from the national and international cases have been gathered (question 4a). Subsequently, the aspects that should be considered regarding the procurement strategy are described (question 4b).

2.3 Methodology

In the following four paragraphs, the methodology has been described. This consist of literature study, case study, evaluation meetings and interviews.

2.3.1 Literature study

This research started with a comprehensive literature study. The topic ‘organisations for Test & Commissioning phases in light rail project’ is quite specific. First, it was needed to zoom out in order to understand the greater picture. This has been done by deepening the knowledge of public transport in the Netherlands and the rest of Europe. Subsequently, light rail itself has been explained on the basis of definitions from researchers. The type of organisations used in light rail projects has been researched consecutively. Moreover, the literature study is needed for the knowledge on Test & Commissioning phases. A vital part of this research is defining what is included in the Test & Commissioning phase, see research question number 1. This is different for every project since different systems, vehicles and infrastructure have to be tested. There is

no international standard, but it is crucial to have a framework of a Test & Commissioning phase. This way, multiple projects are compared. Moreover, people who work on light rail projects with different perspectives provide answers within this framework.

The literature study is the fundamental bases for the report and the interviews. No recommendations could be given without a good understanding of light rail projects. The literature includes sources from scientific articles, but also non-academic documents provided by Mott MacDonald, suppliers and procuring authorities.

2.3.2 Case study

Literature study alone is not sufficient enough for research questions 2, 3, 4 and 5. Therefore, multiple cases were compared in a case study. This case study does not stand by itself since the projects used in the case study are the same projects as used for the interviews. The information found in the case study is complemented by the interviews. In figure 7 is displayed how a theoretical framework has been created. Subsequently, national and international projects are studied and compared.

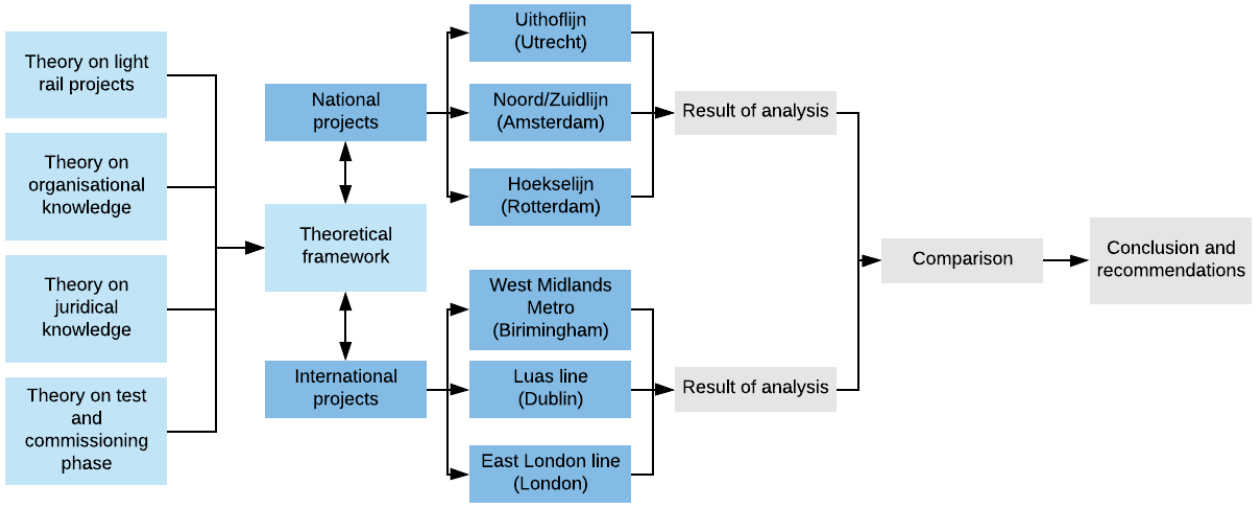


Figure 7 Analysis of cases

The criteria for choosing these cases are the type of project (light rail), the location (national and international cases), the size (costs 50+ million), the duration of T&C phase (minimal a couple of months), and the status (all project must be in or past T&C phase). In Table 1, an overview has been given of the selected cases. Paragraph 3.2 describes the projects in further detail.

Table 1 Projects used for the case study

Project	Country	City	Start of operations
Uithoflijn	Netherlands	Utrecht	December 2019
North-South line	Netherlands	Amsterdam	July 2018
Hoekselijn	Netherlands	Rotterdam	September 2019
West Midlands Metro	United Kingdom	Birmingham	May 1999
Luas line	Ireland	Dublin	June 2004
East London line	United Kingdom	London	May 2010

2.3.3 Evaluation meetings

The research has started during the changeover from test to trial phase for the Uithoflijn in Utrecht. This gave a unique opportunity to learn from this project. Multiple actors such as BAM, Mott MacDonald, municipality of Utrecht and Transportation authority of Utrecht (Province) have organised meetings to evaluate the test phase in the project. This gave the opportunity to make notes, ask questions and use this information to prepare the interviews. These were organised at the start of this research at the beginning of March 2019. After these meetings, which focussed specifically on the test phase for the Uithoflijn, more meetings were attended. There were knowledge exchange sessions on 'system integration during the Test & Commissioning phase' with experts from engineering consultant offices. These experts worked on projects such as the North-South Line (Amsterdam), Uithof Line (Utrecht), Tramlijn 19 (Delft) and even international projects as far as in China. These sessions contributed to the development of the generic model of the Test & Commissioning phase, which can be seen in figure 10 on page 27. This model is used to compare projects in terms of Test & Commissioning phase.

Furthermore, the Railtech Europe 2019 conference has been attended. More than 10,000 people participated in this event, and 200 businesses presented their innovative services and products. Presentations on stakeholder influence (political and residents) during the construction of the North-South line gave useful inside information about the importance of including and informing the social environment.

2.3.4 Interviews

A great deal of detailed information is gathered by performing a literature study and a case study. However, the practical knowledge which is not accessible through literature is gathered by interviews. The approach is semi-structured to compare the different interviews, but it also leaves room for discussion for what is not covered by the prepared questions. All the interviews were conducted face-to-face. The questions were sent a couple of days in advance to let the interviewee think about the answers. Face-to-face interviews are chosen because the quality of the answers is higher. People put more thought in it, there is a higher focus, and verbal and non-verbal cues are captured.

As stated in the case study, 3 national projects and 3 international projects have been researched. For every project, at least one person has been interviewed. Most of the research has been conducted in the Netherlands, and the evaluating meetings were also in the Netherlands. Therefore, the number of interviews where national projects were discussed is higher than for the three international projects, see Table 2. Besides the national and international projects, persons have been interviewed on their general perception of light rail projects. Because of their broad knowledge, more information was gained by asking questions about projects in general. It must be noted that almost all the other interviewees also had experience on multiple projects but focussed on one specific project mentioned below. The full method applied for the interviews is described in appendix 1-4.

Table 2 List of projects discussed with interviewees

Uithoflijn	Hoekselijn	North-South Line	London	Birmingham	Dublin	General
Client	2 Clients	Project organisation	Project organisation	Project organisation	Project organisation	Client
Project organisation	Operator	Supplier				3 Knowledge centres
2 Suppliers		Knowledge centre				
Operator						

3 Background information

This chapter describes the background information and the fundamental components of the research framework. First, the scope of light rail projects is defined (3.1). Subsequently, the 3 European cases and 3 Dutch cases used for the analysis are presented (3.2). Then, the types of organisational structures for construction projects in general are described (3.3). During the case study, it has been assessed whether the types of organisations for construction projects are applicable to light rail projects. Consequently, the Test & Commissioning phase and the generic model are explained (3.4). Finally, the view upon forms of organisations for the Test & Commissioning phase is outlined (3.5).

3.1 Scope of light rail

The following definition the Office of Rail and Road (ORR) is used throughout the report (Office of Rail and Road, 2019):

'Light rail is an urban rail transportation system that uses electric-powered rail cars along exclusive rights-of-way at ground level, on aerial structures, in tunnels, or occasionally in streets.'

Light rail is using lighter equipment at lower speeds than those used by heavy rail, such as train operations. Many tram systems are integration with public realm and can share public space with other traffic to some extent. Sharing space can be done with other public transportation modes such as busses or tram, as well as with regular traffic such as cars and bicycles. In the case of tram-style light rail, it can be shared even with pedestrians.

There are many definitions of light rail. (Knowles & Ferbrache, 2014) include metro in the field of light rail as well. This view is different compared to the definition of (Bijl & Oort, 2014):

Light rail is a rail-bound mode of public transport for cities and urban regions. Contrary to train (heavy rail) and metro (subway, underground) light rail principally is able to be integrated within public realm, sharing public space with other traffic to some extent.

3.2 Case study projects

Three national and three international projects have been used for this case study. A list of information is summarised in table 3. This research focusses mostly on the three national projects. The projects are further elaborated in appendix 5.

Table 3 List of project information

	Uithoflijn	North-South line	Hoekselijn	Luas line Dublin	West Midlands Metro Birmingham	East London Line
Total Length	8 km	10 km	24 km	42 km	20 km	9 km
Extension existing line	Yes	Yes	Yes	Yes	No	Yes
Greenfield/ Brownfield	New line in a build environment	New line in a build environment	Conversion from heavy rail line	New line in a build environment	Conversion from heavy rail line	New line in a build environment
Tram/Metro	Tram	Metro	Metro	Tram	Tram	Metro
Opening	December 2019**	July 2018	September 2019**	June 2004	May 1999	May 2010
Number of stops	9	8	9	67***	23	23
Delayed	Yes	Yes	Yes	No	Yes	Yes
Total costs	€440 million	€3.160 billion	€462 million	€ 368million	£145 million	£1 billion
Number of (expected) daily passengers	34.000	93.000	12.000	114.500***	19.000	50.000

*Expected at time of writing
** Total amount for the whole project, not only the extension

3.3 Types of organisations for construction projects

For this research, there is a focus on the organisational structures of the Test & Commissioning phase. Before, deepening in too much in this subject. A broader understanding of organisational structures for construction projects has been created in this paragraph. Subsequently, the Test & Commissioning phase is explained (3.4). And then the types of organisational structures for the Test & Commissioning phase are discussed.

The formation of project coalitions depends on specific project characteristics and political preferences. There is no standard form of project coalition which is broadly applied for light rail projects. There are multiple forms of public private partnerships (PPP). All these forms exist somewhere in between the two most extremes; complete public responsibility and privatisation, see figure 8. The three most common forms of PPP are traditional, integrated and concession.

- Traditional

The traditional procurement route, often referred to as design bid build (DBB) is the most commonly used method for procuring construction works. The client appoints the architect and other designers; the designer leads the team. The architect selects trade contractors to execute the site works. This can be on the base of competitive tenders or appointment. The architect is responsible for the overall coordination of the activities of the trade contractors, but he is usually

not liable for failings on their part. The tender documentation, including drawings, bills of quantities and work schedules are prepared.

- Integrated

The most standard form of an integrated contract is design and build (DB). As can be seen in figure 8, the contractor can take on more responsibilities such as Finance, Maintenance, and Operation. Subsequently, the risks are decreased for the client. However, this has consequences for the price contractors ask since they increase the buffer for risks. In a Design-Build-Operate (DBO) project, the government owns and finances the construction of new assets. The private sector designs, builds, and operates the assets. Build Operate Transfer (BOT) project is used for single infrastructure projects rather than a whole network. The project company receives its revenue through a fee charged to the authority and not directly to customers. For instance, when the government wants a water treatment plant or recycling plant.

- Concessions

A concession agreement is a negotiated contract which gives a concessionaire the long term right to operate on infrastructure within the government's jurisdiction. The ownership of the asset remains with the client. A significant share of European Union constructions and network industries such as motorways, railways, airport services and water distribution networks are built this way (European Commision, 2019). Typically, the concessionaire obtains most of its revenues directly from the consumer through fees and tolls.

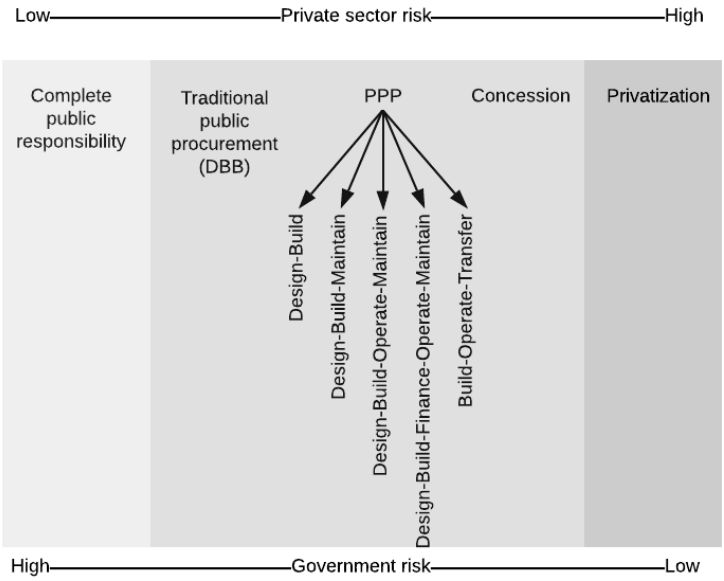


Figure 8 Risk transfer for organisational structures

3.4 Test & Commissioning phase

A light rail project can be divided into distinct phases, as described in the research framework. These phases are the initiating, planning, realisation, Test & Commissioning, and operation. The Test & Commissioning phase has an essential role in light rail projects. The T&C phase consists of multiple activities, as can be seen in Figure 9. It includes part of the installation, namely the Site Integration Test (SIT), test phase and trial phase. A large version can be found in Appendix 2.

The various parts of the systems must first work separately, then be integrated and eventually work as an overall system. The test phase has a more technical focus, while the trial phase focusses more on operations and procedures. The phases are described separately in the following sections; FAT/FIT, Installation, Test phase, Trial phase, Operation phase.

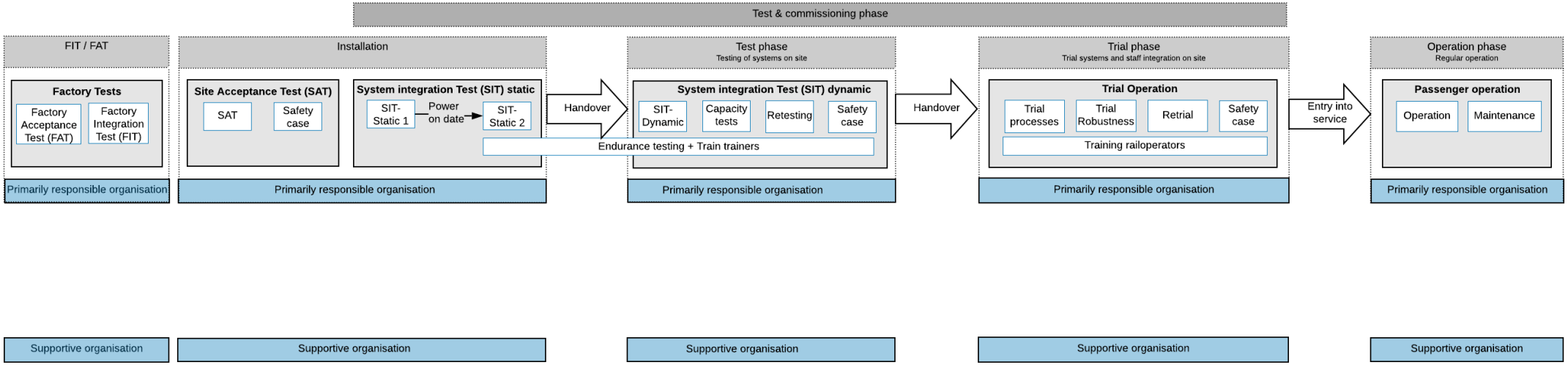


Figure 9 Generic model Test & Commissioning phase

- FAT/FIT

The Factory Acceptance Test (FAT) is used for equipment to be tested separately in the factory, thereafter some elements can be integrated in the factory during the Factory Integration Test (FIT).

FATs and FITs are beneficial for both the buyer and end-user as for the manufacturer itself. With these tests, all parties are assured that the elements and systems meet the specifications. Possible issues can be addressed before the equipment is installed on-site. Issues can be rectified while the manufacturer is still in control; this can help to keep the project within time and budget. Usually, it is cheaper to fix issues in the factory than it is on-site. Moreover, it assures the safety for the workers that all systems function properly. In the FIT, only some elements can be integrated in certain occasions. Others can only be integrated on-site.

- Installation

The installation phase is used to step by step install equipment on-site and let it integrate with other systems.

During installation, the equipment is built outside in public space. The test to prove that this is done correctly and that the separate systems function, is called the site acceptance test (SAT). It is to verify that no damage during shipment and installation did occur. The installer must prove that the system works according to its agreed-upon specifications and is safe to use. In specific situations, this can end with a safety case.

When all the separate systems work according to the specifications it is time for the System integration testing (SIT). First, the systems are tested without power and ,vehicles on the track. The systems must function properly before the high voltage power can be turned on and vehicles can be driven and tested. In SIT Static 1, the system is tested without high voltage and vehicles. Subsequently, the power is turned on in SIT Static 2. This is usually a critical moment since a lot of the safety protocols change. Parties must grand permission to work on or beside the track.

Once most of the infrastructure elements are integrated, the systems are transferred to the test phase. When the installation is executed according to plan, the next step is to integrate the infrastructure with the vehicles.

- Test phase

The test phase is a period in which infrastructure and vehicles are integrated and tested on the site location.

The test phase starts with integrating the infrastructure and vehicles, SIT dynamic. Generally speaking, it is first tested with one vehicle and subsequently with more. The precise content of the tests was not shown since this can differ per project, this depends on, among other factors, the scale, type of the line (tram vs metro) and location.

Typically, the instructors are trained in the test phase to educate the future tram drivers in the trial phase. This is an ongoing process separate from the installation and adjustments of systems.

Usually, the main contractor and project organisation both have a list of tests needed to prove the safety of the system. Together with other suppliers and manufacturers they make a programme that includes each element of the testing phase. Depending on the project, the responsibilities for this activity could be different.

- Trial phase

In the trial phase, the operator and administrator must prove that the light rail system can achieve the pre-defined requirements within the operational context.

The objective of the trial phase is to prove the operator and the administrator that the transport system is operating safe and reliable. Besides a safe and reliable system, it must also meet the pre-set timetable to transport the passengers. This must also prove the robustness of the timetable. This includes the drivers being obliged to stop and open the doors at every stop. Other parties, such as maintenance and calamities, must be able to work according to the guidelines. The exact implementation depends on the specific project characteristics.

In this phase, the human aspect is included. The tram operators are trained to operate the vehicles. Depending on the size of the project, multiple tram operators must learn how to drive the tram safely. This usually takes several months and can only start when the test phase is finished.

Another aspect could be to include calamities processes, including emergency services. In case something goes wrong, emergency services must be able to react quick and adequate. Therefore, it is a prerequisite to execute necessary preparation. All the required trials must be finished successfully before moving over to the operation phase.

- Operation phase

In the operation phase, the light rail system is opened for commercial operation.

Once the Test & Commissioning phase has been successfully executed, the light rail system starts its commercial operations. The project organisation has finished the works and takes their hands of the project. For parties like the operator, asset owner and maintainer the job just starts. The project organisation and suppliers usually leave in a short time after the operation starts.

Purpose of Test & Commissioning phase

The Test & Commissioning phase is to be carried out on systems to ensure that they are safe and meet the design requirements. With a safety case, the project can be handover from the constructor to the owner. A safety case is a structured argument, intended to justify the safety of a system for a specific application in a specific operational environment. Thus, the operability in terms of performance, reliability and safety is guaranteed. A comprehensive Test & Commissioning phase is required for new light rail projects and often for extensions as well. Unfortunately, since this stage is so close to the operation, there is often time pressure to shorten the Test & Commissioning phase (Chartered Institute of Building, 2019). This should be strongly resisted since many problems could be solved within this phase. It is usually cheaper to fix issues during testing than in operation.

Relation with the rest of the project

The research framework (paragraph 1.4) emphasised on all the project phases, including testing and commissioning. A project passes through the following phases over time; initiation, planning, realisation, test phase, commissioning phase and exploitation. Within construction projects, and certainly for light rail projects, a V-model is used. In figure 10 a generic V-line diagram of a light rail project is shown. The left-hand side of the V diagram depicts the flow of an increasing level of detail. The first step is to set up requirements which are conducted by the client. A more specific design follows and subsequently this is built by the contractor. In the right-hand portion of the V diagram the elements are integrated. In the test phase, the results are verified according to the design (Bhamra & Georgaras, 2018). As shown a FAT, SAT and SIT are required. Finally, the results are validated against the list of requirements that was created in the definition phase. The model is based on Railway applications –Part 1: Basic requirements (NEN-EN 50126-1, 1999).

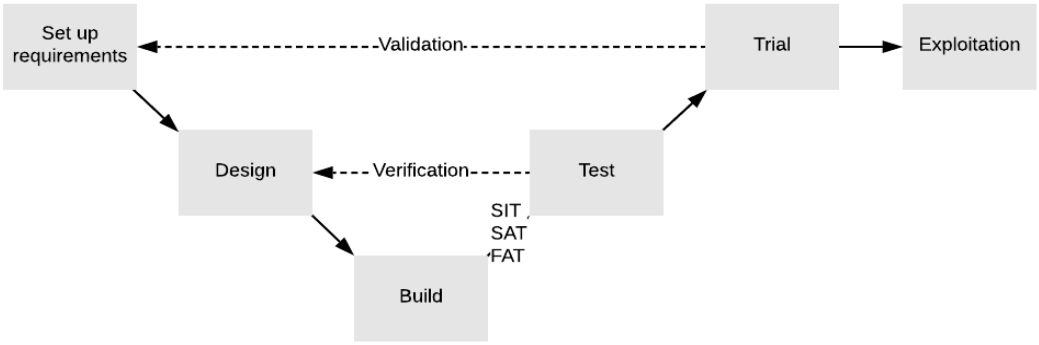


Figure 10 V-Line model for a light rail project

3.5 Types of organisations for Test & Commissioning phase

The decision on including the Test & Commissioning phase in the contract has consequences for the client as well as for the suppliers, operator, and knowledge centres. Parts of the responsibilities and risks are shifted from one party to the other. This can result in benefits but has potential flaws as well; these are described in the following sections.

Table 4: Alternatives for the distribution of responsibilities

	Test phase	Trial phase
Alternative 1	Client	Client
Alternative 2	Main contractor	Client
Alternative 3	Main contractor	Main contractor

The client usually organises a public tender for large infrastructure projects. In the requirements, they put the activities and responsibilities for the Test & Commissioning phase. The decision can be made to let the client be responsible for the whole Test & Commissioning phase (alternative 1). Another alternative is to let the main contractor be responsible for only the test phase (alternative 2) or for both test and trial phase (alternative 3). It is not logical to let the client be responsible for the test phase and the main contractor responsible for the trial phase. The responsibilities are usually handed over only once to the client. This is not a process going from one to the other and back.

Alternative 1

In this alternative, the client is responsible for both the test and trial phase. The benefit is that the client has full control and can manage the involved parties. Moreover, the client does not have to pay a risk premium to the contractor. The drawback could occur when the project is approved and handed over after building. If issues are detected it is difficult to let the suppliers solve it since these since acceptance has taken place and it can be hard to prove the reason for failures.

Moreover, there is the risk of wrong incentives from the main contractor in the design and building phase. He could do the minimum, deliver minimal quality and hand the project over without all systems working integrated. In this alternative, after the building phase, the project is handed over from the contractor to the client. It is inevitable that some problems do occur during the test phase. The client, who signed for acceptance, can only charge the contractor for extra costs when he can prove that it was the supplier's responsibility and that he delivered not or poorly. This can lead to a lawsuit which takes a considerable amount of time and other resources. It implies that the client has to execute the rework. While it sounds like a risk, this option is most applied in practice.

Alternative 2

By making the main contractor responsible for the test phase, he must consider the quality and the integration of systems in the early design phase. Assumingly, he puts more thought in this process compared to the first alternative. Thus, more than when the project is handed over after the build phase.

On the other hand, it implies that the client has less control over the test phase. The client is no longer entitled to arrange this part of the project. The contractor is free to define the test phase themselves, considering it is compliant with the requirements set by the client.

The precise interpretation depends on the project itself and the demands and expertise of the client and the contractor.

Alternative 3

The role of the project manager extends even further when the contractor is not only responsible for the test phase but also the trial phase. This could lead to enhanced performance and quality. However, the contractor probably asks for a higher risk premium because contractors are often unknown with coordinating a trial phase. It is unknown if the advantages of quality outweigh the extra costs.

When the main contractor also leads the operation and/or maintenance phase, it is more likely that alternative 3 is preferred. Then the project is the responsibility of the contractor for 25-30 years before handing over.

This is the least used alternative in practice. Alternative 1 is most commonly used in practice in the Netherlands. Alternative 2 had been applied for the Uithoflijn. Likewise, internationally alternative 1 is most accepted. A variant of alternative 2 was used in Nottingham.

Note

These three options have been found on the basis of the literature study. This has been used as the scope for the start of the research. However, the results from the interviews give better insight into the practical implementation. The result provided in chapter 6 emphasises on these types of organisations. On the basis of the literature study, it was assumed that with the use of a generic model, the best option for the organisation could be chosen. The interviews, however, have shown that the projects were much more complicated.

3.6 Conclusion

This chapter describes the need for transporting people in European cities. There is a high demand for a mode of transport with low air pollution, high capacity and smooth rides. Light rail is a form of high-quality transportation, and it is the mode of transport where this research focuses on. The theoretical background provides the following definition for light rail:

Light rail is a rail-bound mode of public transport for cities and urban regions. Contrary to train (heavy rail) and metro (subway, underground) light rail principally is able to be integrated within public realm, sharing public space with other traffic to some extent.

Chapter 3 describes the different types of organisations applied in general construction projects. This broad scope has been used to analyse which organisational structures would be best applicable for the Test & Commissioning phase of light rail projects. Six projects have been analysed in the case study. From this generic model, three types of organisations for the Test & Commissioning phased have been identified, see Table 5. These alternatives comply with the project's organisations found in the literature. The interviews have been used to validate these results.

Table 5 Alternatives organisation Test & Commissioning phase derived from the literature study

	Test phase	Trial phase
Alternative 1	Client	Client
Alternative 2	Main contractor	Client
Alternative 3	Main contractor	Main contractor

Consequently, knowledge has been gathered on the capabilities of the parties and the project characteristics that influence the organisation of the T&C phase. There has been researched what capabilities the involved parties should have for a light rail project and specifically during a Test & Commissioning phase. Moreover, the influence of the project characteristics on the organisational structure of the T&C phase has been researched. Following this reasoning, when the required capabilities of the parties and the project characteristics are known, there can be assessed which organisational structure would match the Test & Commissioning project best.

Contradictory, an alternative conclusion could be that the organisational structure is not the critical factor during the Test & Commissioning phase. This would imply that the distribution of responsibilities would not be the main factor of importance. The contribution towards the success of the Test & Commissioning phase has been assessed.

4 Capabilities

In this chapter, the capabilities that are required by the involved parties are described. In this research capabilities are defined as follows: 'Measure of the ability of a party to achieve its objectives'. The capabilities are different for the client, the supplier, the operator and the knowledge centres and are therefore specified in separate parts. A comparison has been made between what has been found in the literature study and what came forward during the interviews. The literature study focussed more on the capabilities during the entire project while the answers from the interviews focussed explicitly on the Test & Commissioning phase. In this manner, a comparison is made between the capabilities required during the whole project and one specific phase. In table 6, all the parties are listed, and a short description has been given.

Table 6 Involved parties

Group	Party	Explanation
Client		Usually, a governmental organisation which gives the order for a light rail project
	Project organisation	Coordinates the project on behalf of the client
	Asset owner	Owner of the infrastructure
	Transport authority	Regulates transportation-related matters
Supplier		Supplier of equipment/systems
	Infrastructure supplier (Main contractor)	Constructs the infrastructure
	Vehicle Supplier	Build the vehicles
	Infrastructure maintainer	Maintenance party for the infrastructure
	Vehicles maintainer	Maintenance party for the vehicles
Operator		Provides the operating service
	Drivers	Drivers of the tram/metro
	Control Room	Monitors operations in the system
	Security & safety personnel	Concern on the security and safety of the passengers
Knowledge centre		Provide specific knowledge which is not in-house for client or supplier
	Engineering consultants	Solving technical issues
	Legal consultants	Solving legal issues
	University	Provides external knowledge

4.1 Client

The client is the organisation for whom the project is executed. The main task of the client seems the involvement and provision of management support. (Koops, Bosch-Rekveldt, Coman, Hertogh, & Bakker, 2016). Besides management support, the client also has a role in enabling those parties carrying out to manage health and safety risks. He appoints a contractor and or designer, depending on the contract. The client can choose the procurement strategy himself, as long as it follows the European procurement laws.

The client usually appoints a project organisation responsible for the light rail project. The project organisation makes sure that the principal contractor is carrying out their duties. He ensures that the contractor prepares and executes the construction plan. The assets are owned by the asset owner, which is usually a governmental organisation. The transport authority is generally also a government-owned body. In the Netherlands there are 18 transport authorities, they all have a district in which they issue concessions for regions or specific lines. London has its own transport authority; Transport for London. It is recognised as a global leading urban transport authority. In all metropolitan areas in the UK, such as the West Midlands focussed on Birmingham, there are transport authorities or their equivalent responsible for producing local transport plans and make recommendations regarding rail infrastructure. (Governance of UK Transport; Foresight, 2019)

The National Transport Authority is in charge of public transport within Greater Dublin. Unlike the transport authority in London, it does not operate services itself. The National Transport Authority in Dublin derives public service obligation contracts with transport operators.

Multiple interviewees mentioned that the most critical capability of the client is its size and experience (source: 1 client, 1 project organisation, 1 supplier, 2 knowledge centre). The size was related to enough staff, and the experience was related to relevant project experience. The client must also manage the technical interfaces, parties must be aware of these interfaces, and an agreement to solve them must be signed by the suppliers. The results of the interface management become apparent during the Test & Commissioning phase but must be managed during the design, in the first stage of the V-line model.

One spokesman of the operator explained that it is crucial that the client is able to oversee all stakes of all the stakeholders during the Test & Commissioning phase. He must make decisions which are best for the project. Two interviewees (1 client, 1 knowledge centre) mentioned that the client should be flexible as well. They have a budget for unforeseen costs and delays. Thus, they should try to avoid consulting lawyers too soon. One interviewee (knowledge centre) suggested that sometimes clients take the role purely as a lender while they should have active management within the organisation and steer where necessary. In England, this view on the role and capabilities of the client was shared; the client or project organisation must manage all the interfaces between the parties (2 project organisation).

Required capabilities client

Found in literature	Derived from interviews
- Provide management support - Role in health and safety management	- Size and experience - Manage the (technical) interfaces - Flexibility and steering power

4.2 Supplier

First, the umbrella term ‘supplier’ must be broken down. In this research, the name is used for the (main) contractors of the infrastructure and vehicles, manufacturers and maintenance parties. The capabilities which are required from the main contractor are different from a manufacturer.

The manufacturer is usually asked to make a piece of equipment which is often a standard product. The task of the main contractor is more comprehensive. Depending on the contract and specifications, he has a lot more freedom for the design and build process. The tests required to show that it works according to specifications can be partly set up by the client. However, a part is usually done by the contractor himself.

The main contractor is responsible for the daily oversight and overall coordination on the construction site. When the client puts out a work, the contractor can submit a bid (tender). The contractor submits a proposal with cost estimates and the price. He is thus employed by a client. The main contractor is responsible for providing the material, equipment, labour and services necessary for the construction of the light rail project. The main contractor often hires subcontractors that are specialised to perform work that the main contractor cannot do himself. Another critical aspect, the same as for the client, is safety. The contractor must have the organisational capacity to carry out the project and minimise health and safety risks. In the literature, the capability of the contractor is described as the ability to achieve simultaneously, time, cost, quality and safety standards (Sik-Wah Pong & Kit-Yung Choi, 2000).

During the interviews, quite some problems with main contractors and ancillary contractors (Dutch: nevenopdrachtnemer) came forward. Especially when one of the parties was not able to deliver in time. This had its results on the whole T&C phase since all the systems had to be integrated. There is a difference in procuring as stated by a client, project organisation and supplier. The governmental procuring authority is a public client and has to procure according to the European legislation. This is time-consuming and sometimes not the preferred party wins the tender. For instance, in hindsight, the client can discover that the supplier did not have enough experience. The interviewees were divided on the required capabilities of the main contractor during the Test & Commissioning phase. Two interviewees who both worked at the North-South line mentioned the most critical capability of the main contractor is to build what is required.

In the North-South line project, the interfaces between the contractors were managed by the project organisation. Initially, the contractors had a coordinating role in this project. Over time, the client pulled more responsibilities towards himself. On the other hand, interviewees (1 project organisation, 2 suppliers) mention the role of the main contractor nowadays as builder, coordinator and system integrator. The field of system integration is relatively new for contractors, but since clients want to shift responsibilities towards the market (1 client) this could be an interesting opportunity for contractors. Michael Hobday et al. confirm that system integration is a core capability of the modern corporation (Hobday, Davies, & Prencipe, 2005).

Another important capability mentioned during the interviews is the ability to collaborate. The culture between two organisations determines for a substantial share the degree of cooperation. By obligating suppliers to write a collaboration plan, the client can make this a soft criterion during the tender. Moreover, during the project, the collaboration can be enhanced by financial incentives if specific deadlines are achieved.

Required capabilities supplier

Found in literature	Derived from interviews
- Coordinating the construction project on time, cost, quality and safety standards	- Build according to specifications - Perform system integration - Collaborate with other parties on the project interfaces

4.3 Operator

The operator has the concession to operate their vehicles on the railway. Usually, the operator does not own the infrastructure themselves. When operators are compared, for instance, in the Great Train Comparison Report, their main focus is the service to the customer they offer. Operators are required to be customer friendly for all users, including elderly, disabled and kids (Loco2, 2018). Literature was not quite extensive on the capabilities that an operator should have during Test & Commissioning phase.

In the generic model, the operator was divided in terms of the Drivers, the Control Room Operator, and the Security & Safety personnel. Usually, the Control room operator was involved from the installation phase or during the test phase. The control room operator has a relatively early role since this party becomes responsible for the operating system. The drivers have a minor role in the test phase and a substantial role in the trial phase. This is because usually only a few experienced drivers are allowed to drive during the test phase. Whereas all the drivers with none or limited experience learn to operate the vehicles during the trial phase. The security & safety personal has a short training period during the trial phase but starts working during operation.

For the light rail project in Dublin, the operator was responsible from the power on date. This meant that from an early stage in the project, he was responsible for the safety of the track. This is a big responsibility and requires an organisation that can manage this well.

The most important capability of the operator (and asset manager) is to clearly communicate to the client and other relevant stakeholders what they expect from the system (1 client, 1 knowledge centre). These expectations have to be put in specifications. During the design phase, the operator must know the conditions in which they accept the system. During Test & Commissioning, it is usually too late to communicate new requirements. Therefore, it is crucial that the operator and asset manager are involved early in the project (1 project organisation). The T&C phase is the final rehearsal where every person must know their role before moving on to operation.

Required capabilities operator

Found in literature	Derived from interviews
- Focus on customer (during operation)	- Clear specifications - Early involvement for a successful handover to operation - Manage the safety on site (Dublin)

4.4 Knowledge centres

The knowledge centres consist of the engineering consultants, legal consultants and universities. Thomas Ng & Chow (2004) performed research on the pre-selection process of engineering consultants. The client selects the engineering consultants on specific criteria. The criteria were classified into four categories; technical capabilities, management capabilities, financial capabilities, and quality attitude. It revealed that technical capabilities were the most important category for clients to select their consultants. This included the previous experience, resources, and creative and innovative ability. The management capabilities were the second most relevant category. The management capabilities existed of the subgroups; management staff and service delivery. The quality attitude was perceived as the least important. (Thomas Ng & Chow, 2004)

The legal consultants were third parties who provided expert advice on law and contracts. These are usually only needed in case of an issue. The universities publish scientific papers which include frameworks for different organisational forms such as Public Private Partnerships. However, for the projects discussed during the interviews, the university was not hired as a consultant. During the interviews, it was stated that the engineers are essential for the project but generally offer a supportive role. They are hired for their technical knowledge. This is usually knowledge that the client or contractor does not have.

Although the role of the legal consultants is minor, it is often indispensable since the project involves a considerable amount of money. For the project in Dublin, there was an independent arbitrator with technical and legal knowledge from the start of the project. His role was written down in all the contracts, and the contractors had to buy-in for the arbitration. He was not involved full time but was there during a meeting once a month, and he was on standby. When there were any issues, he could solve them as an independent person. This was cheaper and quicker than having legal claims with lawyers on both sides. ‘If you go down the legal road, it takes years to solve. Thus, an independent assessment is well worth the money’. (Source: Project organisation)

Required capabilities knowledge centres

Found in literature	Derived from interviews
- Technical capability (engineering consultant)	- Technical capability (engineering consultant) - Quickly solve issues (legal consultants))

4.5 Conclusion

The required capabilities of the parties involved in a light rail project were researched in the literature. The capabilities needed to be part of the Test & Commissioning phase were found during the interviews. The main tasks for clients identified in the literature were to give management support and provide a safe work environment. For the T&C phase, the client requires adequate size and experience. This is needed to sufficiently manage the technical interfaces sufficiently and steer the relevant parties. Literature indicates that the supplier coordinates the construction project on time, cost, quality and safety standards. The interviewees agree on this part, however some extent the role of the main contractor as the system integrator. The operator focuses on the customer, as shown in the literature study. From the interviews, it was derived that the operator must have clear specifications of the system they want. Moreover, when the operator is involved in an early stage, the project can be handed over successfully. The knowledge centres are hired for their technical or juridical knowledge, as indicated both in literature and interviews.

5 Project characteristics

In chapter 4, the required capabilities for the involved parties have been discussed. Besides the capabilities, other factors potentially have an influence on the organisation of a Test & Commissioning phase. These factors are called the project characteristics. The project characteristics are being assessed by the client before the project starts. This must be done to make an appropriate procurement strategy. The influence these project characteristics have on the procurement strategy is researched in this chapter. First, all the project characteristics are explained (5.1). Then the method used during the interviews is outlined (5.2). Subsequently, the results of the project characteristics found during the interviews are described (5.3).

5.1 Introduction of project characteristics

The project characteristics could influence the procurement strategy, which determines the type of organisational structure. For instance, the responsibilities between client and contractor can differ between two projects which can lead to a preference for traditional contracts or on the opposite, integrated contracts.

The project characteristics are based on 'kosten en omvang van projectorganisaties' by AT Osborne. They developed a list of 27 factors to better estimate the organisational costs for an infrastructure or building project. The factors were validated by 20 experts from 'Gemeente Amsterdam', 'Gemeente Rotterdam', 'ProRail', 'Rijksvastgoedbedrijf' and Schiphol. The report states that the type of contract determines in a high degree the distribution of work between the client and contractor. For a traditional contract, the client has the responsibility for the design and must manage the construction. While in an integrated contract, the contractor has more responsibilities and the client is just supervising. Therefore, the type of contract is determinative for the organisation of the T&C phase.

The list contains hard (measurable) factors such as scale and project lead time but also soft factors such as the physical environment and organisation. In Table 7, the list of project characteristics is shown, including the explanation.

Table 7 Project characteristics influencing the organisation of a T&C phase

Project characteristic		Explanation
Scope:	**1.** Clear scope boundaries	Clear definition of the project objective and delimitation of the scope for all stakeholders
	2. Technical complexity	Degree of technical complexity and requirements of new technologies
	3. Scale of the project	Size of the project, expressed in activities and objects
Resources:	**4.** Project lead time	The time between the start date and end date of the project
	5. Type of financing	Publicly, private or otherwise funded projects
	6. Procurement method	The procurement strategy that has been used for the project. Whether the client/contractor Should determine the type of contract.

	7. Contractual relationship between client and contractor	Relationship with contractor in the way specifications are written down in the contract and the flexibility for the contractor.
	8. Existing contracts	Existing (framework) contracts that have already been awarded and are still running
Physical environment	**9.** Existing infrastructure in the city	Existing presence of light rail projects in the city
	10. Location/ environment	Properties of the physical environment in which the project is carried out
	11. Interface with other projects and processes	Interfaces with and interdependence of other projects
Stakeholder environment	**12.** Nature and size of stakeholder (including residents)	Quantity, character and influence of stakeholders
	13. Transfer to operator	The activities needed to let the project result be accepted by the operator
Government	**14.** Political sensitivity	Influence of politics on project decisions and developments and vice-versa
	15. Image	The image of a project or an organisation that exists
	16. National laws and regulations	Influence of laws and regulations on the project
Expertise project organisation:	**17.** Expertise in team	Team members/organisation that have experience in similar projects
	18. Degree to which the organisation learns	The ability of the organisation to gain knowledge and experience to put in a new situation

The procurement strategy has a direct influence on the way the Test & Commissioning phase is set up. This is because the responsibilities and risks for the involved parties depend on the organisational structure.

5.2 Obtaining information on project characteristics

The project characteristics that influence the organisation of testing & commissioning phases for future projects were discussed during the interviews. The list of 18 project characteristics was presented on a paper, and the interviewees were asked to read them thoroughly. Thereafter, the question was which 3-5 project characteristics had the most significant influence on the organisation of a test and commission phase. The project characteristics must impact the way that the responsibilities and risks between the client, supplier and operator are divided.

For instance, the client or supplier should take a more prominent role in the case of a technical complex project (factor 2). The interviewees came up with on average 4 project characteristics in which they would recommend increasing the responsibilities for either the client, main contractor or another party. The results are discussed in the following paragraph.

5.3 Results project characteristics

The number of identified project characteristics are visualised in Figure 11. Below the 8 factors that were most often mentioned are clarified. These are:

1. Technical complexity
2. Interface with other projects and processes
3. Expertise in team
4. Transfer to operator
5. Clear scope boundaries
6. Relationship between client and contractor
7. Procurement method
8. Political sensitivity

Some project characteristics were related. For instance, existing contracts (number 8) and existing infrastructure (number 9) were associated. When there already was light rail infrastructure in the city, then there were usually also existing contracts with certain parties. However, based on the interviews, this did not have the most significant impact on the manner of organising the T&C phase for a new light rail project.

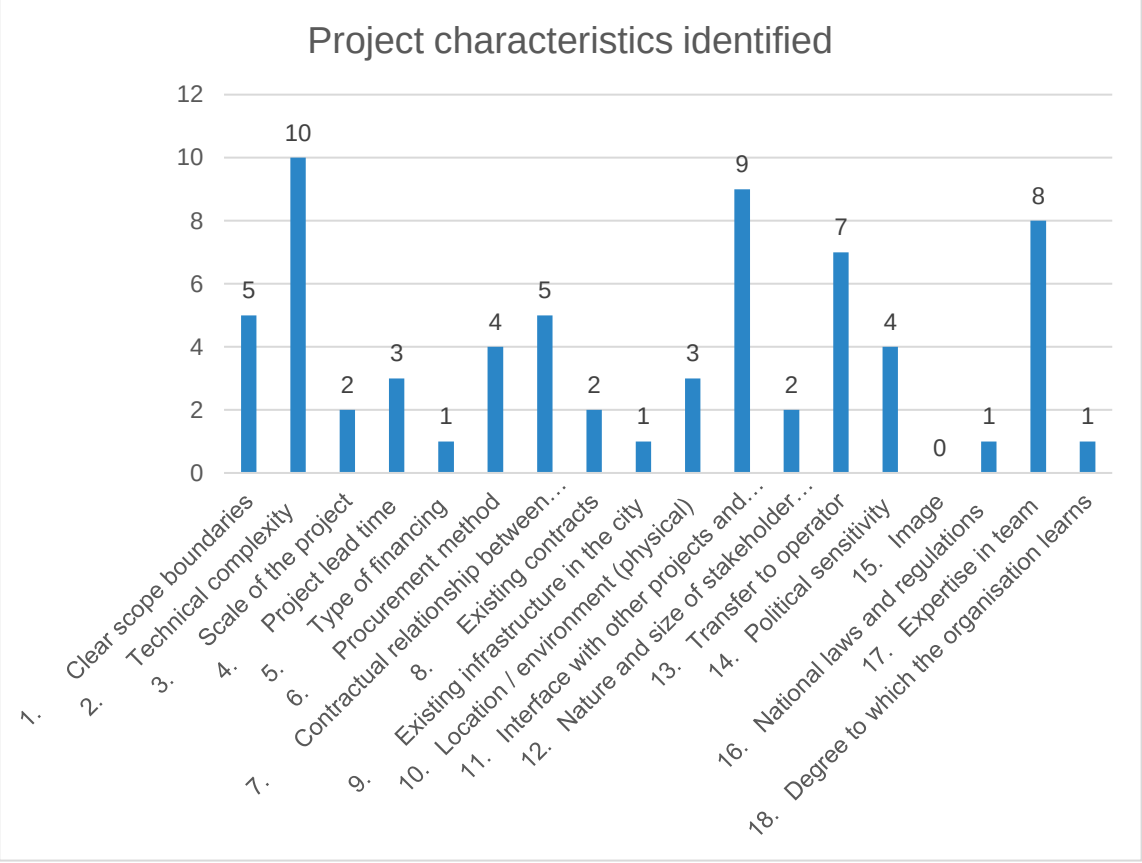


Figure 11 Number of project characteristics mentioned

The following tables describe the top three project characteristics most frequently mentioned. The number of respondents that mentioned the specific project characteristic is specified. In case the project characteristics did occur, people stated whether the client or contractor should take more responsibility. For instance, the technical complexity, 10 persons mentioned this project characteristic as being crucial. 5 of them said that the client should take more responsibilities, 3 favoured the main contractor, and two others were divided. The other project characteristics can be found in appendix 6.

1. Technical complexity

Main responsibility	Number of respondents (10 total)	Arguments in favour
Client	5	The complexity of the project is a significant risk. The client must take control and manage the stakeholders. System integration is difficult, and the main contractor is not able to do this task and does not want to be liable for other contractors and their systems.
Main contractor	3	Technical complexity is what the contractor is best in, on the condition that it is in its field of expertise. The contractor must have the freedom to build and implement themselves. The client should not try to steer too much. The main contractor is competent at managing the risks that they can influence. He can manage subcontractors well, but ancillary contractors are difficult. The client should just define clear specifications.
Dependent	2	It depends on the size of the technical complexity and the involved parties. For every project, there should be considered who is best capable of bearing the risks. It is a crucial project characteristic, but you cannot generally say that one of the two main parties can carry the responsibilities. Furthermore, it depends on whether it is an extension of an existing system or a brand-new line. For an extension of an existing line, the client should be closer to the project and manage more active. The contractor can have more freedom for a new line.

2. Interface with other projects and processes

Main responsibility	Number of respondents (9 total)	Arguments in favour
Client	7	Light rail projects in the Netherlands are usually built in an urban inner-city environment. This implies many interfaces with other projects and is complicated to manage. The client can balance those interests best. The contractor does not have authority over other contractors from other projects and would only think about what is best for him. This is not in the interest of the total development of the city and its residents.
Main contractor	1	The physical environment does not make a big difference. If there are addition project/facilities around, then you have to take that into consideration. However, you should still follow the basic Test & Commissioning model. You always have the internal and external integration test. You could have more external integration tests, but you always have them. It is just a different emphasis.
Dependent	1	In a greenfield environment, a fully integrated contract would be feasible. Here, the contractor is also responsible for the interfaces with other projects and processes. However, as a client, it is not as easy to shift the risks to the contractor. It also requires a lot from the client's project organisation.

3. Expertise in team

Main responsibility	Number of respondents (8 total)	Arguments in favour
Client	0	
Main contractor	1	In practice, the contractors have to increasingly carry out system integration since the technical knowledge is no longer with the client. Typical for the client is the difference in project organisation, infrastructure owner and transport authority. The infrastructure owner and transport authority are only concerned with managing the transport system and are unable to perform system integration. This task must be carried out by the project organisation or contractor. Contractors are now taking steps to acquire this knowledge. Managers system integration are hired. Small contractors cannot take on this role as a system integrator.
Dependent	7	Multiple interviewees indicated that this was the most critical project characteristic. The expertise of the client organisation is needed to oversee and manage the project and all of its stakeholders. Many parties are busy with their own work and increasing their own profit. The aim of the client should be to align and coordinate the parties in the T&C phase. This increases the predictability in the project, which reduces lead time and costs. The organisation should be of substantial growth and have enough experts with relevant project experience. If this is the case, the client should be responsible for the organisation of the T&C phase. Otherwise, they could let the contractor, or an independent market party give responsibility.

5.4 Conclusion

Three options were mentioned the most frequent during the interviews. These were:

1. Technical complexity
2. Interface with other projects and processes
3. Expertise in team

Technical complexity was mentioned during the interviews the most frequent, as an essential factor in the organisation of the T&C phase. It was often mentioned together with the scale of the project since there was a relationship between the two. The interviewees did not fully agree on which party should be primarily responsible in case of a technically complex project. Some said that only the client is capable of managing a technical complex project. They stated that the risks were too high for contractors. However, others mentioned that technical complexity is just the strength of the contractor.

The interviewees were more single-minded on the second project characteristic. In the case of many interfaces with other projects and processes, they almost all agreed that the client should take a more significant role. The main contractor does not have the same authority over contractors from other projects as the client does. The client is usually a governmental body and can steer over multiple projects. One of the interviewees mentioned that in a greenfield environment, where there are limited interfaces with other projects and processes, the contractor could bear more responsibilities.

Expertise in the team is also crucial for the organisation of the Test & Commissioning phase. The client is regarded as responsible for the overview of the project and manages all parties. The client must coordinate the parties during the Test & Commissioning phase, which requires technical knowledge. When the client does not have the ability to organise, this should be the responsibility of the main contractor.

The other project characteristics were mentioned fewer times and could be seen as less critical. However, there is a high number of project characteristics that are mentioned 3 to 7 times. These have to be considered for future projects as well. Other project characteristics that were mentioned once or twice and could be seen as less relevant for the organisation of a Test & Commissioning phase.

Although the interviewees did not always agree on which party should take more or fewer responsibilities, it can be concluded that the top three project characteristics are essential. The three most frequently mentioned project characteristics are (1) technical complexity, (2) interface with other projects and processes and (3) expertise in team. These determine the organisation of the project and Test & Commissioning phase in particular. Thus, for future projects, attention must be devoted to these project characteristics in particular.

6 Procurement strategy

The capabilities of the parties have been described in chapter 4. In the following paragraphs, there is a focus on the involvement of parties in daily practice. For all the 6 cases, there has been examined which parties were involved (6.1). Subsequently, the point in time when the parties were involved has been researched (6.2). This has been done with the help of the general model of the Test & Commissioning phase, in which the activities are described. The interviewees placed cards with the names of the involves parties in the model, as has been described in the methodology (2.3). Moreover, suggestions for improvements for when parties should be involved are given. Then, the four types of organisational structures are presented and explained(6.3). The conditions for successful implementation of the organisational structure are described in paragraph 6.4. The following paragraph analysis these conditions found in the interviews (6.5).

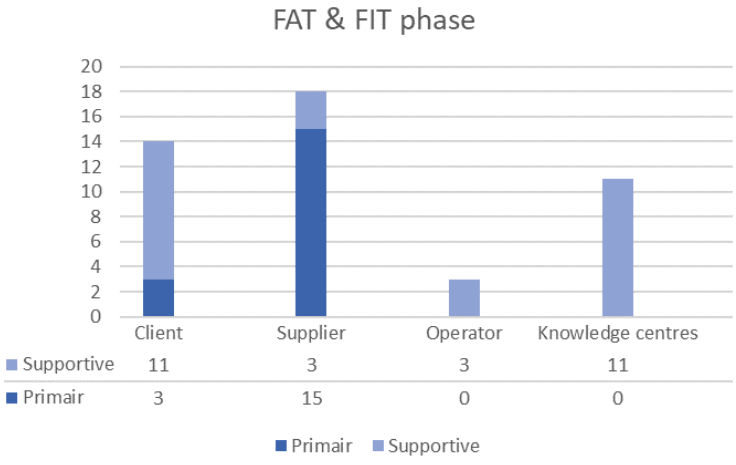
6.1 Which parties were involved?

The roles in the generic model are described in this paragraph. The primarily and supportive organisation have been distinguished for the five phases. These phases are FAT & FIT, Installation, Test phase, Trial phase, and Operation. For all phases, the number of cards per group is counted. Sometimes multiple cards have been put down under one phase. This means 2 or more parties were responsible for that phase. For instance, the contractor, the maintainer, the engineering consultant and the operator were a supportive organisation.

FAT & FIT

- Primarily responsible organisation
  - Client (3/18)
  - Supplier (15/18)

According to the interviewees, in the FAT & FIT phase, the suppliers were most often primarily responsible. In 15/18 interviews, the supplier was indicated as the most appropriate party to be held responsible. The reason for choosing the supplier is because of his technical knowhow of the systems.

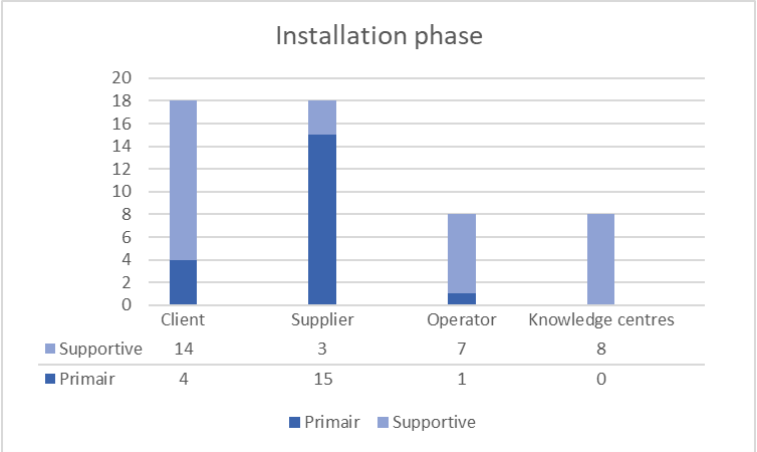


- Supportive organisation
  - Client (11/18)
  - Supplier (3/18)
  - Operator (3/18)
  - Knowledge centres (11/18)

The project organisation could fulfil a supportive role. Also, the engineering consultants had a supportive role with technical knowledge. The legal consultants were mentioned in small numbers. The university did not play a role. The operator was only involved three times during this phase. The other 15 interviewees said that the operator was later included.

Installation phase

- Primarily responsible organisation
    - Client (4/18)
    - Supplier (15/18)
    - Operator (1/18)



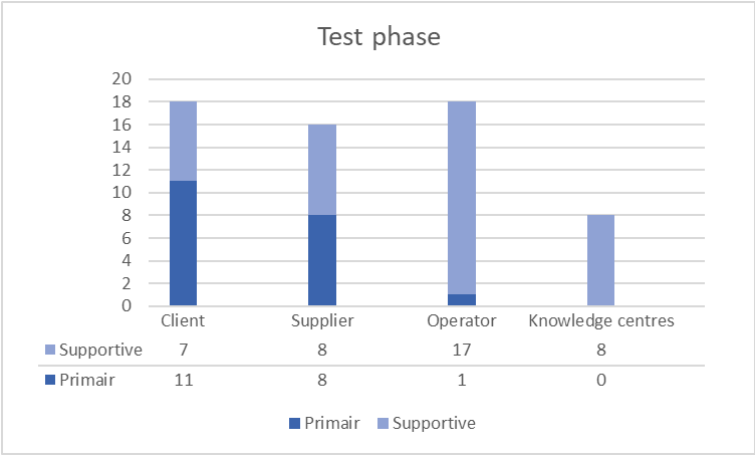
The installation phase is somewhat similar to the FAT & FIT phase. The supplier was most often primarily responsible, and the client had a supportive role. One interviewee mentioned that the operator in Dublin had the primary responsibility from the power on date at the end of the installation phase. Therefore, there were multiple parties primarily responsible during this phase. Another interviewee (project organisation) pointed out that the responsibilities between the contractor and project organisation switched after the SAT for the North-South line. From the SAT, the project organisation became primarily responsible. During construction, the project organisation decided that it was better if it had a more significant role in system integration. This was partly due to the many suppliers and the interfaces between them.

- Supportive organisation
    - Client (14/18)
    - Supplier (3/18)
    - Operator (7/18)
    - Knowledge centres (8/18)

The project organisation is fulfilling a supportive role. Moreover, the asset owner and transport authority had a supportive role as a governmental body. The engineering consultants had a supportive role as they provided technical knowledge. The legal consultants and university were mentioned in small numbers.

Test phase

- Primarily responsible organisation
    - Client (11/18)
    - Supplier (8/18)
    - Operator (1/18)



The test phase is where the infrastructure is integrated with the vehicles. Both the client and the suppliers have a significant role in this phase. Just over half of the interviewees said that the project organisation (on behalf of the client) was responsible and should be responsible for this phase. Interviewees who worked on the Uithoflijn represented a large part of the group who suggested that the main contractor (infrastructure supplier) could coordinate this phase. The main reason was that the main contractor had the technical knowledge of the infrastructure. One condition was that the vehicles were already driving in other cities to prevent having too many errors on the vehicles itself (interviewee project organisation).

Moreover, the main contractor and vehicle supplier should have mutual dependence since they need each other to perform the necessary tests. In the contract, an incentive to work together could be built-in. This way, they can put together a realistic scheme for the tests (interviewee client).

This would also be beneficial for the operator since he has to become familiar with driving the vehicles. One of the problems that occurred during the test phase is the delays of test drives. Sometimes it was cancelled just a couple of hours in advantage. An interviewee from the Hoekselijn said ‘Everything is scheduled for testing and then a few days prior to testing it appears that not every party is ready. Suddenly, it must be postponed again. The cables, sandbags or other material / equipment must then be dismantled and reinstalled several times. The costs are ultimately added up to the total project costs. Better coordination between contractor, vehicle supplier and transporter could reduce this problem.

One interviewee who was representing the project organisation for the Uithoflijn agreed on authorising the main contractor responsible for a part of the test phase for future projects. The technical knowledge is within the supplier’s organisation. The Interviewee said ‘It is good to let the contractor be involved in the test phase. Then there is no hard cut between delivering and starting a test phase. For example, certain systems could already be tested while others still had to be delivered. Otherwise, you would have had to wait until everything is delivered. In retrospect, there should have been room after the contractor's testing to get the client to perform tests. Latest technical issues can then be resolved instead of having the operator already run the timetable.’

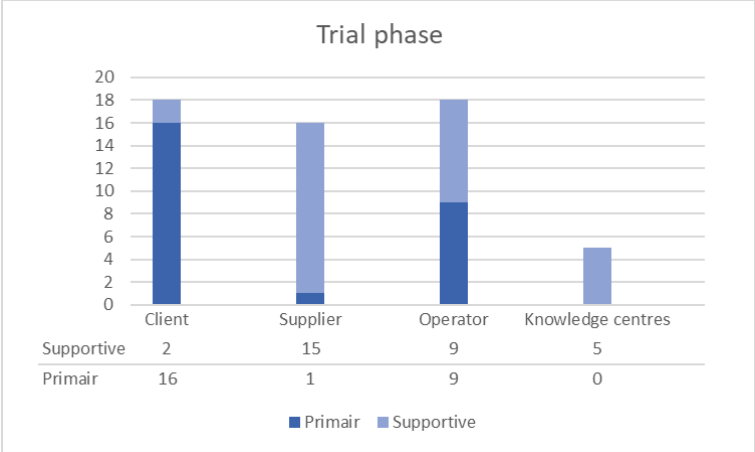
- Supportive organisation
    - Client (7/18)
    - Supplier (8/18)
    - Operator (17/18)
    - Knowledge centres (8/18)

The last major integral tests between all systems must be performed. Client, suppliers and operators are almost always involved. In addition, this is a phase transition where the operator must accept the line and other parties must execute maintenance for the coming years. This makes it a complex phase with many stakeholders.

The suppliers who have built and installed their equipment want to deliver and move to the next project. This phase is usually not profitable for them. The operator wants to be guaranteed that everything runs perfectly because they have to generate income from selling tickets. The operator wants a well working system since it would only cost them more if problems occur during operation. The maintenance parties also want to have a high-quality light rail system. The conflicting interests of the contractor and operator & maintenance parties have to be sorted out by an umbrella organisation such as the client's project organisation.

Trial phase

- Primarily responsible organisation
    - Client (16/18)
    - Supplier (1/18)
    - Operator (9/18)



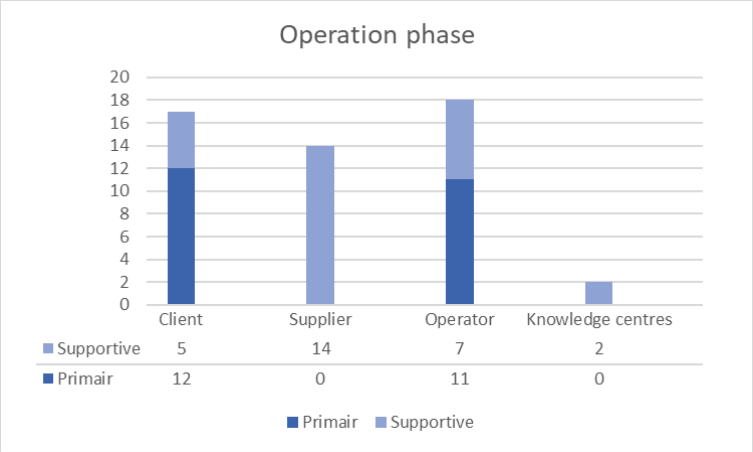
The client is still heavenly involved during the trial phase. The transport authority, asset owner and project organisation have had a role during the trial phase in most projects. This should not be changed according to the interviewees. The operator is involved since all tram and metro drivers are required. The interviewees were divided on the role of the operator. Half of the interviewees said that the operator was primarily responsible, often together with the client. The other half looked upon the operator as a supportive organisation during the trial phase.

- Supportive organisation
    - Client (2/18)
    - Supplier (15/18)
    - Operator (9/18)
    - Knowledge centres (5/18)

The contractors (suppliers) have become supportive organisations in the trial phase. While the maintenance parties for the infrastructure and vehicles start to become actively involved. The operator is coaching their new drivers, security & safety personnel and the control room operators. Knowledge centres had a minor role; engineering consultants were hardly needed. Some legal disputes were solved with the help of legal consultants.

Operation phase

- Primarily responsible organisation
  - Client (12/18)
  - Operator (11/18)



The client and operator are the only two parties that have a primarily responsible role in the operation phase. Often mentioned was a combination of the operator together with asset owner and transport authority. Amsterdam, Rotterdam and Utrecht all have different transport authorities. These are respectively; The Vervoerregio Amsterdam, Metropoolregio Rotterdam Den Haag and Provincie Utrecht. The operators are GVB, RET, HTM and Qbuzz. Combinations of these parties were responsible for the operation service.

- Supportive organisation
  - Client (5/18)
  - Supplier (14/18)
  - Operator (7/18)
  - Knowledge centres (2/18)

Only two interviewees indicated that the legal consultants were still involved and had a supportive role. The other interviewees mentioned that their role was not significant anymore. The work has fully started in operation for the maintenance parties. They play a vital supportive role during the operation phase.

Conclusion

Almost all the parties which were put on the cards were involved in some part of the Test & Commissioning phase. Only the university was not mentioned as having an active role during the T&C phase. There were also cards without a name on them. Interviewees could write down additional parties. This has been done several times and the following cards where;

- Independent arbitrator (Knowledge centre)
- Ancillary contractor (Supplier)
- ISA/NoBo/Asbo (Safety related parties)

The interviewees said that they would not change the parties who were involved. However, in hindsight, it would have sometimes been better to choose another supplier, but you never know which parties cannot deliver what they promise (2 clients). This is difficult for clients and main contractors since the works have been procured following European rules. The interviewees did indicate changes on when certain parties should be involved. Some parties were involved too late, and others left the project too soon. This is addressed in the next paragraph.

6.2 When should the parties be involved?

When the primarily responsible parties are summed together with the supportive parties, there is a distribution over time of these parties. If the main contractor was liable over subcontractors, then these are seen as one group of suppliers.

From this analysis, the parties involved per phase of the project can be derived. During the FAT, the suppliers were always involved, and only a few operators were involved. This developed over time, as can be seen in Figure 12. There were 18 interviews; thus, the maximum number of times one party can be involved is 18 per phase. All 18 interviewees said that the supplier was involved during the FAT/FIT and Installation. Therefore, this value is 18. The operator was always involved during the operation phase. It can be seen that the supplier and knowledge centres decline in involvement over time while the operator is increasingly getting involved. A table with all values can be found in appendix 7.

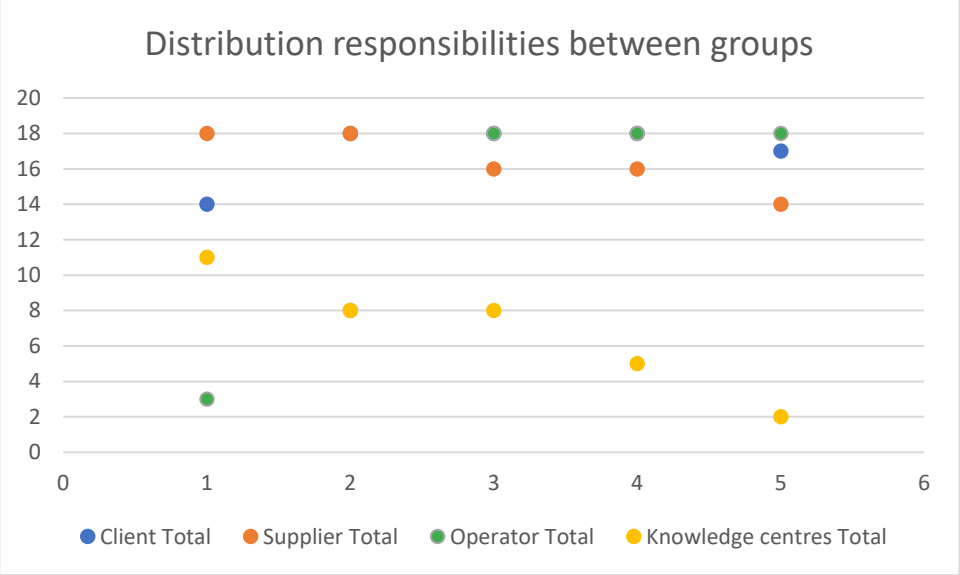


Figure 12 Involvement parties

Earlier involvement of the operator

In the last phase of the project, the operator is involved in the project and eventually accepts the project. However, due to the deviation of the original master plan (Interviewee Client) or not having the proper documentation (Interviewee Client), the operator could not accept the project in time. Therefore, the operator should be involved earlier in the project.

An operator mentioned ‘when the main contractor tests its own systems, he could perform minimal effort since he approves his own work. During the trial phase, the client and operator can encounter problems that the main contractor should have solved during the test phase. Problems could emerge when the contractor has already handed over the project. Even if the contractor is liable, the client usually does not want a lawsuit. The operator wanted to be involved earlier to impart their knowledge and learn about the new system. Possible problems could be encountered sooner. A solution would be to let the project organisation take responsibility (halfway) during the test phase. Then problems could have been solved with the test phase instead of the trial phase.

Number of parties involved

Interviewees indicated that the test and trial phase was complicated to manage due to a large number of parties with various responsibilities. In figure 13, the accumulated number of groups (source; client, supplier, operator, knowledge centres) are visualised.

The high number of groups involved during the test phase and the trial phase is because more supportive organisations were involved. The number of persons working on the project could be higher in the FAT/FIT or installation phase because the contractor and subcontractors have many workers. These are all steered by the contractor, which is easily managed. However, a high number of different groups is more difficult to manage. As stated in paragraph 4.1, there needs to be a party capable of handling all the stakeholders. Compared to other construction projects, light rail has a high number of groups involved in the Test & Commissioning phase (source; project organisation).

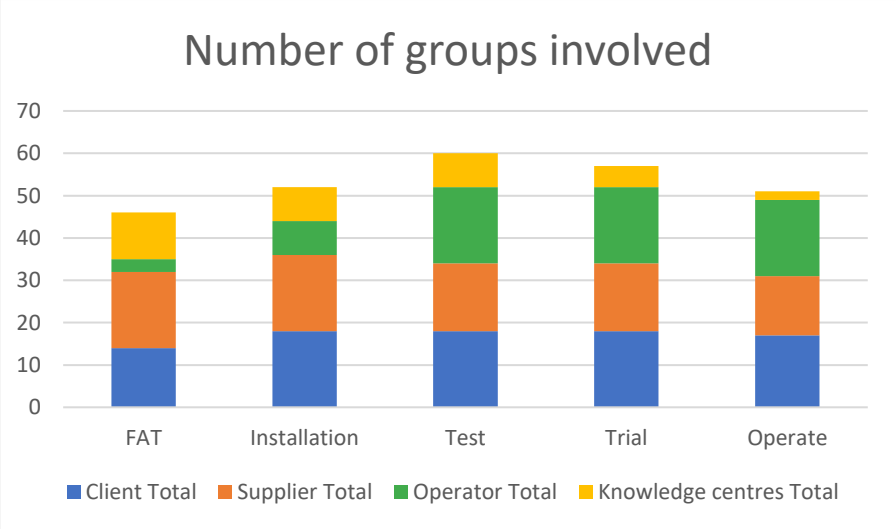


Figure 13 Number of groups involved

6.3 Four types of organisational structures

The organisational structures found in literature can be found in 3.5 ‘Types of organisations for Test & Commissioning phase’. These have been compared with the organisations found during the interviews.

The type of organisation for the project is related to the organisation of the Test & Commissioning phase. These cannot be seen separately. As an example, if the project has a fully integrated structure, the client is unlikely to perform their own Test & Commissioning phase. The design, build, Test & Commissioning, maintenance and possibly finance and operation are executed by the contractor.

That being said, the focus point during the interviews was from the installation phase to operation. Thus, the question of whether the design and build phase should have been in a traditional form or integrated form has not been addressed. All the interviewees worked on integrated contracts, and none of them made a comment that the design and building should be separated. The benefit of the integrated contract is that the design and construction overlap which leads to savings in time. In a study from the San Francisco transportation plan, it is suggested that this method saves around 8 to 10 months on average for transit projects (Transportation Authority San Francisco County, 2013). Therefore, all the suggested organisational forms are integrated. The

organisational structures differ in responsibilities for the client and supplier, and this also has an influence on the handover to the operator. An overview of the four types of organisations is visualised in figure 14. This is a simplified version in which the activities are left out. The full version is displayed in the explanation in the subsequent paragraphs.

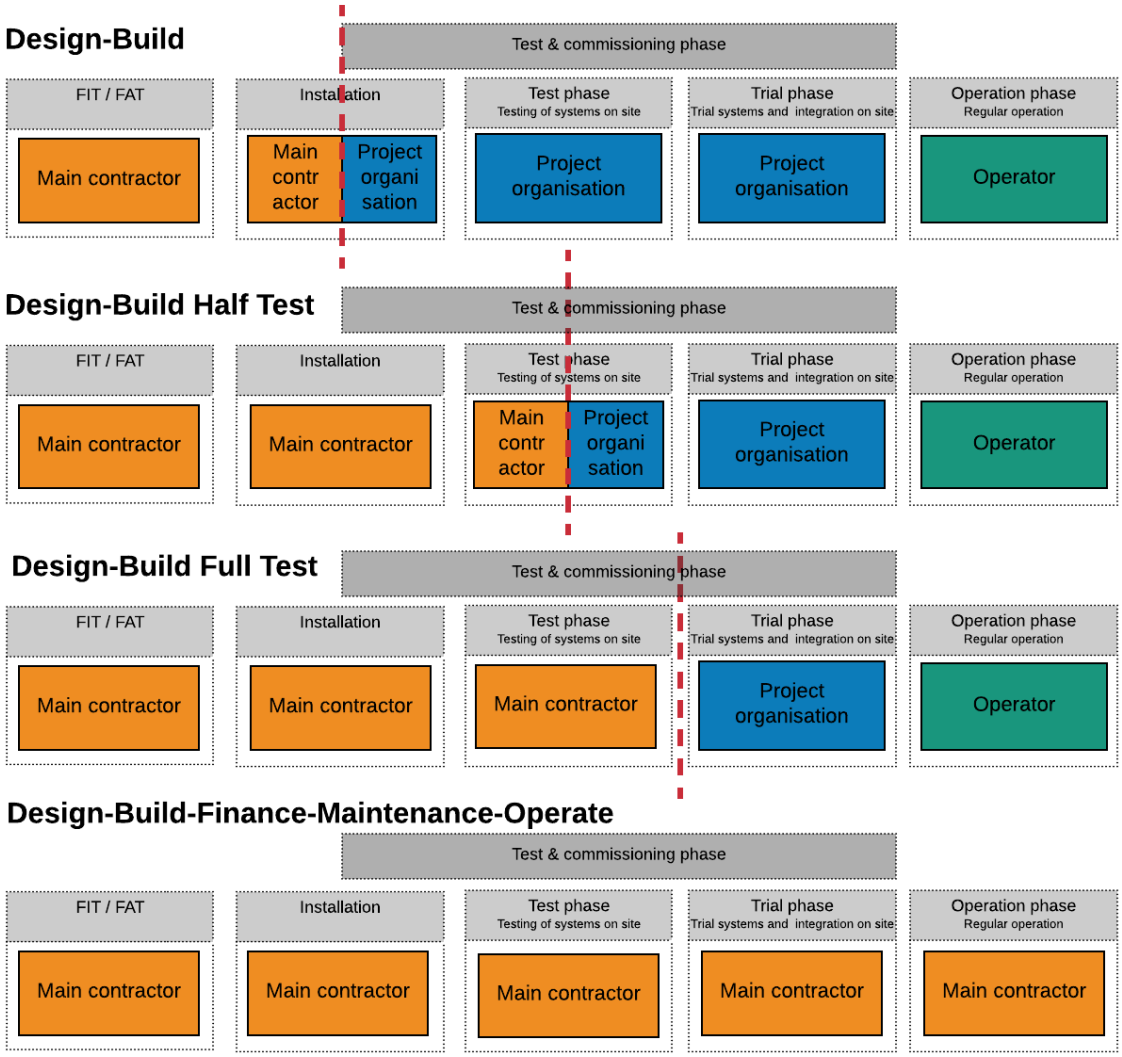


Figure 14 Types of organisational structures

The organisational structures discovered in the interviews are discussed and compared with literature. The interviewees' preferences could be divided into two groups:

- Semi-integrated organisational structure
- Fully integrated organisational structure

The first three organisational structures belong to the semi-integrated organisational structure. The project is handed over from the main contractor to the project organisation at the red dotted line. For the fully integrated organisational structure, the main contractor remains responsible throughout the project and in operation.

6.3.1 The semi-integrated organisational structure

The semi-integrated organisation has been mentioned the most during the interviews. The semi-integrated organisational structure is characterised by the fact that the client is handed over the project before, during or after the test phase. This implies that at least the trial phase and handover to the operator are the responsibility of the client. The exact point of the handover between contractor and client still differs depending on multiple factors. This could be done directly after building, after specific system integration tests, after the power on date or another moment. The organisation and contract determine until which point in time the contractor is responsible. The semi-integrated organisations could be divided into subgroups as well.

- Design-Build
- Design-Build Half Test
- Design-Build Full Test

- Design-Build

Design-Build stops directly after the Site Acceptance Test (SAT), as visualised in figure 15 on the next page. The suppliers are installing their equipment on-site, and then the project management takes the role of coordinator for system integration. The coordination of the Test & Commissioning phase is the responsibility of the client. The suppliers, operator and knowledge centres maintain having a supportive role until the operation phase. The role of the contractors is limited since the project is already handed over to the client. This poses a potential risk for the client since the contractors are less involved. Luas Line and West Midlands Metro Birmingham are examples of a Design-Build organisation.

Potential risks	The main contractor could deliver minimal quality
	The project organisation is not capable of coordinating
Potential benefits	The project organisation can steer the project from an early stage in the project
	Interfaces with other projects and processes can be managed by the client

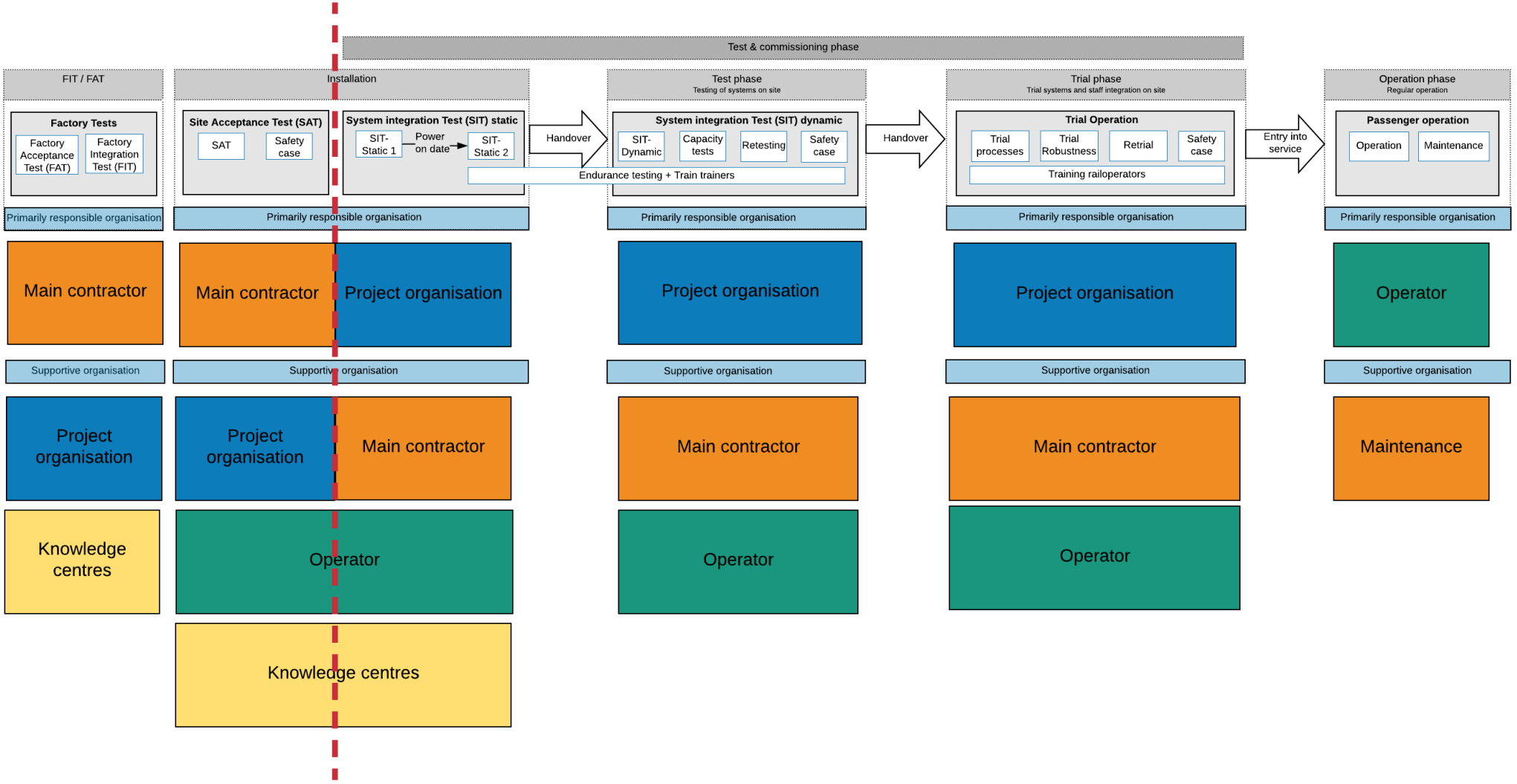


Figure 15 Design-Build Organisation

- Design-Build Half Test

Within this organisation, the test phase is split up in two stages. The main contractor coordinates part of the test phase and decides upon the testing schemes. The main contractor executes the first tests and coordinates the system integration. He is performing tests to prove that his equipment and system works according to his specifications. This is quite similar as has been done for the Uithoflijn. However, in the second half of the test phase, the project is handed over to the client. Tests related to the operator can be executed on behalf of the project organisation. This must be done to let the operator and asset owner accept the system. In this second half, the project organisation can prove that everything works according to the specifications of the client and satisfy the operator. The downside of this organisational structure is the soft separation within the test phase. Thus, strict agreements must be made beforehand. The client must deliberate on what they minimally require from the contractor before they can accept the handover. There usually is remaining work which could be done after the handover to speed up the process.

The suggestion for this organisational structure came from the project organisation and operator from the Uithoflijn. They both suggested that it would have been better if the project organisation had some more time to do tests before moving to the trial phase.

The North-South line and Hoekselijn were examples of the Design-Build Half Test organisation. The main contractors performed part of the tests and then the project was handed over to the project organisation. They coordinated the second part of the test phase and the full trial phase together with the operator.

Potential risks	Difficult to make a hard division between the responsibilities of the main contractor and project organisation. The main contractor has limited control over other projects and processes.
Potential benefits	The main contractor demonstrates to the client and operator that the systems work. The project organisation has time to perform additional tests more relevant for the client and operator.

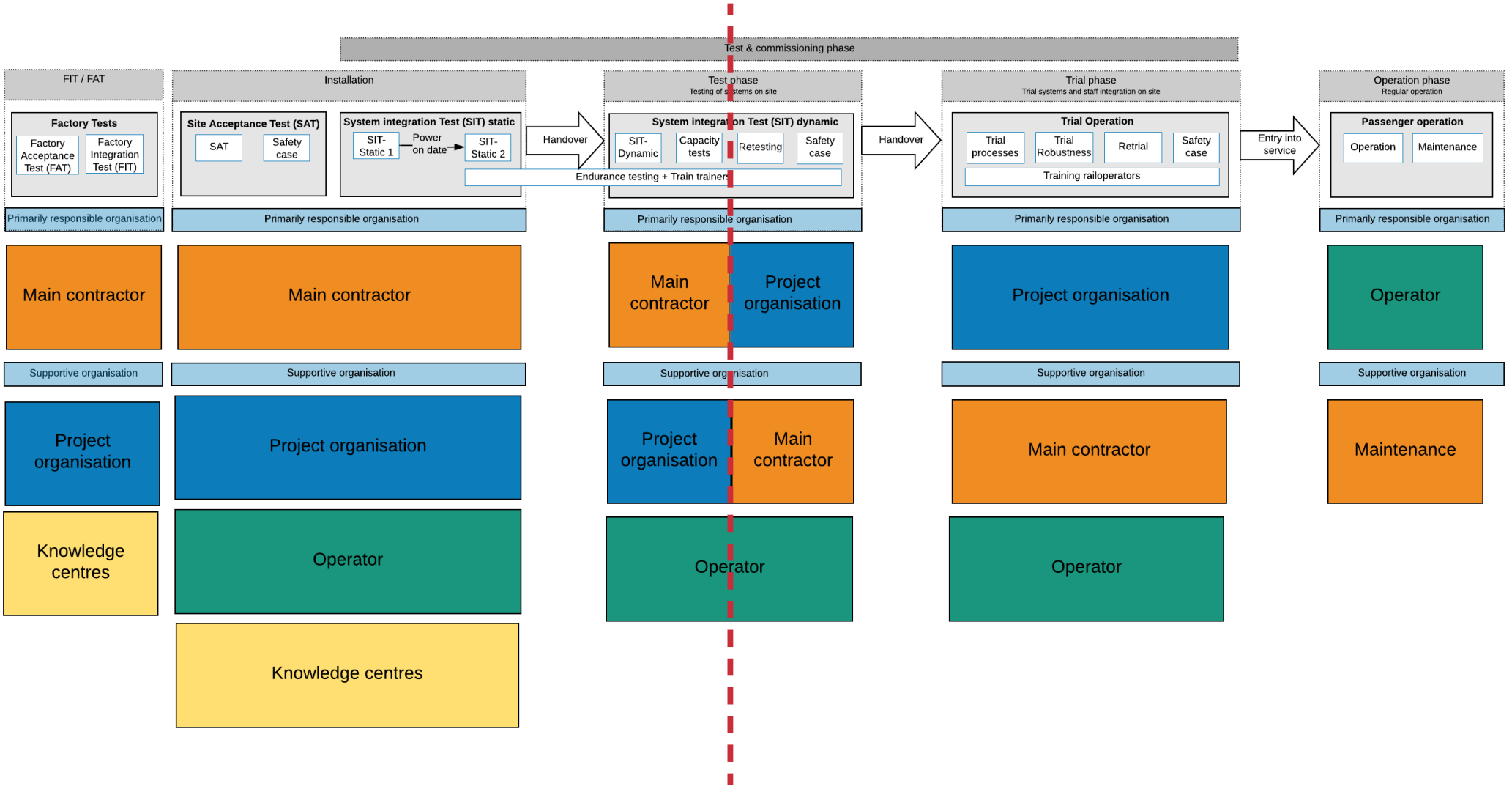


Figure 16 Design-Build Half Test

- Design-Build Full Test

In the Design-Build Full Test organisation, the main contractor is handing over the project to the project organisation from the test phase to the trial phase. This implies that the full responsibility of the coordinating task during the test phase is for the main contractor. The benefit of this organisational structure is the strict segregation between the test phase and trial phase.

This organisation is similar to the one in the Uithoflijn. For this project, the operator claimed that the main contractor was testing his own equipment and thus accepted his own system. This could reduce the quality of the system. If the client had tested the system, it could have been stricter according to the operator. Also, the East London line is an examples of Design-Build Full Test organisation.

Potential risks	The main contractor is possibly not able to coordinate all parties due to difficult contractual relations
	The main contractor has limited control over other projects and processes.
	The project organisation cannot influence the test phase.
Potential benefits	The main contractor has the technical knowledge and performs the system integration
	Beneficial for the client since this implies less coordination for him.

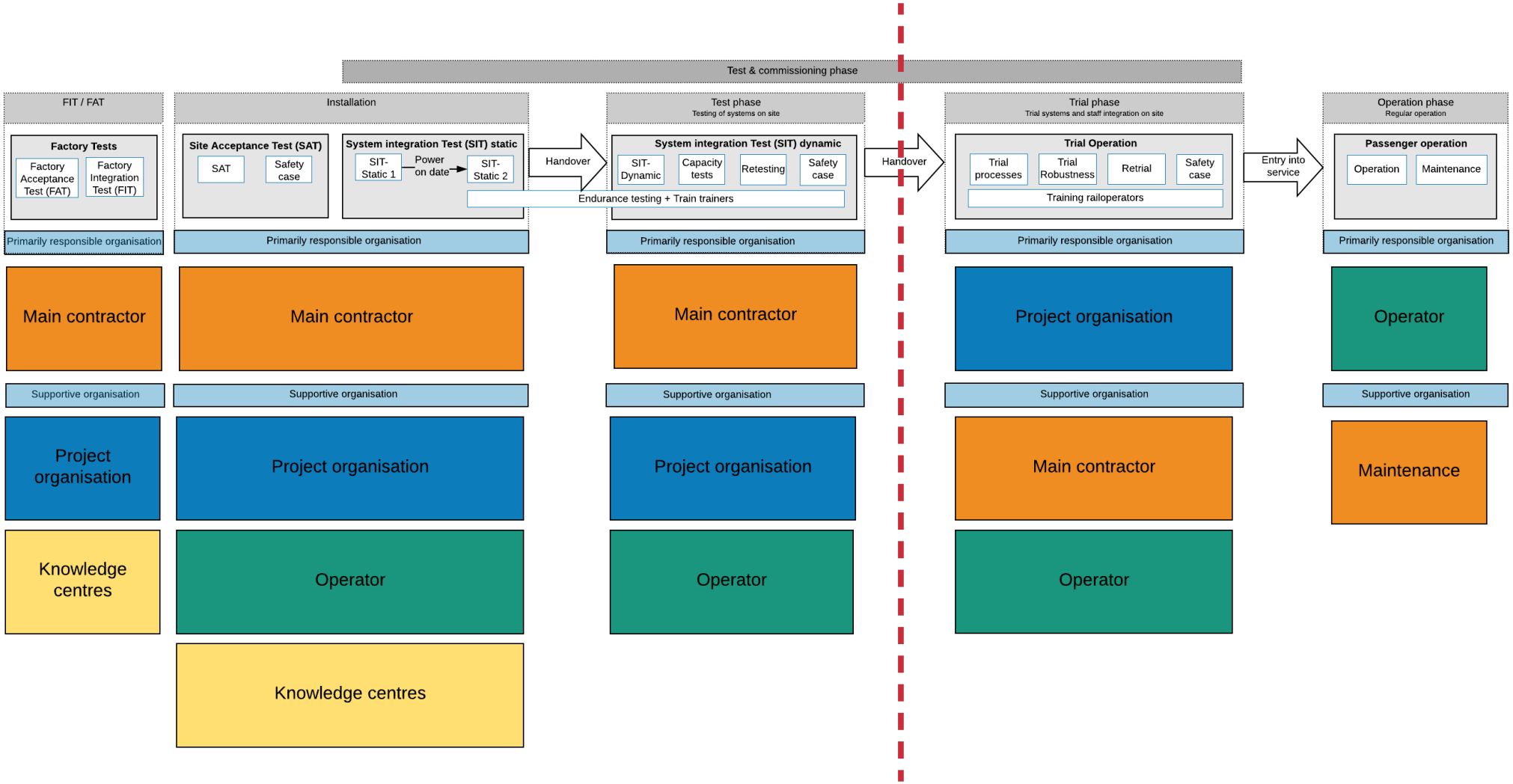


Figure 17 Design-Build Full test

6.3.2 Fully-integrated organisational structure

- Design-Build-Finance-Maintenance-Operate

For the 6 cases, the main contractor was usually primarily responsible until installation or until test phase. One of the questions asked was what could be improved and whether it would have been better if the main contractor had a fully integrated organisational structure. Multiple interviewees mentioned that it would be better if the main contractor would also be responsible for the maintenance part. The duration for the maintenance should be at least 5 years, but preferably between 10 and 20 years. In a Design-Build contract, contractors tender for the lowest price and the quality of the materials is reduced. But when contractors are responsible for the maintenance, they would be stimulated to think about the long-term. This would imply higher costs during the build phase but savings on maintenance work. Assuming that the contractor would still earn the same percentage fee on the project, his charge to the client is lower.

Eventually, this could be cheaper for the client since the overall project cost decline. This would also be beneficial for the taxpayer. This type of organisation would be most appropriate in a greenfield environment. In a greenfield environment, there are limited interfaces with other projects and processes. Thus, this could be managed more easily by the main contractor. It must be stated that most light rail projects are built in a brownfield environment within a dense and urban city. For the RegioTram Groningen a DBFM has been selected, this project has never been finished and stopped in 2012. It showed the financial risks for this organisational structure.

Potential risks	Too difficult for the main contractor
	The client cannot directly control the project
Potential benefits	Fewer risks for the client since these are transferred to market parties

Conclusion

Above four organisational structures are visualised. It is not possible to pick one structure that would always be considered the best option. Neither is it possible to count the number of times interviewees were in favour of one of the organisational structures. This is due to the fact that this depends on multiple factors, including the project characteristics. Each project is unique, and there should be assessed which organisation fits best.

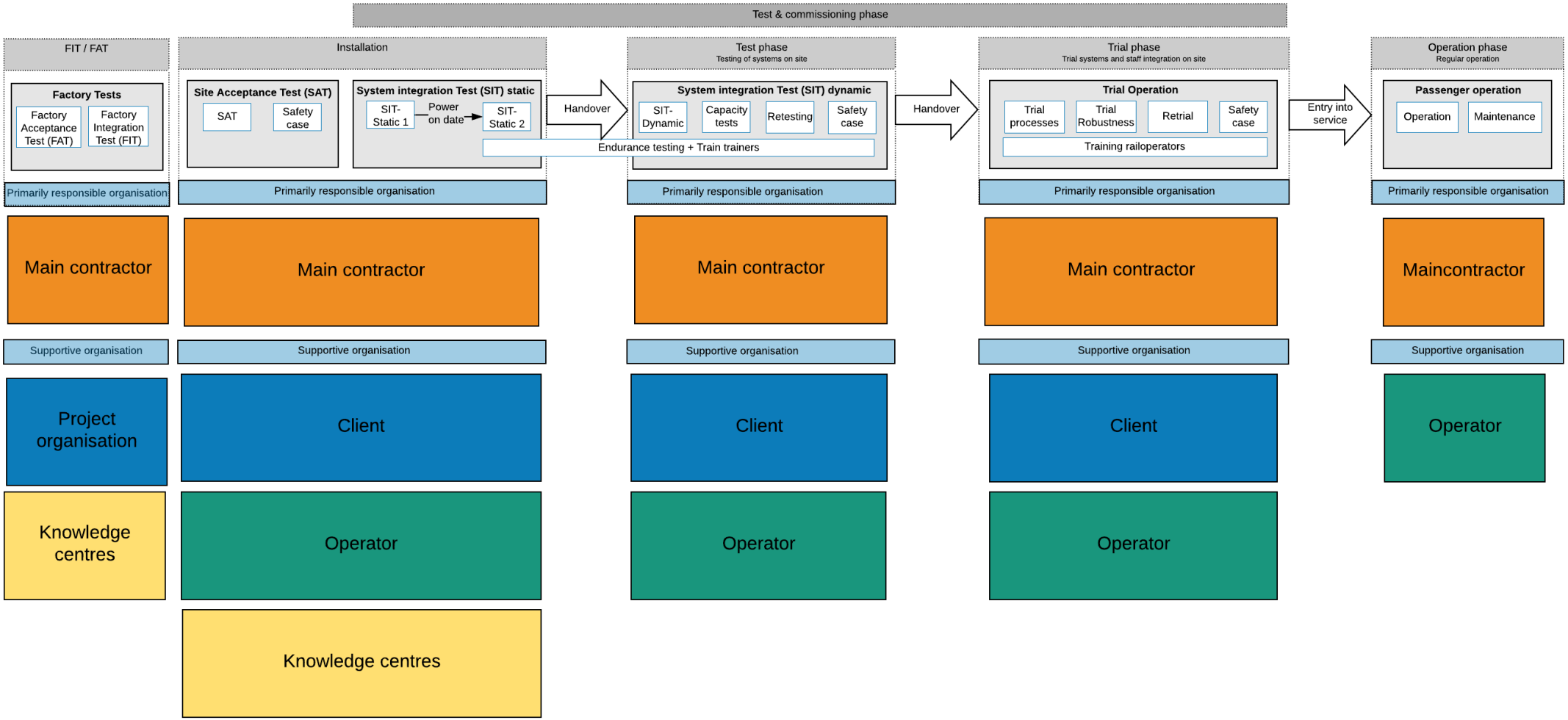


Figure 18 Design-Build-Finance-Maintenance-Operate

6.3.3 Organisation of Test & Commissioning phase is not the critical factor

Multiple interviewees were sceptical on the influence the type of organisation has during the Test & Commissioning phase. The division of roles was not a significant success factor. According to these respondents, it does not really matter whether the client or main contractor has the primary coordinating responsibility. There were other reasons why projects were a success or failed. It is essential that:

1. Parties know what to expect from each other
2. Client and contractor cooperate in the project team

The responsibilities for the Uithoflijn were clearly specified (source: client & knowledge centre). The main contractor had to perform tests up to a certain point. There were clear agreements and the parties managed to adhere to these. 'The clarity of these agreements is more important than who is responsible until when. The cooperation between the parties was crucial. The parties must; have the right competences, respect each other, collaborate and create added value' (knowledge centre). The interviewee thinks that this handover of responsibilities during the T&C phase is less trivial. Although the difference between brownfield and greenfield does have its influence on the responsibilities. 'In a brownfield environment, the client should be the party responsible for managing the interfaces between other projects and processes. In a greenfield, the main contractor could bear more responsibilities.'

Other interviewees (client and knowledge centre) mention the social engagement which is needed to let a project become a success. The resident, people who are living and working in the project's environment need to be involved. Currently, there is a lack of empathic capabilities. Light rail projects like Hoekselijn and RandstadRail were scheduled too tight. Subsequently, the projects are delayed, residents experience nuisance, and too little is communicated. Nobody understands how this could have happened. This makes it challenging to create a positive image of light rail projects. Thus, involving the residents and planning more widely has a more significant impact on the project than the organisation of the T&C phase. The communication strategy for the North-South Line changed from technical to more human over the course of the project. Eventually, the residents were updated more often, even in setbacks. This was received more positively (Interviewee North-South Line).

6.3.4 Differences between perspectives of the parties

One of the motivations for this research was the curiosity whether the parties (client, supplier, operator and knowledge centre) would have different perspectives. Would they all point the finger at each other on what is going wrong with light rail projects or are they like-minded in terms of improvements. First of all, a disclaimer must be made that the size of the groups is too small to point out any significant results. Based on these interviews:

The perspectives from client, supplier, operator and knowledge centres did not much differ.

The interviewees did give different perspectives on improvements for the Test & Commissioning phase of light rail projects. Some interviewees were extremely in favour of fully integrated contracts and others opposed. There was, however, no clear sign of distinctive division between the client, supplier, operator and knowledge centres. Some clients supported the integrated contracts since they wanted to let market parties take risks while others preferred to let their own team perform the testing and commissioning.

The different perspectives depended more on the project that parties had been working on. There was a contrast between the North-South line and the Uithoflijn.

The parties who worked on the Uithoflijn were more enthusiastic about main contractor involvement in the T&C phase. Hoekselijn and North-South line respondents were more conservative on letting the contractor having extensive responsibilities.

With the Uithoflijn, the main contractor was able to perform system integration well. In the case of the North-South line, this responsibility went back to the client halfway through the project, making them more conservative in this regard. There was a clear distinction between the interviewees and how they thought about letting the main contractor handle the test phase. The interviewees who worked on the Uithoflijn were much more positive about the main contractor and their responsibilities during the test phase.

Results of analysis of the organisational structure

The main findings from the generic model have been enumerated below:

- FAT, FIT and installation is almost always the responsibility of the suppliers (contractors and manufacturers). And the interviewees see this as logical and it should not change.
- During the Test phase, most parties are involved, these work for all disciplines, (client, supplier, operator and knowledge centres). This makes it complex to coordinate.
- Operation phase is coordinated by a combination of operator and asset owner. They steer the maintenance party.
- For larger projects, the project organisation should take primary responsibility and control earlier. (On the condition that the client is sufficiently capable and experienced).
- The operator is in some projects involved during installation and system integration tests, from the test phase, he is always involved.
- The operator should be involved from an earlier stage.
- While residents are an important stakeholder, the active involvement of residents is limited and could be enhanced.

Four types of organisations for T&C phase were found during the interviews. No significant differences in the perspectives of the various parties were observed for the organisation of the T&C phase. Parties who were involved at the Uithoflijn were positive on the role of the contractor as the system integrator. Multiple interviewees mentioned that the organisation of the Test & Commissioning phase isn't the critical success factor. In their view, a successful Test & Commissioning phase depends on the cooperation between the different parties. This could be arranged in all organisational structures.

6.4 Conditions for successful implementation of the organisational structure

This paragraph provides the answer to the fourth and final research question. It has been researched what the conditions are for a successful implementation of the organisational structure is. In the following paragraph, the lessons learned for light rail projects are discussed (6.4.1) . Then, the aspects that should be considered during the procurement strategy are described (6.4.2). Those include the early decisions which need to be made for a successful Test & Commissioning phase.

6.4.1 Lessons learned

An interviewee (knowledge centre) said that the people in the organisations change over time during long-term projects. This is adverse to the continuity of the project. When new people join the organisation, it is difficult to transfer the knowledge on the prior history of the project. This implies that in the beginning, technical decisions have been made and that people who join the

project later can alter these decisions. There is a lack of knowledge transfer within the project. But also, over the projects could be learned. A member of the project organisation for the Uithoflijn claims that projects are not as unique as people think. Standards could provide guidance for future projects. For instance, checklists with what a client and contractor must do. The respondent already noticed that there is little exchange of knowledge on the extension of the Uithoflijn to the SUNJI line. The project organisation saw this happening in Dublin as well. 'For an extension of the line, it is important to know what went wrong with the original line and take the lessons learned. It is important to speak to the operator, infra maintenance parties etc. Then you must sign them up to work together for the new line.'

And why are these lessons learned not shared then? The interviewee mentioned: 'Lessons learned are kept private. If something failed, you keep it out from the public. You let nobody know and bury it. Otherwise, it may have consequences. This means that the same mistakes could be made again. Luckily the people who worked on a project keep it in mind.' The role of the respondent and other senior consultants is to pass on the lessons learned. The lessons learned should be more open and transparent so that they could be used for the scope of a new project. It is challenging to make this cultural change and become more open and transparent. Other interviewees (Clients, knowledge centres) confirm that a lot of knowledge is lost after a project.

However, some others were more positive. One client mentioned: 'For large projects, the focus is on knowledge exchange. For instance, Neerlandsdiep, where large clients are affiliated, and project managers learn from each other's experience. This is organised knowledge exchange.' People learn over the projects and they take that knowledge with them to subsequent projects. Rail Forum also consists of people who exchange experience in the field of system integration for light rail projects.

A knowledge centre for these types of projects would be very sensible, according to multiple interviewees. This should be funded by the government. New projects can use the experience from past projects and learn from them. This should be organised nationally, so different municipalities and provinces can make use of this.

6.4.2 Considerations for the procuring strategy

Decisions on the organisation of a Test & Commissioning phase must be made during the procurement strategy. The interviewees were asked about the improvements to the organisational structure and how this could be juridically enhanced. One of the suppliers mentioned: Minimizing delays and work efficiently should be the main priority (Supplier).

How can this be accomplished? One of the causes of these delays is the self-interest of the involved parties. This has been brought up by the Client, Project organisation, Supplier, and Knowledge centre. Besides the self-interest of parties, there was also a solution which was broadly based. The establishment of a Bouwteam and early involvement of parties could increase the collaboration. The findings on the reduction of self-interest, collaboration agreement and early involvement are discussed in the following paragraphs.

- Reduce self-interest parties

A project benefits from optimum collaboration. An interviewee (supplier) noticed that parties try to minimise risks and optimise profits at the expense of the total project. Suppliers are defensive if changes are needed. While the client wants that parties should act in favour of the project and would care less about their own interests. They must operate as a team and create common interest. Unfortunately, this is easier said than done. For suppliers, it is hard to change this mentality since they compete in the market. Therefore, the client needs to be pro-active in stimulating the parties. This could be accomplished by providing an excellent organisational

structure and positive financial incentives. The client can establish contracts in which the parties are legally obliged to cooperate. For several cases, the suppliers already had to hand in a plan for how they would cooperate with other parties. This sometimes is one of the criteria during the tender period. But it is challenging to let parties commit to these contractual agreements since these are often soft criteria and hard to measure. Therefore, financial incentives are deployed to reduce project delays.

- Collaboration agreement

The word Bouwteam (collaboration agreement) was mentioned several times during the interviews. The Bouwteam could enhance the collaboration in the early phase of the project and also during the T&C phase. First, the Bouwteam has been explained as described in the literature. Then the suggestions of the interviewees are clarified.

A collaboration agreement (Dutch: Bouwteam) is a project-based collaboration between a client and one expert or several experts who, in a coordinated context, work together on the design, the engineering of the design and the construction (Riggelen, 2019). The aim of the Bouwteam is to jointly arrive at an implementation-oriented design that can then be realised. The collaboration is established at the start of the design process and before the tender. In principle, the Bouwteam has a duration for the duration of one specific construction project.

The benefits of a Bouwteam is the stimulation of the collaboration between client, contractor and other suppliers. This is especially useful for projects with some degree of complexity, such as time pressure, tight budget, no clear scope definition, large risks or other uncertainties (Koenen, 2019).

In the literature, the Bouwteam is focussed on the early phase of the project. This is beneficial for the design and to align the planning for system integration. When the systems must be integrated in the T&C phase, it is still a benefit to sit together with the same group of people who initiated the plan. The interviewees suggested that at least the following parties should be included:

- Client
- Project organisation
- Main contractor
- Vehicle supplier
- Operator
- Other large suppliers
- Engineering consultant*
- Legal consultant*

*The group should not become too big, thus depending on the phase of the project they should be in- or excluded.

Light rail projects have many stakeholders involved in the Test & Commissioning phase compared to other construction projects. This makes it complicated to manage. Therefore, these stakeholders should collaborate and be coordinated by one party. This could be the project organisation or an independent party. Their focus should be on what is best for the project.

The integration of all systems is difficult because of the interfaces between different stakeholders. A Bouwteam can help solve problems in system integration. If changes in the original plan are needed, then parties should be flexible and help each other to solve it. The party who could fix the problem with minimum costs should do it, on the condition that the party has the resources (Client, Project organisation and Supplier). ‘This should be done instead of focussing on the contract too much. Perhaps the problem would be costly for one party (who should do it contract

wise) but could be solved cheaper by another party' (Knowledge centre). It is then in the interest of the project that it is rectified with minimum costs and maximum quality. The compensation could be discussed at that moment or afterwards. This flexibility speeds up the decision making and thus the project delivery.

Two interviewees (Project organisation and Supplier) agreed on the Bouwteam but emphasised on the hierarchical level of this group. The involved parties should be represented by people who are working on an operational level within the project. Otherwise, if only high ranked managers and directors are sitting at the table, it could result in legal issues. The group should be solution-oriented and should not escalate too quickly to their supervisors. Another point mentioned by a supplier is that the Bouwteam must be able to meet directly. An appointment should not have to wait for two weeks to be scheduled. Depending on the situation, you involve specific disciplines. The interviewee also suggests that an independent third party could be involved. In Dublin, this independent technical and legal adviser was already directly involved from the start of the project.

- Early involvement of parties

System integration is an essential aspect of the Test & Commissioning phase, as stated in paragraph 3.5, where the V-line model is explained. System integration corresponds to the right-hand side of the V-line model. However, the integration activities are planned well in advance during the design (Sharma). An interviewee (Supplier) claimed that reversed system engineering is an important aspect. The question needed to be asked was; What is needed to create an integrated transport system? Parties should have been organised more flexible to come to solutions. A client said that for all projects there had been put much thought about the interfaces between processes. For the Hoekselijn this has been mapped as well, and the suppliers knew their role and interfaces with other parties. Thus, clients know the importance of system integration although it remains a difficult task to execute successfully since unexpected occurrences always happen. For successful system integration, it is crucial to have all concerned parties involved.

Furthermore, suppliers, clients and operators all agreed on the earlier involvement of the operator and asset manager. For a successful handover from Test & Commissioning to handover, the approval of these parties is needed. Without the successful adoption of these parties, the system cannot move into the operation phase. Although the client and suppliers are already occupied with other tasks around the project, they should increase the involvement of the operator and asset manager. A person from a project organisation also suggests that the Security & Safety personal had to be involved earlier as well. At least from the Trial phase or preferably earlier. The earlier involvement should be effective as well since it brings along costs when more parties are involved for a longer time.

6.5 Analysis conditions and organisational structure

In paragraph 6.3, four types of organisational structures have been described. Subsequently, the conditions for a successful implementation of the organisational structure are outlined. In this paragraph, the relation between the organisational structures and conditions for successful implementation are described.

The three conditions that could enhance the success of the Test & Commissioning phase were (1) Reduce self-interest, (2) Collaboration agreement, (3) Earlier involvement of parties. In the following paragraphs, these are connected to the organisation structure in which they are critical.

Design-Build

The (1) self-interest of parties is particularly a problem for the Design-Build organisation in which the suppliers are installing their equipment and do not coordinate system integration themselves. Risks are that the main contractor or other suppliers deliver less quality. The risk for the client is that equipment is accepted during Test & Commissioning and that it breaks down during operation. Afterwards, it is hard to prove that the quality was not sufficient or that the equipment was not correctly handled. Another risk is that one of the suppliers cannot deliver in time. This gives problems for the integration of the system and could result in delays. Therefore, the interfaces between parties must be managed in this phase with extra care.

A solution is that the client builds financial incentives in the contract. For instance, when deadlines are met by all parties, they get a bonus. This increases the willingness to cooperate and increases communication on the interfaces of parties. The idea is that the stakeholders make firm agreements beforehand. The project organisation could also increase guiding the stakeholders more proactive. Actively managing stakeholders and financial incentives are especially vital for this organisation form.

The (3) earlier involvement of parties should be managed by the client. He should decide which party should be when involved. The client will guide these parties with the help of the project organisation. Usually, the project organisation should be capable of including the parties on time. From past projects can be learned that the operator could be involved earlier.

Design-Build Half Test

During this phase, the (2) collaboration between the main contractor and project organisation is especially crucial. These two parties are required to cooperate due to the handover during the Test phase. The responsibilities and expectations of the parties have to be clearly specified. However, the parties should not be too strict on these responsibilities. If the main contractor can help the client or vice versa by performing specific tests they should do that. By being flexible in the test schedule, activities can be executed more efficiently. For instance, when one test is not yet ready, the contractor and client should quickly communicate for an alternative. Communication between the parties is critical for successful Testing & Commissioning. Not only the contractor and client need to collaborate. The other stakeholders need to be actively involved as well since the responsibilities switch during the test phase. The collaboration agreement in the form of a Bouwteam is especially relevant for this organisation.

The (1) self-interest of the supplier is automatically reduced by having the main contractor responsible for the installation and part of the test phase. It is in the own interest of the main contractor to align the work and collaborate on the interfaces with other parties. Therefore, the reduction of self-interest is less important in this phase than it is for the Design-Build form. However, the long-term maintenance is the responsibility of another party; thus, the suppliers

could take advantage of this. For a DBFMO contract, the self-interest of the main contractor is reduced even more.

Design-Build Full Test

In this organisational form, there is a stricter separation between the role of the contractor and client. This could make it easier to agree on the responsibilities. The (2) collaboration between the parties is still crucial for a successful handover from Test phase to Trial phase. Therefore, a collaboration agreement between the parties would still be favourable.

Another important aspect is that the main contractor involves the operator (3) early in the process. The communication between the main contractor and operator is more important in this phase than for the Design-Build Half Test. Because the main contractor is longer responsible and there is less time between handover and going into operation.

For this organisational form, the contractor must (1) reduce the self-interest of parties since the contractor has a significant role throughout the project. The main contractor is responsible for the system integration of the equipment from the suppliers. Therefore, he must check the quality since it is his responsibility to prove that the system works according to specifications.

Design-Build-Finance-Maintenance-Operate

The responsibilities for this organisation form are different than for the other forms. The contractor has greater responsibility, and the client is less involved. This implies that the (2) collaboration between the client and contractor is less critical for this form and more important for the structures mentioned above. Therefore, a collaboration agreement is not preferred since this indicates close cooperation. The contractor has more contractual freedom.

The (3) early involvement of parties is still essential. This is entirely managed by the contractor within this organisational structure. He can choose when to involve which party.

The (1) self-interest of parties is a risk for the client in the Design-Build organisation. The suppliers could deliver less quality and do not co-operate with other parties on the interfaces of the equipment. For this organisational structure, the main contractor is responsible for the parties. He performs maintenance and therefore, it is in his own interest to deliver good quality. He will demand excellent quality from his suppliers as well. This is beneficial for the client since he will receive a well working light rail system.

Comparison to literature

The organisational structures mentioned in the literature were described as static. The organisational structures appeared to be clear-cut, and the same outcome could be expected for different projects. While in the six projects researched, the organisational structures were influenced by multiple factors and the outcome differed. Expected is that the people working within the organisation determine the success of the Test & Commissioning phase. This appears to be more crucial than the structure of the organisation itself. The conditions could enhance the success of the Test & Commissioning and provide guidance for a new project. But eventually, the people working on the project determine the success.

6.6 Checklist organisational structure

The following table can support advice for future light rail projects. The 8 most mentioned project characteristics have been analysed, and a polar question must be answered.

Project characteristic	Question	Answer	Importance
Technical complexity	Is it a technical complex project compared to other light rail projects?	Yes = A No = B	High
Interface with other projects and processes	Are there many interfaces with other projects and processes?	Yes = A No = B	High
Expertise in team	Is there enough expertise in the client's team available?	Yes = A No = B	High
Transfer to operator	Is it a difficult transfer to the operator?	Yes = A No = B	Medium
Clear scope boundaries	Are the scope boundaries clearly defined?	Yes = B No = A	Medium
Relationship between client and contractor	Is there an existing relationship between client and contractor?	Yes = A No = B	Medium
Procurement method	Is the procurement method accomplished together with market parties?	Yes = B No = A	Medium
Political sensitivity	Is the project politically sensitive?	Yes = A No = B	Medium

The answers on the question will lead to the outcome A or B. The number of A's and B's can be summed up, which will give a certain score. When the number of A's is higher than the number of B's, the project is likely to be built in a brownfield environment. If the number of B's is higher, then the project could be more towards a greenfield situation. The consequences for the organisation structure are described below with the use of both situations.

Situation A = Brownfield

The most appropriate organisational structures for a brownfield environment are the following:

- Design-Build
- Design-Build Half Test

Especially for a Design-Build organisation, the client (often governmental body) can provide guidance during the Test & Commissioning phase of the project. In the Design-Build Half Test organisation, the handover to the client organisation is later than for the Design-Build. However, the client can still manage part of the test phase. This is beneficial for highly complex environments. Not only when the projects are technically complex, but especially when there is organisational complexity. As stated, before, in paragraph 6.2, the number of stakeholders is the highest during the Test and Trial phase. This makes it difficult to manage these organisations with a high number of stakeholders. For light-rail projects this is even more complex than for other

construction projects such as tunnels and roads. For these projects, the number of stakeholders is usually lower, and the building period is often shorter.

Moreover, the number of people who are interested in a light rail project is higher than for other ordinary construction projects. Often because light rail is built within the residents' physical surroundings. Therefore, the governmental body (often transportation authority or municipality) should keep close contact with the residents throughout the project. For the Test & Commissioning phase, it is even more important to communicate with the residents because they see and hear the vehicles operating. However, in this last phase of the project they are not allowed to take a trip yet. This needs to be clearly explained by the municipality, especially is problems occur.

In a brownfield environment, the government wants to lead a successful handover to the operator. Thus, it is recommended that the risks are not transferred to the full extent towards the market parties. At last, for a politically sensitive project, it is often better to have a governmental body takes a leading role. They can better deal with the press, stakeholders and residents than contractors. That is not the contractor's specialty and they do not earn money with it.

Thus, within an inner-city with a highly-populated environment, where the client has experience with extensive infrastructure or even light rail projects, it is probably better to choose for a more traditional Test & Commissioning organisation.

Situation B = Greenfield

In a greenfield environment the following organisational structures should be considered:

- Design-Build Full Test
- Design-Build-Finance-Maintenance-Operate

With these two organisational structures, the main contractor receives more freedom, but also takes more responsibilities and risks. This is often applied when the client is not adequately sized, there are other priorities or does not have enough experience. Or when the client wants to let the suppliers perform system integration but manages the trial and operation phase itself (Design-Build Full Test). If the client cannot or does not want to manage the trial and operation phase, it can choose for a fully integrated DBFMO organisation.

For a full DBFMO organisation, it is a prerequisite that there is no existing light rail infrastructure. This means that there are no contracts already with maintenance and operating parties. Otherwise, the main contractor cannot freely choose these parties anymore in a consortium. The benefits of a fully integrated contract are then absent.

For this greenfield environment, it is essential that the client does not interfere with the suppliers too much. When the client expects that multiple significant changes will occur and that they should manage the project, this organisational form is not suitable.

In conclusion, for a city within a less urban environment, for instance from minor city to city, and a small or less experienced client, it is recommended to choose an integrated contract.

Must be mentioned that light rail projects are most often build in a brownfield environment. Therefore, situation A, with the corresponding organisation structures, are more plausible in practice.

6.7 Conclusion

The interviewees provided numerous suggestions for the improvement of the organisation of a Test & Commissioning phase. The lessons learned from past projects should be more transparent and widely shared across different projects. This could be enhanced by having a national knowledge centre funded by the government. Municipalities and provinces can then exchange knowledge on light rail projects.

Subsequently, the client should consider the reduction of self-interest, collaboration agreements, and early involvement during the procurement strategy. The self-interest of parties can be reduced by building financial incentives into the contract. This is especially relevant for the Design-Build organisational structure. Within this organisation, suppliers move to other projects after delivering. They are less involved during the system integration and not involved during maintenance, and this could lead to a reduction of quality.

Moreover, collaboration agreements could be signed to reduce self-interest and increase cooperation. A Bouwteam is an example in which parties work together from an early stage in the project duration. This option is favourable for when the main contractor is involved during Testing & Commissioning, thus for Design-Build Half Test and Design-Build Full Test. The cooperation between the suppliers and the client is critical for these organisational structures.

The parties should be early involved to increase successful system integration. In this manner, the interfaces between the processes of all parties are considered in time. The operator and asset manager should be involved in an early stage to ensure a successful handover to the operation phase. Early involvement is difficult to stipulate in a contract. However, when the activities are planned, the project organisation should initiate the involvement of parties. For the Design-Build Full Test and DBFMO, it is critical that all parties are involved early. For these two forms, this is the task of the main contractor and he should be capable of managing other parties.

7 Conclusion

In order to provide insight into what determines the organisational structure, the capabilities of the involved parties and project characteristics have been assessed. With a case study, three national and three international light rail projects were compared. Eighteen persons were interviewed to provide an answer to the following research question:

How can a Test & Commissioning phase be organised for light rail projects?

In this research, six projects have been analysed with the use of a case study and eighteen interviews. Four organisational structures have been evolved, as can be seen in figure 19. The risks and benefits are shortly discussed on the next page.

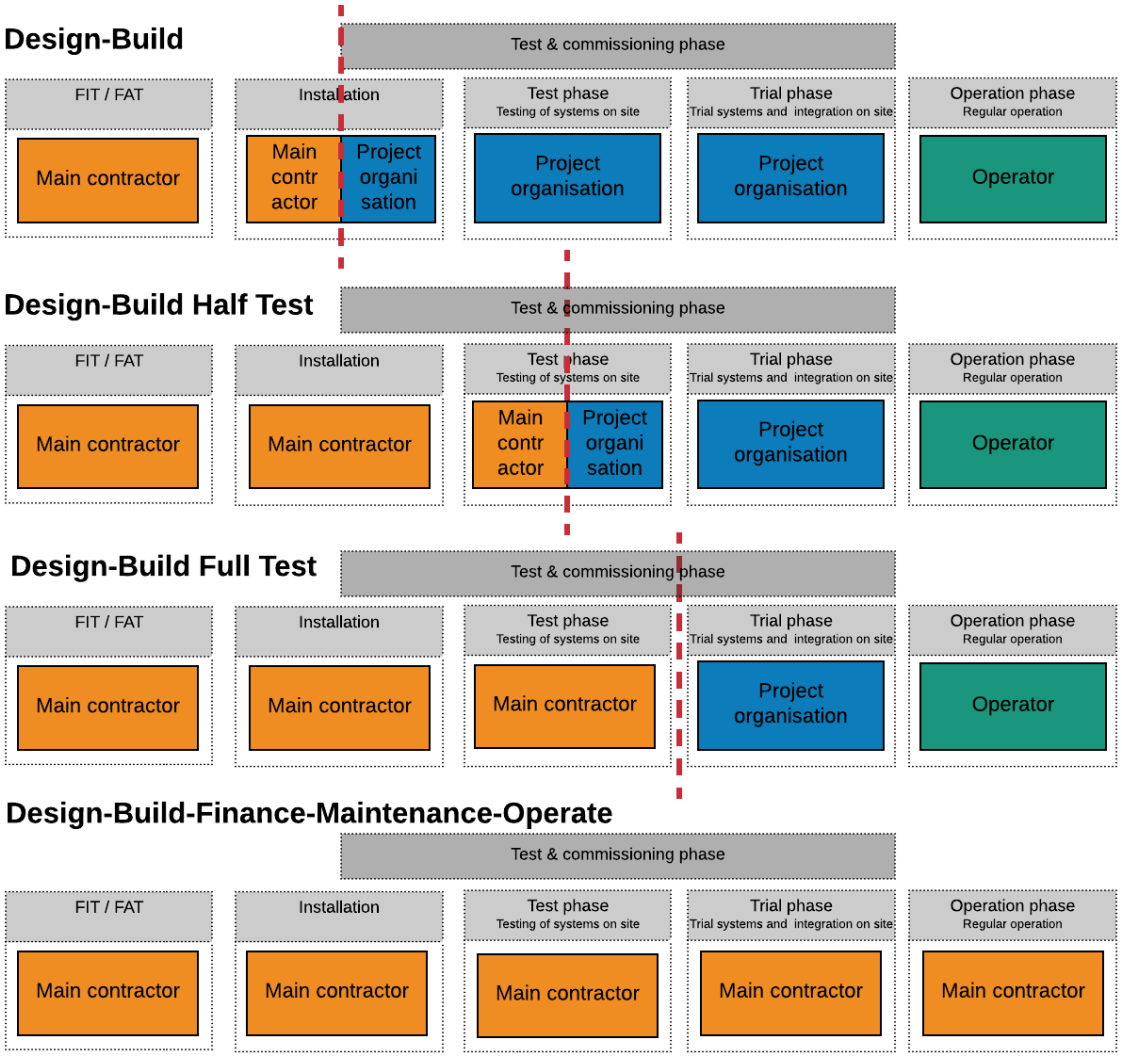


Figure 19 Four types of organisations for Test & Commissioning phase in light rail projects

Design-Build

The benefits of this organisational structure are that the project organisation can control the project directly from the Test & Commissioning phase. This means that the interfaces between projects and processes can be managed by the client. The client needs to have adequate size and experience to coordinate this. A potential risk is that the suppliers could potentially deliver less quality since they are not responsible for the system integration. Therefore, the self-interest of the parties must be reduced by making clear agreements. Luas Line and West Midlands Metro Birmingham are examples of a Design-Build organisation.

Design-Build Half Test

For this organisation, the main contractor executes tests to demonstrate to the client and operator that the system works. Halfway the test phase, the project organisation is handed over the project and can perform additional tests. This could be beneficial for the main contractor, client and operator. However, it is difficult to make strict segregation in the test phase. While this has to be put clearly in the specifications. The cooperation between suppliers and client could be enhanced by a collaboration agreement. The North-South Line and Hoekselijn are examples of this structure.

Design-Build Full Test

In this organisational structure, the main contractor coordinates the full test phase. The main contractor must possess the technical knowledge in-house or through subcontractors. The risks for the client are reduced, however, he can also control less. The risk for the main contractor is the limited control over other external projects and processes. This is especially relevant within a brownfield environment. The client, who is often a governmental body, can manage these interfaces more easily. Therefore, a collaboration agreement between contractor, client and other parties is favourable. Moreover, for this organisational structure, it is essential that the main contractor involves all parties from an early phase. The Uithoflijn and East London Line are typical examples of the Design-Build Full Test organisation.

Design-Build-Finance-Maintenance-Operate

In a fully integrated organisational structure, the risks are transferred to the market parties. This implies that the main contractor, often in a consortium, must coordinate the whole project. The client must set out the specifications, and it is up to the main contractor to execute these. The client cannot exercise any control during the project. The main contractor must align with the other parties when they should be involved.

These are the four feasible organisational structures for a Test & Commissioning phase. In order to choose the most appropriate organisation for a future project, the capabilities of the parties and project characteristics should be taken into account.

Capabilities and project characteristics

The client must have sufficient size and experience. This is required to manage the technical interfaces adequately and control the parties. The main contractor must coordinate the project on time, costs, quality and safety. Recently, the role of system integrator has been governed by the main contractor as well. Furthermore, the collaboration of the suppliers is vital for the project. The operator should have precise specifications during the design of the project. In the Test & Commissioning phase, the operator should be involved earlier, as stated during the interviews. The knowledge centres must have the capability to solve technical or juridical issues, according to the literature and interviews.

There were three project characteristics discovered that mostly influence the division of responsibilities during the Test & Commissioning phase. These were (1) Technical complexity, (2) Interfaces with other projects and processes, and (3) Expertise in team. The interviewees were divided on whether the client or main contractor should be mainly responsible in a technical complex light rail project. When there are many interfaces with other projects and processes, the client should take control of the Test & Commissioning phase. The expertise in the team is vital for organising a Test & Commissioning phase. When the client does not have the expertise, then the main contractor should play a more significant role in the T&C phase.

Procurement strategy

The organisation of the Test & Commissioning phase is determined in the procurement strategy. The interviews showed that certain aspects have to be considered for future projects. These are the reduction of self-interest, collaboration agreement, and early involvement of parties.

Financial incentives written upon in the contract could reduce the self-interest of parties. Then, parties are interdepended of each other, which makes them collaborate. A collaboration agreement could enhance this. Bouwteam is a type of collaboration agreement which is advocated by the interviewees to support collaboration. The system integration should be better organised by involving parties from an early stage. Furthermore, the operator and asset manager should be early involved to successfully handover the project to the operation phase.

These measures have to be considered for future projects in the procuring strategy. All of the improvements could be realised in all four types of organisational structures. Certain improvements are more relevant for specific types of organisational structures as described in the section above. All organisational structures have their advantages and disadvantages in terms of responsibilities towards the parties involved.

However, multiple interviewees mentioned that the success of the Test & Commissioning phase did not strictly depend on the organisational structure. The collaboration between the parties is more essential than determining who is formally responsible for certain activities. The collaboration agreement and early involvement of parties are manners to increase the cooperation between parties. For all projects, it is crucial that the parties know what to expect from each other. The client cannot foresee everything in the project, and therefore it is unrealistic to organise the whole project perfectly. This implies that a project undergoes changes throughout the duration. The organisation should be dynamic to adapt to these changes. The parties should trust each other and collaborate in a light rail project.

8 Discussion

Like all research, the results of this research are open for multiple interpretations and have certain limitations. The limitations for this research and recommendations for further research are provided in this chapter.

General limitations

The topic was very specific, not much can be found in the literature when looking for the capabilities to successfully perform a Test & Commissioning phase for light rail projects in the Netherlands. This made this master thesis an exploratory research.

Due to the limited time for this research, the sample size was rather small. On average 3-4 persons were interviewed for every subgroup. This number is sufficient in terms of sample size found in literature, but the answers were diverse. A larger group could make the answers more reliable.

The number of interviews on national projects was higher than for the international projects. Therefore, this research is not a balanced comparison. The Dutch projects weighted heavier than the international projects.

Organisational structure

The impact of the organisational structure is difficult to measure and was called into question by several interviewees. It can be learned that the organisational structures not always have the expected outcome. This differs for all project and is influenced by many factors and circumstances. Every structure consists of people, some collaborate well, and others do not. This is hard to tell from the start of the project and can only be learned over time. The organisational structures found in the literate were more clear-cut. While in practice, the project organisations are subject to changes and therefore have to be dynamic.

The explored organisation forms only focussed on the Test & Commissioning phase, while the procurement strategy is focussing on the entire project. In practice, the Test & Commissioning phase cannot be viewed separately from the rest of the project. For this research, it has been assumed that the contractor was responsible for an integrated Design & Build contract. From this perspective, it has been viewed whether the contractor should also coordinate the Test & Commissioning phase. While another alternative is that the client chooses a traditional contract in which design and build are separated. This could influence the Test & Commissioning phase as well but has not been in the scope of this research.

The projects from the case study and the interviews differ significantly, which makes it difficult to compare them. If one interviewee suggests a solution, it could work for one project but possibly not for the other project. Therefore, it is challenging to implement these organisational structures directly for all projects. For future projects, there has to be assessed to what extent the recommendations are applicable.

The interviewees were asked to putt down the cards in the generic model during the interview. Because of the large number of cards, they were not always placed in the model for every phase. Some interviewees only put the most important parties down. Therefore, it could be that in some of the interviews, the generic model does not provide a full picture, while in others it does.

Project characteristics

A list of 18 project characteristics was given to the interviewees during the interview. Due to the limited time, these 18 factors were not extensively explained. This implies that the project characteristics were open to interpretation for the interviewees.

The interviewees were asked for additions on the project characteristics. However, only a few interviewees had other suggestions. This could imply that the list was absolute or that the interviewees were steered in a particular direction.

Recommendations for further research

In this exploratory research, many interesting results have been found. However, a validation of the results is recommended. This could be done by verification of the organisational structures, capabilities and project characteristics. Alternatively, a more comprehensive research scope or different perspective could also be interesting.

Possible directions for further academic research:

1. The project characteristics could be further researched. The interviewees were divided on which party should bear which responsibilities in case specific project characteristics occur.

2. This research was a purely qualitative research; however, it would be interesting to perform a quantitative study on light rail projects. For instance, when multiple light rail projects are evaluated on costs, type of contract and organisational structure.

3. The organisational structure of the design and build phase could be researched. For this research, there has been assumed that the main contractor would execute at least design & build. However, the client could choose another organisational structure by separating the design and build phase.

4. The type of contracts could be further researched. For instance, whether a traditional contract or integrated contract is more suitable for light rail projects. Moreover, the factors that determine the type of contract could be researched as well. The organisational structures described in this research could provide the starting point.

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Appendix 1

Sample size

For this research, 18 interviews are conducted. (Guest, Bunce, & Johnson, 2006) suggest that for a data collection procedure, at least 12 participants are needed as minimum sample size recommendations. For this research, different perspectives on light rail projects were required. Since the aim is to improve the organisation of a T&C phase, not only clients are interviewed. For this investigative research, it is interesting and most exhaustive if interviewees from different companies and sectors are interviewed. These people contribute with different perspectives for this research. Therefore, five groups are made; Client, Project organisation, Supplier, Operator, Knowledge centres. These groups represent the parties involved in the project. An overview of the interviewees per party has been given in Table 8. The minimal number of 12 participants has been reached, but since this research used groups of participants this number must be adjusted. For subgroup sampling at least 3 participants are needed per subgroup (Onwuegbuzie & Leech, 2007). For this research six cases have been used. The number of interviews performed in the Netherlands is higher than for the international cases. Therefore, the national cases weigh more heavily in this research.

Table 8 Number of interviewees per group

Client	4
Project organisation	5
Supplier	3
Operator	2*
Knowledge centres	4

*Two more interviewees joined the conversation with one of the operators. They worked for the operator at the Uithoflijn (Qbuzz). Together they discussed the questions, and they collectively gave input for the generic model.

All persons were asked to answer the questions with the perspective of the organisation they worked for at the time of the project. However, several persons have been working for multiple parties, for instance, both at the client and supplier side.

The procedure for the interviews

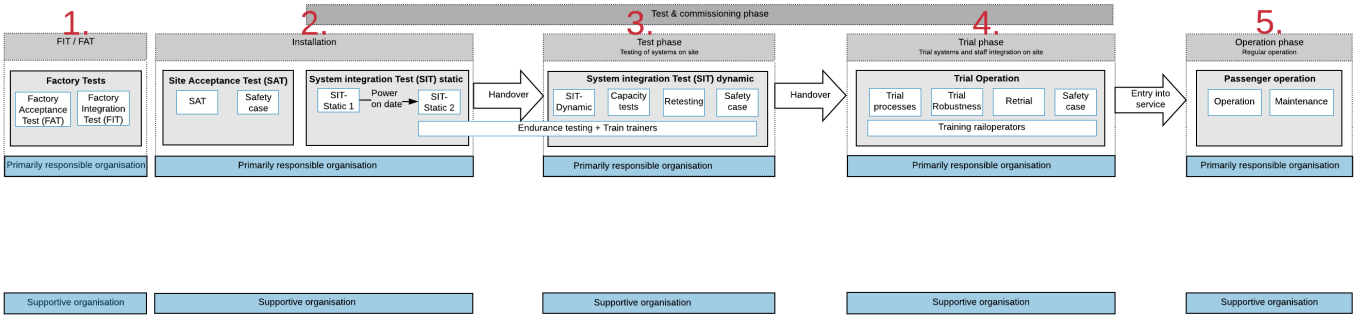
Each interview was set up in three stages. The first stage was used as an introduction to learn about the background of the interviewees. Their experience with light rail, test and commission phase, and national and international projects was discussed.

The second part of the interview was used for the generic model. In this model, all the activities within the test and commission phase have been put in order. The activities were split up in 5 phases:

1. FIT/ FAT
2. Installation
3. Test phase
4. Trial phase
5. Operation

For every phase, the interviewee had to put down a card with a stakeholder. The interviewees were asked which stakeholders were primarily responsible and which were a supportive organisation. In figure 20, the activities (in grey) and the choice for the primarily responsible or supportive organisation (blue) can be seen. The figure is visualised without the cards for the different stakeholders. A large version can be found in appendix 2.

Figure 20 Generic model Test & Commissioning phase



Explanation of the cards

This section explains how the model has been applied during the interviews together with the cards. The parties are printed on cards. All interviewees were asked to determine which party was responsible for which activity in the model. Subsequently, they placed the party under the activity. They could choose between the parties in Table 9. The parties could be put as a primarily responsible organisation, supportive organisation or not be placed if they did not have a role in this phase. The interviewees did this for all the 5 phases. Parties could be involved in multiple phases; thus the cards had 5 copies. To put emphasis on the contrast between the groups' different colours have been used.

Table 9 List of parties on the cards

Client	Supplier	Operator	Knowledge centre
Project organisation	Infrastructure supplier	Drivers	Engineering consultants
Asset owner	Vehicle supplier	Control room	Legal consultants
Transport authority	Infrastructure maintenance	Security & safety personnel	University
……..	Vehicle maintenance	……..	……..
	……..		

The full list of questions can be found in appendix 3. The following questions give an impression of the questions asked during the interviews:

- Which organisations had a primarily responsible role, and why? (putting down cards)
- Which organisations had a supportive role, and why? (putting down cards)
- What are the capabilities that parties need to have to organise a test and commission phase?
- What went well during the project you worked on regarding the Test & Commissioning phase?

- What went less well during the project you worked on regarding the Test & Commissioning phase?
- What could be done differently next project?
- Would it be better if the responsibilities would be different?

The third part of the interview was focused on the factors determining the organisation of a T&C phase for future projects. Future projects have specific project characteristics. The size, complexity and political sensitivity are just a couple of examples which could influence the organisation. The full list of project characteristics, including explanations, can be found in chapter 5. A list of 18 project characteristics was given to the interviewees during the interview. They had to choose 3-5 factors with the most significant influence on the organisation of the Test & Commissioning phase. The interviewees had been explained that the factors should influence the manner in which responsibilities and risks between the parties should be divided. The preferred answer could finish this sentence; For a future project with this project characteristic, it is better to put the responsibility of the T&C phase towards the client / supplier / operator / knowledge centre. When interviewees said: 'The technical complexity is essential', the supplementary question was: 'Is the client / supplier / operator / knowledge centre or another party more capable of bearing these responsibilities or does it make no difference?' The answers and quotes have been processed anonymously, although the origin of the party is used as a source, e.g. (2 Clients, 1 supplier).

Analysing interviews

All the interviews have been recorded and summarised in meeting documents. The interviewees were able to review the interview and make adjustments. These documents have been analysed using MAXQDA 2018, which is a qualitative data analysis software program. All the interview transcripts were uploaded in this program. The interview data has been coded on the basis of the report structure. Thus, if interviewees mentioned something about the capabilities of the client, supplier or operator, this would get its own code. The same accounts for project characteristics, organisational structures, and contractual support. In total, there have been 26 different codes used. This way, the substantial amount of qualitative data could be efficiently structured. A print screen, including the codes can be seen in the figure below. A large version can be found in appendix 4.

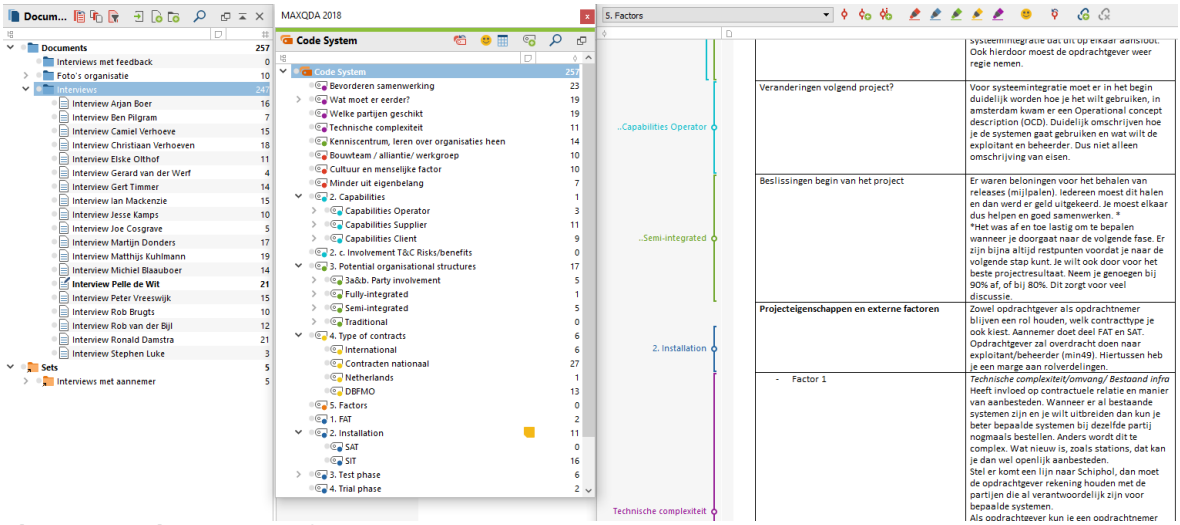
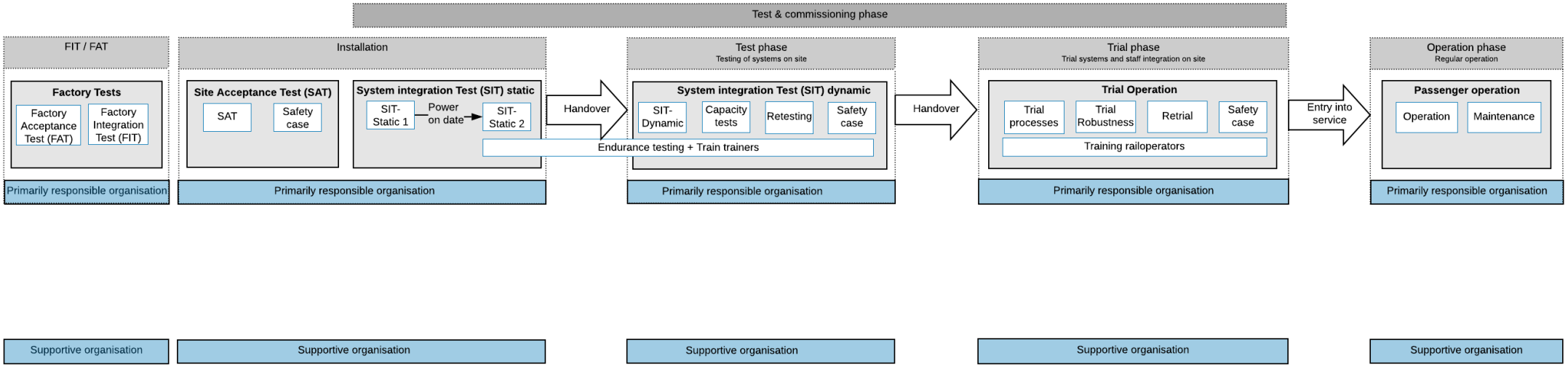


Figure 21 Print screen of MAXQDA

Appendix 2


Test & commissioning phase
FIT / FAT
Factory Tests
Factory Acceptance Test (FAT)
Factory Integration Test (FIT)
Primarily responsible organisation
Installation
Site Acceptance Test (SAT)
SAT
Safety case
System integration Test (SIT) static
SIT-Static 1
Power on date
SIT-Static 2
Primarily responsible organisation
Handover
Test phase
Testing of systems on site
System integration Test (SIT) dynamic
SIT-Dynamic
Capacity tests
Retesting
Safety case
Endurance testing + Train trainers
Primarily responsible organisation
Handover
Trial phase
Trial systems and staff integration on site
Trial Operation
Trial processes
Trial Robustness
Retrial
Safety case
Training railoperators
Primarily responsible organisation
Entry into service
Operation phase
Regular operation
Passenger operation
Operation
Maintenance
Primarily responsible organisation
Supportive organisation
Supportive organisation
Supportive organisation
Supportive organisation
Supportive organisation

Appendix 3

Algemene vragen

1. Wat is uw ervaring met light rail projecten?
2. Wat is uw ervaring met test en proefbedrijf?
3. Heeft u projectervaring met test- en proefbedrijf in het buitenland, zo ja wat is uw ervaring?

Uitleggen generiek model

1. Mijn definitie test en proefbedrijf
2. Vragen naar op/aanmerkingen

Definitie

1. Substantieel project, 50+ miljoen
2. Sprake van ombouw/nieuwbouw die een uitgebreid test en proefbedrijf nodig hebben.
3. Toevoegen de term uit de Wet lokaal spoor: het betreft een project met een “Wezenlijke wijziging”.

Vier categorieën stakeholders

1. Opdrachtgever (Vervoersautoriteit / Infra eigenaar / Project organisaties)
2. Leverancier (Aannemer Infra (nieuwbouw) / Onderhoudsaannemer Infra / Voertuigleverancier / Voertuigonderhoud (werkplaats))
3. Vervoerder (Bestuurders (voertuig), Verkeersleiding, Veiligheidsfunctionarissen (tickets controleren/service en veiligheid medewerkers)
4. Kennisinstituten (Universiteiten / ingenieursbureau , Juridisch adviseurs)

+ Van alle stakeholders ook lege kaartjes voor eigen inbreng

Interviewvragen:

1. Welke partijen waren primair eindverantwoordelijk voor welke activiteiten?
2. Welke partijen hadden een ondersteunende rol?
3. Hoe bepaal je welke partijen geschikt zijn voor het organiseren van een test en proefbedrijf?
4. Wat ging er goed bij het genoemde project?
5. Wat ging er mis bij het genoemde project?
6. Wat zou u bij een volgend project anders doen?
7. Welke beslissingen in het begin van het project zijn cruciaal voor het wel/niet integreren van een test en proefbedrijf binnen het hoofdcontract?
8. Welke projecteigenschappen en externe factoren zorgden ervoor dat deze verantwoordelijkheden op deze manier verdeeld werden?
    a. Eerst vrije invulling
    b. Dan lijst met factoren laten zien en top 3 maken
    c. Vervolgvragen stellen
9. Welke factoren waren niet relevant?

Samenwerking

1. Hoe was de samenwerking georganiseerd binnen test en proefbedrijf (kaartjes)?
2. Hoe kan de samenwerking bevorderd worden?
3. Wat zijn de mogelijke voor- nadelen van de organisatievormen m.b.t. samenwerking?

Contracten:

1. Hoe kunnen de verschillende organisatievormen het best vertaald worden naar een contract?
2. Wat ziet u als gevolgen voor een hoofdaannemer verantwoordelijk maken van test dan wel proefbedrijf?
3. Hoe zouden toekomstige projecten met test en proefbedrijf gecontracteerd moeten worden?

Veranderingen op de markt:

1. Wat is de huidige tendens van aannemer en overheid met betrekking tot aanbesteden, willen aannemers nog DBT (design, build, test) + FM (finance, maintenance) contracten aannemen?
2. Wordt er nu anders aanbesteed dan vroeger?
3. Is er een verschuiving van risico’s, zo ja, hoe?
4. Zijn de veranderingen positief/negatief? Hoe kan de situatie verbeteren?

Laatste vraag: Nu we al deze projecten, factoren en risico’s besproken hebben. Als u een ding moet kiezen wat u hiervan geleerd heeft, welke wijze les zou u dan willen delen zodat het organiseren van test en proef bedrijven in de toekomst beter gaat?

Factoren met invloed op organisatie van test- en proefbedrijf:

Scope:

1. Heldere afbakening van de scope
2. Technische complexiteit binnen project
3. Omvang van het project

Resources:

4. Doorlooptijd project
5. Type financiering
6. Manier van aanbesteden
7. Contractuele relatie opdrachtgever en opdrachtnemer
8. Huidige contracten

Fysieke omgeving

9. Bestaande infrastructuur in de stad
10. Locatie/omgeving (fysiek)
11. Interface met andere projecten en processen

Stakeholder omgeving

12. Aard en omvang stakeholder (inclusief bewoners)
13. Overdracht naar beheerder

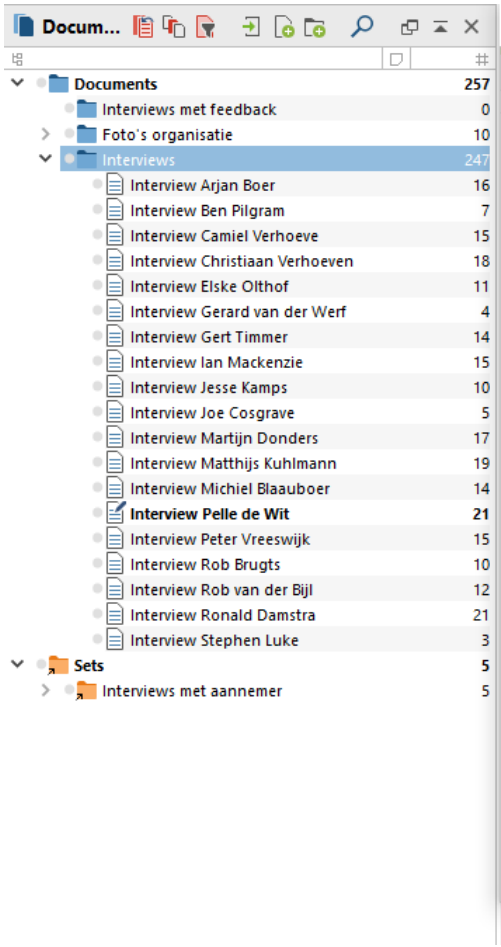
Politiek

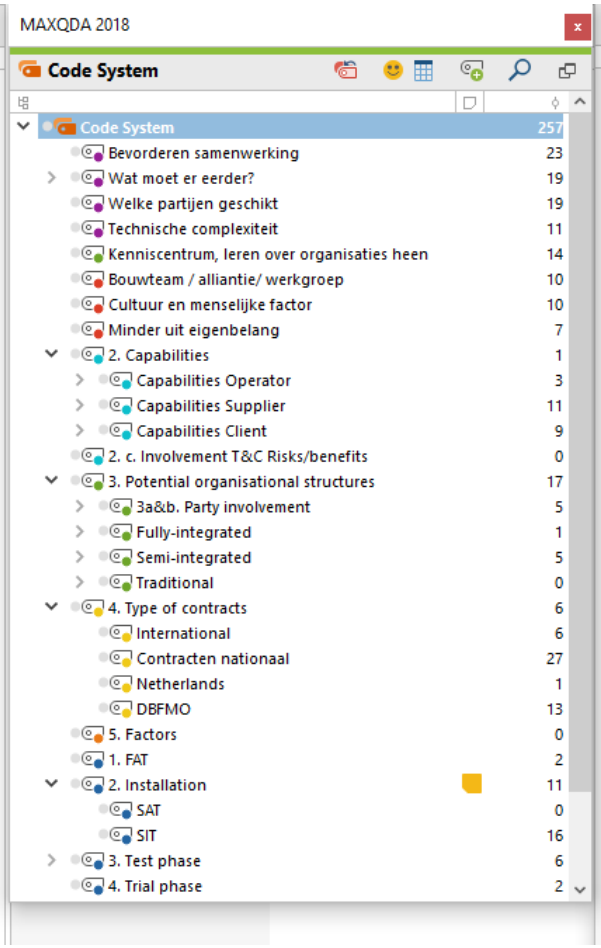
14. Politieke gevoeligheid
15. Imago
16. Wet- en regelgeving

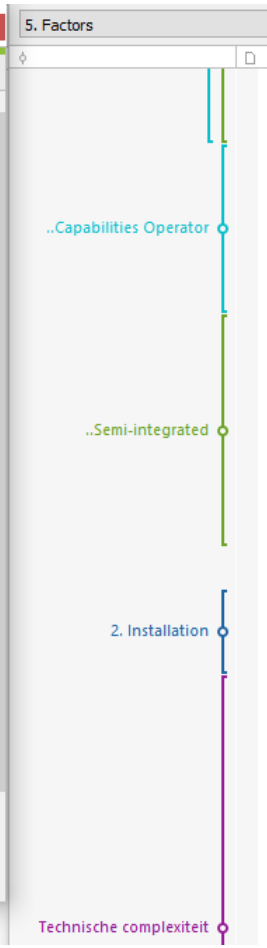
Ervaring projectorganisatie:

17. Ervaring in team beschikbaar
18. Mate waarin organisatie leert

Appendix 4







	systeemintegratie dat dit op elkaar aansloot. Ook hierdoor moest de opdrachtgever weer regie nemen.
Veranderingen volgend project?	Voor systeemintegratie moet er in het begin duidelijk worden hoe je het wilt gebruiken, in amsterdam kwam er een Operational concept description (OCD). Duidelijk omschrijven hoe je de systemen gaat gebruiken en wat wilt de exploitant en beheerder. Dus niet alleen omschrijving van eisen.
Beslissingen begin van het project	Er waren beloningen voor het behalen van releases (mijlpalen). Iedereen moest dit halen en dan werd er geld uitgekeerd. Je moest elkaar dus helpen en goed samenwerken. * *Het was af en toe lastig om te bepalen wanneer je doorgaat naar de volgende fase. Er zijn bijna altijd restpunten voordat je naar de volgende stap kunt. Je wilt ook door voor het beste projectresultaat. Neem je genoegen bij 90% af, of bij 80%. Dit zorgt voor veel discussie.
Projecteigenschappen en externe factoren	Zowel opdrachtgever als opdrachtnemer blijven een rol houden, welk contracttype je ook kiest. Aannemer doet deel FAT en SAT. Opdrachtgever zal overdracht doen naar exploitant/beheerder (min49). Hiertussen heb je een marge aan rolverdelingen.
- Factor 1	*Technische complexiteit/omvang/ Bestaand infra* Heeft invloed op contractuele relatie en manier van aanbesteden. Wanneer er al bestaande systemen zijn en je wilt uitbreiden dan kun je beter bepaalde systemen bij dezelfde partij nogmaals bestellen. Anders wordt dit te complex. Wat nieuw is, zoals stations, dat kan je dan wel openlijk aanbesteden. Stel er komt een lijn naar Schiphol, dan moet de opdrachtgever rekening houden met de partijen die al verantwoordelijk zijn voor bepaalde systemen. Als opdrachtgever kun je een opdrachtnemer

Appendix 5

- Uithoflijn

The Uithoflijn will be the most important link in the accessibility of Utrecht Science Park. The project organisation realises the tram line for the province of Utrecht and the municipality of Utrecht. The service was intended to start operation on 29 July 2019. However, this was delayed due to technical problems. It is currently postponed and will most likely run in December 2019. As a result, the costs increased with €84 million above the initially estimated project costs of €323.5 million. The project is currently within the Test & Commissioning phase. To be more precise; the project is in its last phase which is the trial period.

- North-South line

In 2002 the construction of the North-South line started. This metro line is running from the northern part of Amsterdam under the IJ River, via Amsterdam Central down to Station Zuid. The actual construction work began in 2003. It was expected that the 9.2km-long line would be opened in 2011. However, that proved to be unfeasible, the opening is being delayed several times, and the project ran 40% over budget. The estimated final costs were 3.1 billion, and it opened on 21 July 2019. The service runs every six minutes during the day and every seven to eight minutes in the evening.

- Hoekselijn

The Hoekselijn is the railway line between Schiedam Centrum station and Hoek van Holland. Between 1893 and 2017, the railway line for passenger transport and freight transport was in use. Since April 2017, the Hoekselijn has been converted from a railway line to a metro line. The metro was initially scheduled to run in September 2017. Soon that date turned out to be premature, and several postponements followed. Mainly due to errors in the track protection software. In addition to the 372 million euros budgeted, an additional 90 million euros was spent. The 'Metropolitan area Rotterdam The Hague' is the granting transportation authority for the Hoekselijn. The metro is expected to run on 30th September 2019. The project is currently in the trial phase.

- Luas Dublin

Luas is an extensive light rail system in Dublin, Ireland. The two main lines are the Green Line and the Red Line, which opened in 2004. Both lines have been extended and split further out of the city. The extension named 'Luas Cross City line' began in 2013 and it was delivered on time and within budget (€368m) in 2017. The managing director of Infrastructure, Pat Lucey, commented 'The co-operation and teamwork with our client, Transport Infrastructure Ireland, and the many stakeholders were essential and are a template for how complex infrastructure projects should be carried out in a busy urban environment'. In total three extensions to the existing Luas Line have been completed. As of 2017, the system has 67 stations and 42.5 kilometres. In 2018 the system carried 41.8 million passengers, and it is expected that this number will increase by several million over a couple of years. Luas is operated by Transdev.

- East London line

The East London Line is a railway line from London Overground in Greater London, which runs from north to south in east London and crosses the Thames. The line was built as a regular railway line but was included in the London metro network in 1913. The line was closed in 2007 for conversion and expansion. Since the reopening in 2010, the East London Line has been part of London Overground and is no longer part of London Underground. The total investment for the first phase of the project was £1bn. The line was extended in phase 2 for 2.5 kilometres which opened in 2012.

- West Midlands Metro

West Midlands Metro is a light-rail line in the county of West Midlands. It is operated and owned by Transport for West Midlands. Line 1 runs over a stretch of 20.1 km from Birmingham to Wolverhampton. The contract for construction and operation of Line 1 was awarded to the Altram consortium in August 1995. The construction started three months later. The project should be finished in August 1998 but was delayed for 10 months. Altram had to pay compensation for this. The costs were estimated at £145 million. It opened on 30 May 1999. An extension into Birmingham City Centre was approved in 2012. The first section of the extension opened in December 2015. The number of passengers in 2018/2019 was 5.9 million. There are more extensions planned for the system.

Appendix 6

The tables below describe the project characteristics most frequently mentioned. The number of respondents that mentioned the specific project characteristic is specified. The top three tables have been put in the report in paragraph 5.3. The numbers 4-8 are described only in this appendix.

1. Technical complexity

Main responsibility	Number of respondents (10 total)	Arguments in favour
Client	5	The complexity of the project is a significant risk. The client must take control and manage the stakeholders. System integration is difficult, and the main contractor is not able to do this task and does not want to be liable for other contractors and their systems.
Main contractor	3	Technical complexity is what the contractor is best in, on the condition that it is in its field of expertise. The contractor must have the freedom to build and implement themselves. The client should not try to steer too much. The main contractor is competent at managing the risks that they can influence. He can manage subcontractors well, but ancillary contractors are difficult. The client should just define clear specifications.
Dependent	2	It depends on the size of the technical complexity and the involved parties. For every project, there should be considered who is best capable of bearing the risks. It is a crucial project characteristic, but you cannot generally say that one of the two main parties can carry the responsibilities. Furthermore, it depends on whether it is an extension of an existing system or a brand-new line. For an extension of an existing line, the client should be closer to the project and manage more active. The contractor can have more freedom for a new line.

2. Interface with other projects and processes

Main responsibility	Number of respondents (9 total)	Arguments in favour
Client	7	Light rail projects in the Netherlands are usually built in an urban inner-city environment. This implies many interfaces with other projects and is complicated to manage. The client can balance those interests best. The contractor does not have authority over other contractors from other projects and would only think about what is best for him. This is not in the interest of the total development of the city and its residents.
Main contractor	1	The physical environment does not make a big difference. If there are addition project/facilities around, then you have to take that into consideration. However, you should still follow the basic Test & Commissioning model. You always have the internal and external integration test. You could have more external integration tests, but you always have them. It is just a different emphasis.
Dependent	1	In a greenfield environment, a fully integrated contract would be feasible. Here, the contractor is also responsible for the interfaces with other projects and processes. However, as a client, it is not as easy to shift the risks to the contractor. It also requires a lot from the client's project organisation.

3. Expertise in team

Main responsibility	Number of respondents (8 total)	Arguments in favour
Client	0	
Main contractor	1	In practice, the contractors have to increasingly carry out system integration since the technical knowledge is no longer with the client. Typical for the client is the difference in project organisation, infrastructure owner and transport authority. The infrastructure owner and transport authority are only concerned with managing the transport system and are unable to perform system integration. This task must be carried out by the project organisation or contractor. Contractors are now taking steps to acquire this knowledge. Managers system integration are hired. Small contractors cannot take on this role as a system integrator.
Dependent	7	Multiple interviewees indicated that this was the most critical project characteristic. The expertise of the client organisation is needed to oversee and manage the project and all of its stakeholders. Many parties are busy with their own work and increasing their own profit. The aim of the client should be to align and coordinate the parties in the T&C phase. This increases the predictability in the project, which reduces lead time and costs. The organisation should be of substantial growth and have enough experts with relevant project experience. If this is the case, the client should be responsible for the organisation of the T&C phase. Otherwise, they could let the contractor or an independent market party give responsibility.

4. Transfer to operator

Main responsibility	Number of respondents (7 total)	Arguments in favour
Client	4	Four interviewees were firmly convinced that the client must be responsible for the transfer to the operator during the T&C phase. Operators are often more suspicious of contractors. In the communication between the contractor and operator, the client is always involved. Otherwise, there is a chance that the contractor and manager deviate from the contract. Moreover, an argument was mentioned which included the subcontractors. Since subcontractors focus on the smaller works, they often do not ask for permits from the operator and do not know if the electricity is on or whether trains are running. This is a serious issue and should be managed better. The client needed to step in and manage the interfaces between all parties. Or a separative project organisation from the client could do this as well.
Main contractor	2	The transfer to the operator should be placed hierarchically low in the organisation, thus with the main contractor. When the main contractor is responsible for the Test & Commissioning phase, he can already proof that the vehicles, infrastructure and systems work. The main contractor must deliver the right quality in documentation to prove its safety. The main contractor should involve the operator early in the design and actively engage from the installation phase (before T&C starts).
Dependent	1	One response was that both the client as well as the main contractor are capable of executing the transfer, but that the operator is usually not involved on time.

5. Clear scope boundaries

Main responsibility	Number of respondents (5 total)	Arguments in favour
Client	2	The two interviewees mentioned that responsibilities during a T&C phase should always be for the client. The client has a dominant role in defining the scope boundaries. The client is also the only party who can alter the scope and therefore, he should be primarily responsible. The client should not take the role merely as a lender.
Main contractor	0	
Dependent	3	Multiple interviewees indicated that the clear scope boundary was a prerequisite for a successful project. Some also mentioned that the scope boundaries changed during the project. When the scope boundary is not clear, the client should bear more risks. When the scope is clear, the contractor could take more responsibilities.

6. Contractual relationship between client and contractor

Main responsibility	Number of respondents (5 total)	Arguments in favour
Client	2	This factor was difficult to mention without having a connection with other factors. Whether the client should specify everything in the contract, or there should be flexibility for the contractor depends on different factors. Interviewees mentioned that when there are already many contractors that the client should specify everything precisely and could not give a lot of freedom to the contractors. When there are more parties involved, the role of the client as a strict coordinator is increasingly important. The same accounts for the project characteristic ‘existing infrastructure in the city'. More existing infrastructure and more existing contracts mean accurate specifications.
Main contractor	1	One person who worked for the Uithoflijn mentioned that an integrated contract type had his preference. Herein, the contractor would have more design freedom. And could coordinate the other subcontractors. One condition was that there should not be ancillary contractors not under a contract of them.
Dependent	2	Contractual obligations are not conducive for a T&C phase. Different forms, such as construction teams (Bouwteam) are possible options. Construction team with joint responsibility, everyone feels involved together. "More respect for each other's role, leaving each other in their strength and contact each other when things do not work". A correct organisational form must be chosen within the European rules for tendering. Another person mentions the possibility of an alliance between contractor and client in the T&C phase. There should be a shared budget. In which gains and losses should be shared as well.

7. Procurement method

Main responsibility	Number of respondents (4 total)	Arguments in favour
Client	2	The question was if the type of contract should be determined by the client contract or both. Two interviewees mentioned that the client is and should be the organisation who should do this. The client procures a light rail project and should decide on the contract type himself, is what two persons stated.
Main contractor	0	
Dependent	2	Two other respondents mentioned that they support a collaboration between the client and contractor in the form of a Public Private Partnership (PPP). In this collaboration, parties should decide together what should be stated in the contract and what could be more flexible.

8. Political sensitivity

Main responsibility	Number of respondents (4 total)	Arguments in favour
Client	4	The client is always responsible if a project has significant delays or cost overruns. They cannot hide behind the contract, not even when it is an integrated contract. ‘When politicians get involved in the project, it usually influences the project negatively’ (interviewee client). This is because the extra pressure on the project creates conflict between the other parties. For a highly political sensitive project, it is better if the client has the full coordination of the test and commissioning phase.
Main contractor	0	
Dependent	0	

Appendix 7

		FAT & FIT phase	Installation phase	Test phase	Trial phase	Operate phase
Client	Primair	3	4	11	16	12
	Supportive	11	14	7	2	5
	Total	14	18	18	18	17
Supplier	Primair	15	15	8	1	0
	Supportive	3	3	8	15	14
	Total	18	18	16	16	14
Operator	Primair	0	1	1	9	11
	Supportive	3	7	17	9	7
	Total	3	8	18	18	18
Knowledge centres	Primair	0	0	0	0	0
	Supportive	11	8	8	5	2
	Total	11	8	8	5	2