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BY FAILING TO PREPARE, YOU ARE PREPARING TO FAIL: A PLAN TO TEST INNOVATIONS IN THE RAILWAY SECTOR

Master thesis for the degree of Master of Science in Construction Management and Engineering



P. (Philippe) Massaar Utrecht, 16 October 2018 Master Thesis

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"By failing to prepare, you are preparing to fail" by Benjamin Franklin.

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Preface

This master thesis marks the end of my period at the University of Twente and is a completion of the Master Civil Engineering & Management. The research was conducted within the department of Innovation and Development at ProRail and focusses on improving testing of innovations in the railway sector between ProRail and market parties.

My goal was to conduct a research at a company that faced a dilemma for which there was motivation and support to solve this problem. ProRail has given me the opportunity to carry out such a research. Not only within ProRail was there interest to perform research on testing, but also amongst the providers of innovations it was felt that testing was a topic on which more research was needed. At the start of the research my knowledge of testing went as far as knowing that it occurred and that it related to trying out something new. Through the research I have seen what an important role testing has within the railway sector (and other sectors) to improve the railway infrastructure. Both for ProRail and providers of the innovations, testing allows for the implementation of innovations in the railway sector. As an experienced user of the railway throughout my student period, I hope my research contributes to the future improvement of testing innovations, and with that also the endless improvement of the railway system.

I would like to thank ProRail and TNO for giving me the opportunity to perform my research at the maintainer of such an important infrastructure. I thoroughly enjoyed my time at ProRail, which I got to know as a fun and very diverse organisation. One in which people are always ready to answer questions or provide help otherwise. Furthermore, I would like to thank everybody who contributed to my research through providing substantive input, feedback and ideas. In particular I would like to thank my supervisors Lisette van Duin and Hendrik van Meerveld from ProRail and TNO. Who, throughout the process, have provided feedback for me to make the right decisions within the research and have contributed to my personal development in this process.

From the University of Twente, I would like to thank both Joop Halman and Andreas Hartmann for their supervision and guidance in giving structure to the research and providing valuable feedback to make the right choices throughout the research.

Lastly, I would like to thank my family for their support during this thesis and my master period.

Philippe Massaar Utrecht, 16 October 2018

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Summary

The railway is a system which is in constant use and must be modified to the constantly changing needs and wishes of society. In order to meet these needs and wishes innovation in the railway is needed (ProRail, 2017a).

The maintainer of the railroads in the Netherlands is ProRail, a government organization (Nauta, 2017). In order to prove that an innovation works and can be implemented in the railway tests are performed. In this way it can be shown that the innovation meets the legal regulations and demands to function in the railway (ProRail, 2017). However, ProRail does not produce their own products but collaborates with other companies (Nauta, 2017) which can be collectively called market parties, such as contractors, suppliers and engineering firms. Market parties mostly provide the innovations which are then implemented. At a certain point in development both ProRail and the market party are involved in the test process, and both parties are needed to implement the innovation into the railway. It is important that through testing both parties are convinced that the innovation can be used in the railway, however, there are many factors which influence the test process, and which can act as barriers for testing or lead to an unclear test process. Thorough preparation of the test is a suggested solution to improve the test process.

The objective within this research is to design a differentiated test plan, for future development and improvement of testing potential innovations by providers. Through this objective it is sought to improve the test process. In order to reach this objective, the following research question has been defined: *What does a differentiated test plan look like to test potential innovations between ProRail and Providers such that the test process can be improved*?

In order to answer this question theoretical and empirical research has been performed. Throughout the research iterative designing has been performed to design a test plan. The theoretical research was performed via a desk study which was used to determine how innovations are developed. Through semi-structured interviews it was determined how tests were performed by market parties and other infrastructural managers. Based on the literature and the interviews a first test plan was designed. A case study was then conducted to determine if the developed test plan, and its contents, corresponded with tests performed in practice. It furthermore yielded more in-depth information on performing tests. Based on the case study analysis, the test plan was revised to a new version. Lastly, in order to evaluate the use of the test plan, a workshop was held. This was done with both the market parties and ProRail, to validate the test plan being practicable to plan tests. Additionally, it should show if the participants agree with the contents of the test plan. Based on the workshop the test plan has been altered one last time to a final design.

The literature shows that innovation is the development and implementation of new ideas, products, processes or services (Van de Ven, 1986). During the development of innovations there are different testing phases: in-house testing, beta testing, field trials and in-use condition testing (Cooper, 2014). It was furthermore found that testing is the process of operating a system or component under specified conditions, observing the results, and making an evaluation of the system or component (Radatz, Geraci, & Katki, 1990). In order to perform a structured test a general description is not sufficient, but a test plan is needed. A test plan describes how one will go about testing, in order to plan tests, one must consider the general development decisions regarding test criteria and test methods, in order to derive and prioritise test activities during product development (Kukulies, Falk, & Schmitt, 2016). This basis was used as a reference framework to conduct the interviews in the emperical analysis.

In the interviews corresponding test phases were distinguished during product development as found in the literature, namely: in-house, technical environment and operational environment testing. Furthermore, the two main goals of testing are to validate and verify the innovation, or to determine what to validate and verify in a later phase of development. Barriers occurring during tests are, among others, lack of information, rules and regulations, low transparency, many incorporated individuals and an unclear scope. Lastly, the interviewees mention that to plan a test a structured work method is needed, demands and risks should be determined, a location is needed and there should be consensus on the test method. A test plan then serves as a communication tool. It describes how the test is planned and gives attention to all attributes needed to perform a test.

The interviews and literature together form test plan V0. One plan is created and is differentiated over the three test phases, namely: a laboratory test phase, a controlled environment test phase and an operational environment test phase. The components of the test plan are structured under test demand and test effort, as found in the literature. Test demand relates to what needs to be known to test and test effort describing what is needed to perform the test.

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The case study shows that per testing phase the goal, test plan and its contents differ. However, the objective of the innovation development stays the same throughout. Two test phases are distinguished namely controlled and operational environment testing. In both phases, the test plans were very different and did not include much information on how to execute the test. In the controlled environment the test plan was characterized by verifying and validating the innovation, with the aim of gaining permission to use the innovation in the railway. In the operational environment, the test plan was characterised by evaluating the innovation with the aim of implementing the innovation into the railway. Barriers found during testing were: too many individuals involved, too many risks that should be mitigated, no project leader and bad communication.

The case study shows that testing in different phases can be completely different and the roles of the stakeholders involved in testing can change. The case input is used to create test plan V1, here the roles of the different stakeholders are added per test component, indicating who should deliver the different test information per component.

Test plan V1 was discussed with both ProRail and market parties in a workshop held for the purpose of validating the components and validating the usability of the test plan. The results from workshop showed that the contents and the format of the test plan can be used to test innovation. However, that the plan could become a barrier if parts of the plan would become mandatory to fill out while this is not possible. In addition, the validation showed that to accommodate testing in the operational environment aspects such as removal, malfunctioning and maintenance should be added to the test plan. Lastly, it was mentioned that although a test plan is designed dialogue between the stakeholders involved in the test is always necessary in order to specify how the test will be performed.

The information gained from the evaluation has led to test plan V2. The outline of this test plan is given in Figure 1. The differentiation of the test plan is thus determined by the phase of development of the innovation, or situation, in which the test is performed. This is indicated under the testing activities.



Figure 1 Outline test plan V2, the result of the research

Based on the findings it is concluded that a differentiated test plan is differentiated over three phases, namely: laboratory, controlled environment and operational environment testing, found within the overall innovation development process. For each phase it can then be decided which demands there are, and which effort is needed, to execute the test. Furthermore, for each phase one structure is provided by using the components of the test plan, based on the fundamental aspects distinguished for testing by providers, clients and the literature, regardless of the type of innovation or the provider. Clarity of what needs to be tested is improved by the differentiation which accommodates change throughout development, considering the various stakeholders involved per test and differentiates the test activities and test effort per phase.

Finally, the workshop showed that the test plan and its components can be used during the various phases of testing described. However, the test plan could present a new barrier if all the components would become mandatory to be filled in when this is not always possible, because one simple does not know how specific parts of the test will be executed. It is recommended that on short notice the test plan is used and evaluated in a test by an experienced individual and then implemented to be used in an existing innovation development process.

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Samenvatting

Het spoorsysteem is constant in gebruik en de samenleving heeft constant veranderende behoeften en wensen. Om aan deze behoeften en wensen te kunnen voldoen wordt innovatie gebruikt om hier een oplossing voor te bieden (ProRail, 2017a).

De beheerder van het spoor in Nederland is ProRail, een publieke organisatie (Nauta, 2017). Om te bewijzen dat innovaties functioneren zoals beloofd, en om deze te implementeren in het spoor, worden testen uitgevoerd. Hierdoor kan worden aangetoond dat innovaties voldoen aan de wet, de regelgeving en de eisen om te functioneren in het spoor (ProRail, 2017). Echter produceert ProRail niet haar eigen innovaties, maar werkt zij samen met andere bedrijven (Nauta, 2017) die gezamenlijk marktpartijen genoemd kunnen worden zoals aannemers, ingenieursbureaus en leveranciers. Marktpartijen ontwikkelen veelal de innovaties die gebruikt worden in het spoor. Tijdens de ontwikkeling van de innovaties komen beide partijen samen om de producten te testen. Beide partijen zijn nodig om de innovatie uiteindelijk te implementeren in het spoor. Het is daarom van belang dat, door middel van testen, beide partijen overtuigd zijn dat de innovatie gebruikt kan worden in het spoor. Er zijn echter veel factoren die het testproces beïnvloeden, wat een barrière kan vormen en tot een onduidelijk testproces kan leiden. Het goed voorbereiden van de test is een van de suggesties om het testproces verbeteren.

Het doel in het onderzoek is om een gedifferentieerd testplan te ontwerpen, voor de toekomstige ontwikkeling en verbetering voor het testen van potentiële innovaties van aanbieders. Door het behalen van het doel wordt getracht het testproces te verbeteren. Om het doel te bereiken is de volgende hoofdvraag geformuleerd: *Hoe ziet een gedifferentieerd testplan eruit om potentiële innovaties tussen ProRail en aanbieders te testen, waarmee het testproces verbeterd kan worden*?

Om antwoord te kunnen geven op deze vraag is theoretisch en empirisch onderzoek verricht. Verder is er door het onderzoek heen iteratief een testplan ontworpen op basis van de vergaarde informatie. Het theoretisch onderzoek is uitgevoerd als een literatuuronderzoek. De literatuur is gebruikt om aan te geven hoe innovaties ontwikkeld worden. Door semigestructureerde interviews met marktpartijen en andere infrastructuurbeheerders is bepaald hoe testen uitgevoerd worden. Gebaseerd op de literatuur en de interviews is een eerste testplan ontworpen. Een casusstudie is uitgevoerd om te bepalen of het ontworpen testplan, en de inhoud hiervan, overeenkomt met hoe testen in de praktijk worden uitgevoerd. De case levert verder een verdiepingsslag in het uitvoeren van testen. Gebaseerd op de verzamelde data is het testplan aangepast. Als laatst is er een workshop gehouden om het testplan te evalueren. De workshop is gehouden samen met ProRail en marktpartijen om te valideren dat het testplan bruikbaar is om te gebruiken voor testen. Verder laat de workshop zien of de deelnemers het eens zijn met de inhoud van het testplan. Op basis van de resultaten is het testplan een laatste keer aangepast.

In de literatuur is gevonden dat innovatie de ontwikkeling en implementatie van nieuwe ideeën, producten, processen of diensten is (Van de Ven, 1986). Tijdens het ontwikkelen van innovaties zijn verschillende testfasen te onderscheiden, namelijk: in-house, beta, veldproeven en operationele omgevingstesten (Cooper, 2014). Verder is testen het proces van een system of component laten functioneren onder specifieke condities, de resultaten observeren, en het maken van een evaluatie van het systeem of de component (Radatz, Geraci, & Katki, 1990). Om gestructueerd te testen is een algemene beschrijving niet voldoende, maar is een testplan nodig (Spillner, Linz, Rossner, & Winter, 2007). Een testplan beschrijft hoe een test uitgevoerd wordt, dient als een blauwdruk voor de test en een communicatiemiddel tussen te stakeholders (Rubin & Chisnell, 2008). Om een test te plannen moeten keuzes zoals testcriteria en testmethodes gemaakt worden om testactiviteiten te kunnen bepalen gedurende de ontwikkeling (Kukulies, Falk, & Schmitt, 2016).

In de interviews zijn dezelfde drie testfases onderscheden gedurende ontwikkeling die overeenkomen met de literatuur, namelijk: in-house, technische omgeving en operationele omgeving testen. Twee hoofddoelen zijn onderscheden voor het uitvoeren van testen, deze zijn: (1) het verifiëren en valideren van de innovatie, of (2) het bepalen wat in een latere fase geverifieerd en gevalideerd moet worden. Barrières die tijdens het testen ondervonden worden zijn: onder andere, te weinig informatie, regelgeving, lage transparantie, betrokken individuen en de scope van het testen. Om een test te plannen is een gestructureerde werkmethode nodig, eisen en risico's moeten bekend zijn, een locatie is nodig en er moet overeenstemming zijn over het uitvoeren van de test. Verder kan een testplan dienen als een communicatiemiddel, het plan beschrijft hoe de test gepland wordt en geeft aandacht aan alle aspecten die nodig zijn om een test uit te voeren.

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Samen vormen de interviews en de literatuur testplan V0. Een testplan is ontworpen die wordt gedifferentieerd over de drie gevonden fasen, namelijk laboratorium, gecontroleerde omgeving en operationele omgeving testen. De componenten van het testplan worden gestructureerd onder testrandvoorwaarden en testinspanning, zoals gevonden in de literatuur. Testrandvoorwaarden geven weer wat bekend moet zijn om te testen en testinspanning geeft weer wat nodig is om uiteindelijk de test uit te kunnen voeren.

De casusstudie laat zien dat per testfase het doel, het testplan en de inhoud hiervan verschillen. Echter, het doel van de innovatieontwikkeling blijft altijd hetzelfde. In beide testen werd een ander testplan gebruikt die totaal van elkaar verschilden, daarbij stond er weinig informatie in het testplan over hoe de test uitgevoerd diende te worden. In een gecontroleerde omgeving werd het testplan gekenmerkt door verificatie en validatie van de innovatie, met als doel toestemming voor gebruik in het spoor. In de operationele omgeving werd het testplan gekenmerkt door evaluatie van de innovatie, met als doel vrijgave in het spoor. De testplannen waren minimaal opgezet. Barrières die tijdens het testen gevonden waren zijn: te veel betrokken individuen, te veel risico's die aangetoond moesten worden, geen test manager en slechte communicatie tussen stakeholders. Aan het eind van de casus is testplan V1 ontworpen.

Een workshop is gehouden met als doel het valideren van de componenten en de bruikbaarheid van het plan voor het uitvoeren van testen. Tijdens de evaluatie van testplan V1 is er gevonden dat de inhoud en het format van het plan gebruikt kan worden om innovaties te testen. Echter, moet er rekening worden gehouden dat per fase de inhoud van het testplan veranderd. In eerdere testfasen zal het testplan minder gespecificeerd zijn dan wanneer er in latere fasen getest wordt. Testen in de operationele omgeving werd als de meest complexe fase gezien. De stakeholders die betrokken zijn in deze fasen moeten vroeg betrokken worden. Verder is er altijd dialoog nodig tussen de betrokken stakeholders om te specificeren hoe de test uitgevoerd wordt.

De informatie uit het test plan heeft geleid tot het ontwerp van testplan V2. Het test plan is weergegeven in Figure 2. De differentiatie van het testplan wordt bepaald door de fase van ontwikkeling van de innovatie, de situatie waarin getest wordt, binnen het aspect testactiviteiten.



Figure 2 Uiteenzetting van test plan V2, het resultaat van het onderzoek

Uit de bevindingen kan geconcludeerd worden dat een gedifferentieerd testplan gedifferentieerd kan worden over drie fases, namelijk: laboratorium, gecontroleerde omgeving en operationele omgeving testen, geïdentificeerd in het innovatie ontwikkelingsproces. Voor elke fase kan besloten worden wat de randvoorwaarden zijn en de nodige inspanning om de test uit te kunnen voeren. Verder is er voor elke fase één structuur door het gebruik van de componenten van het testplan. Deze zijn gebaseerd op de fundamentele onderdelen voor het uitvoeren van testen onderscheden door de literatuur, aanbieders en klanten van innovaties, ongeacht het type innovatie of de aanbieder hiervan. Duidelijkheid van het plannen van de test is verbeterd door te differentiëren over de onderscheden fases



wat verandering door de ontwikkeling heen accommodeert, de verschillende stakeholders per test vaststelt en onderscheidt wat de randvoorwaarden en inspanning zijn per testfase.

Als laatst, heeft de workshop laten zien dat het testplan toepasbaar is binnen de onderscheden testfasen, maar dat het een barrière zou kunnen vormen wanneer bepaalde onderdelen verplicht worden om in te vullen wanneer dit niet nodig is. Dit kan omdat men simpelweg niet weet wat er ingevuld moet worden, en om deze reden blijft dialoog om te bepalen wat er precies getest moet worden belangrijk. Het wordt aanbevolen om het testplan te evalueren in een test begeleidt door een individu ervaren in het uitvoeren van testen en het daarna implementeren van het plan om gebruikt te worden in een bestaand innovatieontwikkelingsproces.



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1 Introduction

"The Hubble Space Telescope (HTS) was launched aboard the Space Shuttle Discovery on April 24, 1990. During checkout on orbit, it was discovered that the telescope could not be properly focused because of a flaw in the optics. Both high-resolution imaging cameras showed the same characteristic distortion. The error in the HST's mirror occurred because the optical test executed in this process was not set up correctly; thus, the surface was polished into the wrong shape. During the critical time period, there was great concern about the cost and schedule, which further inhibited consideration of independent tests" (Allen, et al., 1990). This shows the importance of testing, and planning the right tests, in order to have a good working project and prevent (sometimes very costly, \$500 million in the case of the HTS (Tahera, 2014)) malfunctions which need to be repaired. The importance of testing is no different in the railway. The railway system is in constant use by a society which has ever changing needs and wishes. In order to respond to these needs and wishes, innovations in and around the railway offer multiple solutions (ProRail, 2017a), innovations which need to be tested before implementation in the railway.

In order to focus on testing and innovation development, first innovation in general is addressed. Innovation is vital to successful, long-term company performance in the construction industry (Gambatese & Hallowell, 2011). The discussion on innovation has been a topic of debate for hundreds of years. In the nineteenth-century economic historians observed that the acceleration in economic growth was the result of technological progress. However, little effort was directed towards understanding how changes in technology contributed to this growth. There are many arguments and debates in virtually all fields of management on innovation, especially when innovation is seen as an event. However, when seen as a process the differences are less substantive (Trott, 2012). Trott (2012) argues that the process from new discovery to eventual product is the innovation process. Van de Ven (1986) describes innovation as the development and implementation of new ideas, products, processes or services. The development of product innovations is often called a product development process (PDP), and in other words transforms an idea and an opportunity into a real product (Baskoro, 2006). Within these development processeses testing is performed. In general testing is described as the phase between a potential model and implementation (Mulgan & Albury, 2003). In his early work Cooper describes the test phase as the validation phase. This phase tests the entire viability of the project: the product itself; the production process; customer acceptance; and the economics of the project (Cooper, 1990). From the perspective of design and development of systems, test activities performed in context of the product development process are activities of assuring product properties (Kukulies, Falk, & Schmitt, 2016). Possibly allowing the innovation to be implemented in the system and thus an important aspect of innovation development. A test process often starts with the planning of a test, using a test plan which can be seen as the foundation for the entire test (Rubin & Chisnell, 2008). Spillner, Linz, Rossner, & Winter (2007) propose that to perform a structured test a general description of the tasks, as found in most development models, is not sufficient. Well-planned testing is required to achieve an accurate model (Camburn, et al., 2017). A test plan serves as a communication tool between parties. Via a plan it forces one to approach the job of testing systematically, and it reminds the development team of the impeding dates (Rubin & Chisnell, 2008).

At ProRail, the company where this research was executed, testing is performed to prove that an innovation works as is promised and meets the law, regulations and demands from ProRail (ProRail, 2017). As maintainer of the railway, ProRail has a monopolistic position and does not produce their own products but collaborates with other parties (Nauta, 2017). The product innovations are often made by market parties and can v in their use and function. At a certain point in development both ProRail (public organisation) and the provider (private organisation) are both involved in testing the innovation. This is a unique moment in the development process, as both parties are needed for the implementation of the innovation in the railway. It is important that through testing both parties are convinced of the added value of the innovation. When executing a test ProRail often has a test-facilitating role and the market party has a developing role. Tests are unique and diverse; each test may have a different goal and level at which the innovation is developed. Additionally, there are numerous providers that contribute innovations, and many stakeholders that are involved per test. Furthermore, factors such as the environment in which a test is performed can influence the test. For example, testing in the railway is riskier, and is often only performed when the initiative is proven to be safe enough to be used in the railway. In this situation, there are various processes and procedures which need to be adhered to which can be time consuming. As one can see there are many factors that influence the test process between these two parties. The trajectory of a test requires good preparation beforehand, and it should be considered which goal and which result are to be reached after the test. Research has already been performed for the planning of tests within ProRail. However, it was not yet known if the providers had the same vision on planning and executing tests as ProRail. Due to the many variables and differences between the various tests, and the different strategy as to the goal of the tests it is thought that there is not one standard test plan that

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can meet the diverse requirements. Factors such as level op development could lead to a differentiation in the test plan. Thus, for this research, a design for a differentiated test plan was sought in which the testing methods of both the providers and ProRail are considered.

1.1 Problem description

When reviewing the various obstacles of testing, and through conducting orientation interviews with ProRail and market parties, it shows that one problem does not stand apart from another and there is a certain influence which they have on one another. In order to determine what the main problem is, an analysis was performed on the various obstacles found. The result of this analysis is depicted in Figure 3. This figure is an Ishikawa diagram through which the various causes of the problem can be mapped and the effect of these causes, in this case the problem, can be derived. The left side of the diagram shows the causes found in the preliminary research. The right side of the diagram shows the problem that has been derived. The fact that both ProRail and providers are necessary for the test of the innovation and there are various factors affecting the test process makes it difficult to prepare a clear test process.



Figure 3 Ishikawa diagram presenting causes which affect the test process and the effect.

The following causes were found in the preliminary research:

- 1. **Provider:** There are various types of providers who develop innovations. This influences the collaboration, as the goal to be achieved by the provider could vary from that of ProRail. These different interests could lead to a situation without a coherent test with the same goal.
- 2. **Collaboration:** A test is normally performed by a minimum of two parties. Multiple individuals are involved if various processes and procedures need to be run through. Late involvement and lack of transparency creates bad collaboration and could delay the test process.
- 3. **Goal alignment:** The goal of the test and purpose of the innovation influences what should be verified and validated during a test. Complications during testing are often linked to dissimilar goals. As a result, there is an uncertain purpose and process of testing, not knowing what should be achieved with the test.
- 4. **Innovation:** The type of innovation influences the test process as every innovation has a different function. Thus, also the goal of the test and the verification and validation method could differ per innovation. It is found that the type of test which should be performed based on the stage of development of the innovation is not always clear.
- 5. **Verification and validation:** If verification and validation is performed in the wrong way or for the wrong aspects it (1) influences the way the test is executed and (2) influences the provability of the test. The results might not be in line with what should be proven. It is questionable if the test has then been successful.
- 6. **Processes and procedures:** The complexity of the innovation could influence the complexity of the processes and procedures. This, again, influences the test process. For example, the duration and number of aspects to be proven.

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The six main causes found, and what they represent, are found as aspects which should be addressed at the front of the test process. The causes provider and innovation are two aspects that are always present at the start of the test process. Following this the degree to which the goal, method of validation and verification and the processes and procedures are defined can largely affect what sort of, and how the, test will be performed. Furthermore, it can determine what is expected of the involved parties and how they will collaborate depending on the procedures or actions for verification and validation within the test process. Defining what all these aspects should be to conduct a test appears to be difficult, leading to a test in which it is not clear what exactly should be performed.

1.2 Problem statement

Various factors affect the test process between ProRail and providers. One factor does not stand alone from another and these make it difficult to prepare a clear test process.

From the problem analysis and the research background the following problem statement is defined:

ProRail and providers experience complications in preparing tests, which leads to an unclear test process.

Complications in this statement in the problem statement relates to the fact that there are various aspects which influence the test process and it, for this reason, becomes difficult to make it clear what should be tested and how the test should then be executed.

1.3 Research objective

The research objective consists of the objective *of* the research and the objective *within* the research.

The objective *of* the research is to improve the current test process of ProRail, and is defined as:

The objective of the research is to improve the test process between ProRail and the providers.

The objective *within* the research contributes to achieving the objective of the research. The outcome contributes to a strategy for testing innovations in the railway system between ProRail and providers. This objective is defined as:

The objective within this research is to design a differentiated test plan, for the future preparation of tests.

Differentiation in this objective relates to the fact that it is assumed that there is not one preparation strategy that can accommodate all the different situations in which tests are performed and consider all the factors which influence a test. A test plan which can divide in different test phases within the overall innovation development process could accommodate tests in various situations.

1.4 Main research question

Based on the objective of this research the main question for this research is formulated. The main question will contribute to obtaining the objective of this research. The main research question is defined as:

What does a differentiated test plan look like to test potential innovations between ProRail and Providers such that the test process can be improved?



1.5 Research approach and sub-questions

The research performed is a qualitative research and can be characterised as design science research in which an artefact is made to solve a problem and addresses an unsolved problem (Geerts, 2011). During this research, design and empirical analysis are alternated to design a differentiated test plan, making it possible to adjust this plan based on the information acquired throughout the research.

This eventually gives the opportunity to evaluate the contents and usage of the plan with stakeholders who test innovations. The various steps of this research are discussed in line with the research process model in Figure 4. The model shows that throughout the research the test plan is iteratively designed based on the input from the empirical analysis. The vertical arrows in the research process model indicate a comparison or analysis of aspects. The horizontal lines indicate input information towards the next product



Figure 4 Research process model depicting the steps taken to conduct this research.



(a) – Desk study

The research starts with a desk study focussing on literature concerning the development of innovations in general, after which the focus is set on the process of testing innovations and creating a test plan. Both private and public parties are involved in this research, so research is performed on innovation between these two and possible barriers. The goal of the literature is to give a general overview of what is known on these subjects and provide a starting base for the empirical research.

Literature sub-questions

- 1. How does the literature define an innovation development process?
- 2. According to the literature, what is a test process/plan?
- 3. Which insight does the literature provide on innovating between public and private parties?
- 4. What does the literature describe as barriers for implementing and developing potential innovations in the public sector?

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(b) - Empirical analysis Interviews + Design test plan V0

The information gathered in the literature study forms a reference framework. This framework is taken into account to conduct semi-structured interviews with market parties and other infrastructural clients. The objective of the interviews is to gain a general overview of what is perceived to execute tests in general. As there are numerous providers and innovations with which tests are performed it gives a broad overview of how testing should be performed. The results of the literature and interviews were used to design test plan V0.

Analysis Interview sub-questions

- 5. What are important stakeholders providing initiatives for ProRail?
- 6. What are the interests of the main stakeholders when testing an initiative?
- 7. What are the barriers when testing innovations between ProRail and its providers?
- 8. What are the existing work methods for testing in other infrastructural sectors?

(c) – Empirical analysis case study + Design test plan V1

In order to validate the accuracy of the acquired information for creating test plan V0, and to go into further depth of the test process, a case study is performed. The case gives insight into factors that are important when testing an innovation. Furthermore, it shows which methods are used to test potential innovations through various development phases. This information is used to revise the first version of the test plan and create test plan V1.

Analysis case study sub-questions

- 9. What factors are important when testing, to prove that a potential innovation can be used in the Dutch railway sector?
- 10. Which methods are used to test a potential innovation between ProRail and a provider, through various phases of the development process?

Design sub-question

11. How can the relevant insights from literature and the empirical analysis be used to design a differentiated test plan, by which ProRail and its providers can test initiatives?

(d) – Evaluation + Design test plan V2

In order to validate that test plan V1 contains the correct information and can be used in real life a workshop was held. The objectives of the workshop were to evaluate the components of the test plan, as they were based on the information gathered in the research and evaluated the usability of the test plan based on test cases performed by the participants. Based on the output of the workshop the test plan could once more be altered creating test plan V2.

Evaluation sub-question

12. What is the expected effect of using a differentiated test plan contrast to how tests are currently performed?

(e) - Conclusion, discussion and recommendations

Based on the final design and the information gathered throughout the research a conclusion was drawn and the main research question was answered. Next to the conclusion the research methods and the acquired information is discussed and recommendations are given for the further improvement of the test process.

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1.6 Practical and scientific relevance of the research

The practical relevance in this research connects to the significance and usefulness for the problem owner, in this case ProRail. As mentioned ProRail does not produce its own products but collaborates with other parties (Nauta, 2017), and innovates to solve existing problems or improve the railway. Providers develop innovations which can solve these problems or may offer a different added value for the railway sector. Through testing it is possible to prove that innovations work in the railway system and can be implemented in this system. It is therefore important that both parties are convinced of the verification and validation of the innovation through the test process. This research will identify the current barriers and fundamental aspects of testing as found by the providers of innovations. This gives ProRail insight in the test methods applied by the developers of innovations. This research will furthermore create a differentiated test plan in order to improve the test process by serving as a blueprint for the test. This plan will serve as a guideline to specify necessary information in order to perform the test in the best possible way, thereby structuring the process and making it clear and transparent for a good collaborative test with a similar goal. This will include a higher objective improving the test process for the future implementation of innovations and improvement of the railway.

The scientific relevance of this research focusses on creating or adding knowledge to the scientific literature. When searching for literature on tests performed in the railway sector between public and private parties limited literature is available. When searching for innovation in the public transport sector some research has been performed on the status of innovation in general (Ongkittikul & Geerlings, 2006). Furthermore, literature focusses on performing tests for software and systems within the railway environment, rather than actual processes or products in and around the railway (Mellado & Duenas, 2001; De Nicola, di Tommaso, Esposito, Flammini, & Orazzo, 2004). Most literature is focused on software testing or product testing in the industry sector. In the construction sector, literature is focussed on the innovation process between public and private organisations rather than the specific test process between these two. Thus, the scientific relevance is characterised by the fact that, although much is known about testing, this information is not yet focussed on testing in the railway or testing between public and private organisations. The research will therefore add knowledge about testing innovations with different providers and a public organisation in the railway sector.

1.7 Outline of the research

In Chapter 2 the theoretical background of this research is discussed. Chapter 3 presents the results of the interviews. In Chapter 4 test plan V0 is designed and in Chapter 5 the results of the case study are presented. In Chapter 6 the designed test plan is improved to test plan V1. Chapter 7 evaluates the designed test plan and in the last chapter alterations are made to design the final test plan V2. In Chapter 9 the conclusion and discussion are given. In Chapter 10 the recommendations for ProRail are given and in Chapter 11, a short reflection is given on how this research was conducted. Chapter 12 gives the references used in this thesis and lastly Chapter 13 gives the Appendices.



2 Theoretical background

This chapter discusses the literature which has been used to approach the problem in this research. The purpose of the desk study is to find methods to perform and plan tests. It should furthermore, provide information on how innovations are developed and how testing fits in this development process. Lastly, the literature gives insight into known barriers when developing innovations between private and public parties. A full overview of the literature is given in appendix C.

2.1 Method desk study

The literature used for the theoretical background has been collected from different data sources. Information for the background was found at ProRail, Google Scholar, FindUT (books from the University library), finished master theses from the University of Twente, articles suggested by supervisors of the University and references in the reviewed literature. In order to find scientific articles from the mentioned sources various key words were used, these are given in Table 1.

	Key words	
Innovation	Verification and validation	Barriers between private and public
		innovation
Prototyping	New product development	Railway testing
Test plan	Public and private innovation	Railway safety
Manufacturing	Concept testing	Development
Test management	Public private innovating	

Table 1 Key words used in the desk study

2.2 Innovation

In order to specify what testing of innovations encompasses it is first sought to define what innovation is and how the process of innovation development proceeds. These two aspects are described in this section.

2.2.1 Definition of innovation

In order to study testing a literature study has been performed to define how innovations are developed and determine what this process looks like, starting by divining innovation in general. Trott (2012) mentions that the discussion on innovation varies greatly when it is seen as an event. Which can be understood if one looks at a citation of Rogers, (2010): 'It matters little, so far as human behaviour is concerned, whether or not an idea is objectively new as measured by the lapse of time since the first use of discovery. The perceived newness of the idea for the individual determines his or her reaction to it. If the idea seems new to the individual, it is an innovation.' However, for this research innovation will be defined as: 'the development and implementation of new ideas, products, processes or services' (Van de Ven, 1986). The interesting aspect to note here is that next to development the innovation should be implemented.

2.2.2 The innovation development process

When focussing on the development process of innovations, from idea to tangible product, these vary between agile to sequental. Within these processes various test moments are distinguished. It shows that testing products cannot be seen separately from the overall development process. Depending on the radicalness of the innovation, the process can be highly iterative (radical) or a step-by-step protocol (incremental) (innov8rs, 2018). Furthermore, most product development processes are not uniform, however they do often use similar actions to manage development and follow the same steps (Unger & Eppinger, 2009). It is also noticed that most development processes distinguish multiple test moments, namely: in-house testing, beta testing, field trials/prototyping and inuse conditions (Cooper, 2014). These test processes can be differentiated from the overall process regardless of the provider of the innovation or the type of development process which is used, as they are part of the main development process.

2.2.3 Innovation drive of private and public firms

When focussing on innovation between public and private firms a different drive and motivation is expected why innovation is performed. It is found that public and private organisations differ to certain standards in this topic. Public firms seek construction innovations to increase the technical feasibility of their projects and improve the performance of the completed facility. Furthermore, governments encourage the innovation as a means to improve the efficiency of the industry and the cost-effectiveness of the facilities (Slaughter, 1998). Private firms, on the other

hand, are slightly different. First of all, they vary from small enterprises run as family businesses, to huge transnationals governed by a complex corporate structure. There are firms with their own Research & Development (R&D) or supplier-driven companies, whose main method of technological change is to adopt new products and processes generated by other firms. On the contrary, public firms tend to be more homogeneous and can be large and bureaucratic organisations that are long-established and monopolistic suppliers of services to society in general. Rather than pursuing profits they are implementing policies that are usually presented as aiming to benefit society as a whole (Miles & Roste, 2011). This gives an indication of the position of ProRail, being a public firm, and its providers, being private firms, when innovating.

2.2.4 Barriers of innovating

For this research five specific barriers of innovating are identified as relevant. The barriers are focussed on the overall innovation development process and not so much on testing. However, as it is found that testing is part of the innovation development process, the barriers are still taken into account to see if they return in the empirical analysis. The barriers are focussed on the construction industry, as the railway sector does incorporate a large part of construction work and the providers are similar to the ones found in the construction industry. An overview of the barriers and their description is given in Table 2.

Barrier	Description
Risk and safety	Unlike a manufacturing product where the set of interactions can often be constrained,
acceptance	construction facilities interact with an open set of components, systems and the
	environment (Slaughter, 1998). As the public sector provides a service towards safety
	in society, this is an issue which can stop innovation (Miles & Roste, 2011).
Rules and regulations	The construction industry is often characterised by a conservative culture, which
	obstructs innovation. Clients are often bound by rules and regulations to test
	innovations within certain criteria (Arnoldussen, Groot, Halman, & Zwet, 2017). The
	construction sector, for that matter, is a strictly regulated sector because systems often
	interact with human users. This slows down innovation but can also block innovation
	when the law and regulations are highly demanding (Klein Woolthuis, Snoeck,
	Brouwer, & Mulder, 2012).
Social and political	Innovation benefits from a strong and stable long-term strategy, changes in goals and
aspects	policies by the government result in a hesitating construction industry for both clients
	and contractors. Constructed facilities often directly influence the safety, health, and
	wellbeing of the population, all portions of a facilities life cycle are circumscribed by
	codes and regulations (Slaughter, 1998).
Equal treatment	An equal treatment is mandatory by law, tenderers need to be treated equally in public
	tenders even if a tenderer has a lead because of an innovation (Zeinstra, 2017).
Collaboration	The Dutch huilding sector is characterised by a strong fragmentation of huilding
Conabolation	companies. A good innovation dimate arises over a longer period, as it takes time to
	companies. A good innovation cimilate anses over a longer period, as it takes time to share knowledge and develop realise and implement ideas. However, often
	scienting and develop, realise and implement fields. However, often
	assignments are executed of granted to individual parties, where each party thes to protect his part of the market (Arnoldussen Groot Halman & Zwet 2017)
	protect his part of the market (Arnoldussen, Groot, Halilan, & Zwet, 2017).

Table 2 Barriers found for innovation in the Dutch construction sector



2.3 Testing

In this section the defition and objective of testing is provided. Futhermore, testing within the innovation development process and the objective of testing are described.

2.3.1 Definition of testing

Radatz, Geraci, & Katki (1990) describe testing as: *'Testing is the process of operating a system or component under specified conditions, observing or recording the results, and making an evaluation of some aspect of the system or component.'* From this definition three distinct steps can be distinguished: (1) operating under specified conditions, (2) observing and recording results and (3) making an evaluation of some aspect. This definition on its own seems to be applicable to a wide selection of test processes, because of the general steps that are taken. This definition is therefore used in this research.

2.3.2 Objective of testing

If one looks further to what objectives there are to perform tests, various reasons are found. Objectives for testing are learning, demonstration, verification, validation and certification (Tahera, 2014). Especially verification and validation terms which are often related to testing physical products (Kukulies, Falk, & Schmitt, 2016). Testing for verification can be performed at different stages of the development process, in order to verify the status of technical progress and minimizing design risks. Testing for validation is often conducted under realistic conditions on any end-product to determine the effectiveness and suitability of the product in an operational environment by typical users (National Aeronautics and Space Administration, 2007). Just as the type of tests in the development process reviewed in section 2.3.3, the objectives of a test reviewed in this section gives the researcher an indication of the purpose of the test in different phases of product development.

2.3.3 Testing in the innovation development process

In innovation development, testing is generally found to be the phase between a potential model and implementation (Mulgan & Albury, 2003). However, to describe testing more accurately it is most beneficial to use the product development process as a reference point to describe various types of tests. When testing is associated with a particular phase in the process it helps to distinguish a purpose and benefit for the type of test (Rubin & Chisnell, 2008). If one relates to the topic of innovation development in section 2.2.2, Cooper (2014) defines the following testing phases: in-house testing, beta tests, field trials and prototying in actual in-use conditions. In-house testing being performed in the early stages of development and actual in-use condition testing being performed in the last stages of product development.

2.3.4 Planning a test

Kukulies, Falk, & Schmitt (2016) mention that when a test is planned, a strategy is determined. This strategy (1) covers general decisions (2) regarding test criteria (3) and test methods (4) in order to derive and prioritise test activities (5) during product development. This strategy is depicted in Figure 5.

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Figure 5 Deriving optimized test planning procedures (Kukulies, Falk, & Schmitt, 2016, p. 97)

Figure 6 Fundamental test process (Spillner, Linz, Rossner, & Winter, 2007)

Spillner, Linz, Rossner, & Winter (2007) argue that to perform a structured test a general description of the tasks is insufficient. A test procedure, or test plan, is needed to perform a test. Figure 6 gives an overview of what they consider to be the fundamental steps in a test process, it furthermore shows that the steps described as similar to the definition of testing given by Radatz, Geraci, & Katki (1990). It furthermore shows that testing is started with the planning of a test.

2.3.5 A test plan and its components

Planning a test is done by using a test plan describing the scope, approach, resources, and schedule of the intended test activities. It identifies tests items, the features to be tested, the testing taks, who will do each task, and any risks requiring contingency planning (Radatz, Geraci, & Katki, 1990). Much as the blueprint for a house describes exactly what you will build, the test plan describes how you will go about testing the innovation. Additionally, it serves as a communication tool between the individuals invovled in the test process. It is therefore important that the management and development team review the test plan in order to understand how the test will proceed and to see whether their particular needs are met (Rubin & Chisnell, 2008). Lastly, it is argued that a different test plan can be set up for different stages of the development process. This would accommodate change when testing (Spillner, Linz, Rossner, & Winter, 2007). This makes sense since each test might have a different objective, as well as different time and research requirements (Rubin & Chisnell, 2008). Relating this to the test phases in section 2.2.2 a differentiation can be made over the test phases, accommodating change and specific testing throughout the development of the innovation. By incorporating all the information needed to execute the strategy for testing a decision can be made on the content of the test plan.

Table 3 Com	nonents which	should be c	onsidered i	in a test r	olan (IFF	F standard	association	2008)
1 0010 0 00111	oonenes winen	Shound be e	onsidered	in a cese p		E Standard	association,	2000)

Components of a test plan					
1-Test plan identifier (test level and product level)	9-Test deliverables				
2-Introduction	10-Testing tasks				
3-Test items	11-Environmental needs				
4-Features to be tested	12-Responsibilities				
5-Features not to be tested	13-Staffing and training needs				
6-Approach	14-Schedule				
7-Item pass/fail criteria	15-Risks and contingencies				
8-Suspension criteria and resumption requirements	16-Approvals				

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Table 3 gives an extensive overview of the various components of a test plan. The reason a more extensive table is given, than a more moderate table, is because the literature provides a first indication of what a test plan should incorporate. This way, throughout the empirical analysis, it can be validated if all parts are found or if parts are obsolete. Furthermore, it can be ascertained if later in this study parts from the literature should be added to the aspects of the test plan found in the empirical analysis.

2.4 Conclusion

Various information on the development of innovations and the performance and planning of tests has been found in the literaterature. The most important information considered for this research has been summarised in a reference framework in Table 4. The framework puts forward the most important items to reach the objective of this research, as found by the reseacher. The framework will be used to compare the information found in the emperical analysis to the literature. Providing an overview of the information gathered throughout the research and input for the design of a differentiated test plan. An overview of all the results of the research compared to the reference framework is given in appendix A.

Items	Theory
Innovation definition	The development and implementation of new ideas, products, processes or services
	(Van de Ven, 1966).
Test phases in	In-house testing, beta testing, field trials/prototyping and in-use conditions (Cooper,
development	2014).
Barriers for	Risk & Safety, Rules & Regulations, Social & Political, Equal treatment, Collaboration.
innovation	
Testing definition	Testing is the process of operating a system or component under specified conditions,
	observing or recording the results, and making an evaluation of some aspect of the
	system or component (Radatz, Geraci, & Katki, 1990). Testing is seen to be part of the
	overal development process.
Goal testing	Verification and validation, learning, demonstration and certification (Tahera, 2014).
Test plan definition	A blueprint for the test, which describes how one will go about testing the innovation.
	Serves as a communication tool between stakeholders (Rubin & Chisnell, 2008).
Test plan	Test plan identifier, introduction, test items, features to be tested, features not to be
components	tested, approach, pass/fail criteria, suspension criteria and resumption requirements,
	test deliverables, testing tasks, environmental needs, responsibilities, staffing and
	training needs, schedule, risks and contingencies, approvals.
Planning strategy	Figure 5, Covers general decisions regarding test criteria and test methods in order to
	derive and prioritize test activities during product development (Kukulies, Falk, &
	Schmitt, 2016)

	<i>c</i>	· ·	<i>c</i> ,	~		
Table 4 Re	ference	framework	formed	from	the	literature

ProRail

3 Analysis interviews

This chapter of the research discusses the results from the interviews. The purpose of the interviews analysis is to give information on how testing is performed in the railway sector and other infrastructure sectors, in addition to the literature that was studied. It also provides a definition of what a test plan should be according to providers and clients. Lastly, it provides information on the barriers and fundamental aspects of testing. This information, together with the theory, leads to a first design of a test plan.

3.1 Method of interviews

The interviews were semi-structured and face-to-face. The same interview protocol was used for both the providers and the clients. This ensured that the same category of information was gathered, and that a comparison of the data could be made. In order to validate that the correct data is transcribed, the interviews were sent back to the interviewees. If this was not the case the interviewees were asked to indicate if information should be changed.

Two groups were interviewed: (1) the providers of innovations and (2) clients performing tests in other infrastructure sectors. From the providers three main stakeholder groups were distinguished: Engineering firms, contractors and suppliers. These stakeholders have provided information on how providers test innovation in the railway sector. They were chosen by means of a power and interest grid based on the innovation strategy of ProRail. The second group interviewed were the infrastructure clients, consisting of road, water, airline and drink water infrastructure. The clients were interviewed to identify if the same problems exist as are found with the providers, but also to find out if solutions for these problems have already been developed. Furthermore, it shows a broader perspective of testing as a client. In total twelve interviews were held. The full extent of choosing these stakeholders is discussed in appendix D.

3.2 Results interviews

In this section the objective of innovating and testing, the distinguished test phases, definition of a test plan, barriers and fundamental aspects of testing are discussed. A conclusion is given on the findings in the interviews.

3.2.1 Objective of innovating and testing

A certain difference is made when defining the objective of innovating and testing. Now this might be no surprise however, when developing a product, innovation and testing are closely related and inextricable to the overall development process.

Objective of innovating

From a provider's point of view the interest of developing innovations in general is being able to implement and apply the innovation in the system, and in that sense, being able to drive business with the innovation. Using the innovation can improve the quality of the work performed and the functioning of the railway. In general, the clients agreed that an innovation should be implemented in the system. However, instead of primarily driving business with the innovation, the innovation should have an extra added value in comparison to already used assets and offer some sort of improvement to the infrastructure for its users., which complies with the literature.

Objective of testing

The objective of testing is somewhat different to that of innovation, and three main objectives were distinguished. Namely: defining what the demands to test should be, proving the set of demands and finally gaining value from testing. The first two objectives were shared by both the providers and the clients. The third objective was defined only by the clients.

The most prominent objective of testing found is to prove a set of demands. The demands in this case should be derived from the specific function that the innovation needs to perform. A demand can be a certain load that a product must bear or a specific performance it must deliver when implemented in the system. In any situation, it should be determined that the demands are met for the goal that is defined, whichever this might be. If the demands are met the results can be approved, otherwise changes need to be made. Meeting the demands makes it possible to implement the innovation into the railway. The demands can be defined by the client, or stakeholders, which are involved in testing and developing the innovation. Both by the market parties as the clients this objective was found to be the most prominent.

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In addition to proving a set of demands it was also found that through testing demands can be determined for a later development stage. For example, through testing certain properties or specific functions of the innovation can be determined. By establishing these aspects in an earlier phase one can determine which demands need to be proven in a subsequent phase. For instance, tests in a controlled environment could be used to determine the demands which need to be proven in the operational environment, helping to determine the tests in the operational phase. When defining the demands the end goal of the overall development process does not change. The goal of preceding test phases can change based on findings throughout development.

From the interviews it was found that both the first and second objective can occur in one developing process. First, the objective of defining the demands can occur, after which in a different stage the objective can be to prove the demands defined earlier.

The third, and last, objective that was found was defined by the clients. Here the objective of gaining value through testing was defined, even if the demands are not proven. An example was given to gain experience by performing the test, in how the innovation works and how one should operate the innovation. In a way this objective is related to defining the demands and through this defining the properties and functions of the innovation, but also finding the *use* of the innovation.

3.2.2 Test phases distinguished in the development process

In both the interview with the providers and the clients three test phases were distinguished when developing an innovation. The testing phases and corresponding environment are given in Table 5.

Testing phase	Description
In-house	In-house testing is characterised by laboratory tests, either performed by
	third parties or the provider. The laboratory test simulates the outside
	situation.
Controlled/technical	This environment is characterised by a facility where railway tracks and
environment	other elements are available, but the environment is not operational. The
	risks in this environment are low and can easily be controlled. The downside
	is that a non-operational environment is often not representable for the real
	functioning of the innovation.
Real-life/operational	This environment is characterised by the real-life operational situation.
environment	Testing is often performed on a location which represents the variables in
	which the innovation needs to perform. This phase is more complex due to
	higher risks and multiple stakeholders that get involved. Tests are often
	performed to meet the specifications.

Table 5 Test phases distinguished in the interviews

The same phases are more or less distinguished as in the literature. Furthermore, it shows that different tests occur in every phase with, most likely, a different goal for each test. It shows that a differentiation can be made in the testing activities over the three phases found.

In the interviews the use of Technological Readiness Levels (TRL) was also mentioned to determine the level of development of the innovation. TRL make it possible to assess to which degree an innovation is adequate to be used in the infrastructure. When using the TRL the size of the innovation does not matter; it can be a small sensor or a large improvement program. Furthermore, the TRL helps to distinguish were further development is possible and when an innovation is ready to be implemented in the railway (de Boer, 2018). In the interviews the TRL were used by both a provider and a client to assess the current level of development of the innovation, but also to assess what types of tests should be performed in the current level of development. For example, the client used the TRL to evaluate if the innovation was ready to be tested in an operational environment or not.

3.2.3 A test plan and its components

From a provider's perspective it was found that a test plan describes how the test should be planned, rather than how it should be executed. The test plan should give attention to all the attributes necessary to perform a test and the phase in which testing should be considered. Subsequently, one should also consider what has been tested in

the previous phase and what should be tested in the next phase, as both these situations have an influence on the current test to be performed. From a client's perspective the test plan is defined as a communication tool between the involved parties when testing and it should be clear what is stated in the test plan. A table of the components which both groups defined as important to be involved in a test plan are given in Table 6.

Components of a test plan							
Functions to test Expected results Testing phase Go/ no go							
Execution of test	Demands	Risks during tests	Risks innovation				
End goal	Stakeholders	Specifications	Monitoring				
Location	Role assignment						

Table 6 Components of a test plan as found in the interviews

Now a test plan is not to be confused with a test protocol, some of the providers gave an example of a test protocol. This was defined as a document written for each individual test in order to know how a test should be executed. A protocol defines the various steps to be taken when conducting the test. For example, the time frame in which steps should be executed or a specific explanation of operating during the test. In a way, these steps could be derived at after a test plan is set-up.

In this research the focus is on planning for the execution of the test. For this reason, the definition of a test plan, given by the interviewees, seems to be more compliant to reach the objective of this research. This focusses more on the organisational side of testing and complies with the definition of a test plan found in the literature.

3.2.4 Barriers of testing in the railway sector

Various barriers are experienced for testing by both providers and clients. The objective of identifying the barriers is to find which obstructions are perceived when testing an innovation. The relevance of identifying these barriers is that they show the difference and similarity in the barriers perceived by both groups, and thus indicates which improvements can be made for the test process.

Most of the providers experience the same barriers when testing innovation, the same is noticed for the clients. However, a difference occurs in how many barriers are perceived by both groups and to what extent both groups experience the same barriers. Table 7 gives an overview of the barriers experienced. First the barriers are presented which are experienced by both the provider and the client, after which the barriers which are experienced separately are presented.

Barrier	Description	Provider	Client
Rules and	Regulations regarding safety are found to be heavy and one of the most	Х	Х
regulations	important when testing in the railway. One could make these		
	regulations more flexible, but it is uncertain whether this would have		
	the correct results. It was found that there are no regulations providing		
	innovation/testing in the railway. With other clients it was found that		
	own rules and regulations can be a barrier if the product to be tested		
	may not be implemented in the system.		
Money	Money is more of a general barrier of innovating in general. This is	Х	Х
	because not all the innovative products can be sold. Reflecting on the		
	test process the end goal of development should be clear as testing can		
	be costly, depending on the type of innovation. Expenses are most		
	frequently linked to testing with trains. Hiring a train is considered		
	quite expensive. On the contrary it was mentioned that in this situation		
	the speed of development can outweigh the costs of the test.		
Time to market	Part of the long lead time is due to clients having to assess and make	Х	Х
	decisions about the implementation of the innovation. Another part is		
	due to testing in the railway. Trains are less flexible to test with and		
	iterations in the tracks are not easily made due to train tables. A		
	solution is to perform more tests in earlier phases.		

Table 7 The barriers that were found when conducting tests

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Transparoney	With radical innovation it can be hard to determine what tests should	Y	Y
Transparency	he mentance innovation it can be hard to determine what tests should	Л	Λ
	be performed and now they should be performed. Furthermore, it is		
	not always clear what should be proven through testing. The goal and		
	expectations are also not always clear, making it hard to determine		
	what should be tested. A collaborative end goal is needed to determine		
	what is expected from each party.		
Lack of	Especially in the case of new parties there is often little or no	Х	
information	knowledge about the rules and demands of working and applying		
	innovations in the railway. The procedures for testing in the railway		
	are often more than presumed at the start		
Processos	It was found that testing with ProPail is more complex because the	Y	
110003505	nt was found that testing with i forcan is more complex, because the	Х	
	processes are unclear. Onclear relating to the steps which need to be		
	taken during testing. Specifying the verification and validation clearly		
	was mentioned as a solution for defining clear processes.	24	
Existing	When an innovation is developed around the existing	Х	
specifications	protocols/specifications, it is very hard to adjust the protocols to the		
	new innovation. This results in a conflict where there is a difference		
	between functional and specified demands. This was found to be the		
	case because specifications are perceived to be known product		
	descriptions rather than demand specifications. As the demands		
	should be based on the goal of testing or the eventual stage of		
	development, the specifications effect the test process.		
Decision	When testing the provider is often the developing party and ProRail is	Х	
making	the facilitating party. It is argued that the decision-making moment		
	during testing should be with the party initiating the test. This would		
	make it easier to inprovate Contrary to this deciding if the product is		
	have it easier to innovate. Contrary to this, deciding it the product is		
	being developed in the correct of incorrect manner depends on the		
	Wisnes and choices of the client.	24	
Fear	Fear relates to the fact that something could go wrong when testing in	Х	
	the railway. This is partly due to safety, a failing railway system and		
	delays for the public. Furthermore, complexity increases when testing		
	in the railway, making the chance of failure greater.		
Moving from	A test location should provide the variables to the specific function that	Х	
controlled to	the innovation needs to fulfil. Therefore, a location cannot just be		
operational	appointed. It is hard to move to the operational environment because		
environment	the test might fail in the railway. This barrier was found by most		
	market parties, as testing in a representative environment would		
	obviously allow for better development, however this is only possible		
	at a certain development level. It was suggested to test certain non-		
	functional aspects in earlier phases to make the innovation safer		
Scope	It is often found that more proof is needed than that which falls within	X	
Jeope	the scope. Extra demands are formulated by individuals who at first	Л	
	were not involved with the test. It is difficult to find a starting mit		
	were not involved with the test. It is difficult to find a starting point		
	from which it is clear that if you meet the demands the innovation is		
.	implemented.		
Location/placi	lesting innovation is most effective on locations where the demands to		Х
ng	be proven are represented. However, the locations can be critical to the		
	overall functioning of the system. Thus, a location is sought where the		
	negative effects can be controlled but is also representative. This was		
	found to be difficult.		
Stakeholders	If one wants to implement an innovation, enthusiastic individuals in		X
	the environment is necessary. Non-enthusiastic stakeholder can prove		
	to be a barrier for implementation.		

The first thing that was observed was that there are only four common barriers between ProRail and the clients, namely: rules and regulations, money, time to market and transparency. As explained in Table 7 both time to market and money are barriers which are strongly linked to the innovation development process, rather than only

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the test process. Testing can be a costly part of development and a choice must be made of how much money is spent for the benefit of overall development. In an operational environment testing is most expensive, but yields the best results, as this environment is often representative for the functions the innovation is expected to perform. If it is not sure that the innovation will be adopted through testing, but high investments need to be made, money can form a barrier. For the barrier: time to market the interviewees mentioned that the lead time from idea to implementation is long. From this lead time the time in between tests is a bigger constraint then the testing itself, such as assessing the next step in development by clients. Focussing on testing, in an operational environment, it was mentioned that, unlike cars or ships, trains are not easily manoeuvred to execute multiple tests in a short time. This makes it harder to perform quick iterations in the testing phase.

The other two barriers experienced by both groups, rules and regulations and transparency, were more specifically focused on the test process. The clients motivated that existing rules and regulations form a barrier for testing as innovations are products which cannot be readily implemented into the system. By providers safety was especially mentioned as most important and as a heavy regulation for performing tests in an operational environment. Regulations to provide easier testing and innovating in the railway next to the existing rules and regulations were perceived as not present. Finally, it is interesting to see that transparency is mentioned by both parties. Having bad or low transparency reflects on the fact that it is unclear what is expected from the test, what is expected from the developing party, and what will happen if the test does not turn out to have the desired result. This could relate to the aspect of making it difficult to plan and prepare tests. A reason for this could be, for example, because the goal or expectations of the test is not the same for the stakeholders involved. Subsequently, this can happen if a radical innovation is tested and it cannot be determined which and how tests should be performed.

3.2.5 Fundamental aspects of planning a test

Apart from barriers the interviewees were asked what fundamental aspects are when testing an innovation, and if they should be taken into account when testing an innovation. The objective of finding these fundamental aspects is to uncover what is perceived as important to execute a test. The relevance of distinguishing these aspects is found in the fact that if these aspects are fundamental to perform a test, they should also be taken into account in the planning and preparation of a test. These aspects are regarded as important to conduct a test, regardless of the stakeholders, innovation or setting. In Table 8 each fundamental aspect is mentioned with a description of what it involves. Furthermore, on the left side of the table which group of the interviewees the aspect was mentioned, has been included. It is apparent that both clients and providers agree strongly on most of the aspects which should be involved in testing, unlike that which was found with the barriers.

Fundamental aspect	Description	Provider	Client
Demands	The demands need to be identified and extracted from the end situation in which the innovation should function. If one knows which demands are to be met, one knows which steps in testing need to be taken. Depending on the goal and the phase of testing the demands need to be suitable for the development stage. Lastly, a distinction was made between stakeholder demands and functional demands.	Х	Х
Risks	Before testing the risks need to be clear, thus a risk assessment session is necessary to define all the risks that can occur. It was even found that risks should be one of the most prominent aspects of the test plan. The extent to which innovations are monitored and tested are dependent on the severity of the risks. This is critical for testing in the railway. A well-prepared mitigation plan should prevent escalations in the case that something may go wrong. Mitigation could be done by testing high level risks in a low-profile environment. All stakeholders need to be involved in defining the risks	X	X

Table 8 Fundamental aspects of conducting tests found in the interviews

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Stakeholders	Everybody who is involved in talking, listening and thinking about testing should have the same goal. Apart from goal alignment it is important to define the roles of every party and individual in the test process, and responsibility for the various risks. For every test phase the stakeholders should be considered, as they might differ per phase	Х	Х
Experts	Among the clients an expert is an individual with in-depth knowledge about the category of the innovation. An expert should be consulted quite early on in the process to give input into the test plan, test performed, test location, risks and judge the outcome of the test. Especially for new market parties, advice for performing tests in the railway is necessary.	X	X
Location	The location for testing is determined by the demands that must be met for the goal of the test. Representative locations can be difficult to find considering the risks but are essential to perform the tests. Performing technical tests in a representative location can provide insights in functionality early in the development process. When a location is chosen it should be ensured that the conditions in the location stay the same, as potential risks might become safety issues.	X	X
Structure/work method	In the case of larger innovations and multiple stakeholders, tests should be well planned and structurally performed. Structure provides clarity and prevents miscommunication. The overall process structure may always be consistent, however, the steps and their contents may change per test, as every provider has its own way of working and testing. Thus, the method of monitoring the test and recording the results can vary. An important aspect is that there are no rules and regulations to provide testing in the railway. Thus, a test regime is needed to provide arrangements to test safely in this environment.	Х	х
Agreement	The organisational aspects of testing are deemed more important than the technical. For example, if all stakeholders agree on the execution of the test, risks could become a smaller barrier. In the case of radical innovation agreement on the execution can be hard. A solution is to include extra go/no go moments to include flexibility. Lastly, there should be agreement that reaching the end of development is not obligatory. This reason should however be stated clearly.	Х	X
Project leader	An individual who controls the test activities, controls activities between stakeholders and pulls the project throughout the organisation is needed. This person could be chosen per test phase or in the overall development of the innovation.		Х
Expectations	It is important to manage goals and expectations between stakeholders. A goal of innovation development is often defined by the end user and should be equal for everyone. An expectation can be a sub-goal of a client.		Х

From the table only project leader and expectations are not mentioned by providers and are explicitly mentioned by clients. This contrasts with the barriers found, where the providers experienced far more barriers than the providers. An explanation for this could be due to the fact that the providers have, in nearly all the situations, a developing role and the client has a facilitating and assessing role. The developer experiencing obstructions for developing earlier on while the facilitator experiences these as "obstructions" for safe and controlled development.

One fundamental aspect does not stand alone from the other aspects. The involved stakeholders and their roles in the test process affect the work method but also the number of risks and demands which should be proven through a test. Subsequently, the demands and risks affect the location, as this should be representable to prove these aspects. It seems, most aspects have an impact on the organisation of the test as to what and how the test will be executed. The fact that both groups agree on the fundamental aspects gives an indication that both groups know

what is needed to perform a test. Reflecting on difficulties arising in order to prepare a test could indicate that both groups do not agree on the contents of the fundamental aspects. For example, the providers mentioned that the demands should be derived from the function of the innovation in the railway system, however, they find that demands are often derived from existing specifications.

3.3 Conclusion

In Table 9 a summary of the results is given in reflection to the reference framework that was formed from the literature (Table 4). In the table the most important findings from the interviews are given on the left and an on the right the most important findings compared to the literature are clarified. A more extensive overview of the interview results is given in appendix D.

Items	Interview analysis	Clarification findings to literature
Innovation	Objective: To implement and apply the	The objective of innovation found is quite
objective	innovation in the railway and perform	similar to the definition of innovation in the
	business with it, having an added value.	literature, both remark on the aspect of
		implementation of the product.
Test phases	In-house testing, technical environment and	Most of the phases found in the interviews
in	operational environment.	comply with what is found in the literature.
development		Namely: in -house, prototyping or technical
		environment and in-use conditions or
		operational environment. The literature
		describes beta testing as well, this is not
		found in the interviews.
Barriers	Lack of information, processes, rules and	Many more barriers were found in the
	regulations, existing specifications, decision	interviews than found in the literature. Only
	making, money, time to market,	risk & safety, rules & regulations and
	transparency, fear, moving from controlled to	collaboration were found as common
	operational environment, scope,	barriers. In the literature, furthermore, equal
	location/placing, individuals.	treatment was distinguished. This was found
		to be a barrier for innovation in general.
Testing	Objective: Verification and validation,	No specified definition of testing was found.
objective	defining demands, gaining value.	The objective was found and is discussed
		under the goal of testing.
Goal testing	Verification and validation, defining what to	Both in the literature as in the interviews that
	verify or validate and gaining value.	verification and validation is a strong
		objective of performing a test. Furthermore,
		learning and defining the V&V- criteria was
		found in both information sources.
Test plan	A test plan is a communication tool. It	In both the literature as the interviews the test
definition	describes how the test is planned and gives	plan is described as a communication tool
	attention to all attributes needed to perform a	and should be used to plan the execution of
	test.	the test.
Test plan	Functions to test, execution of test, end goal,	The literature was more elaborate on the
components	location, expected results, demands,	components a test plan should involve than
	stakeholders, role assignment, testing phase,	that found in the interviews. However, the
	risks during tests, specifications, Go/no go,	components found in the interviews were
	risks innovation, monitoring.	more specific than the literature.
Planning	Demands, risks, stakeholders, experts,	No distinct strategy was found in the
strategy	location, structure/work method, project	interviews, however, fundamental aspects of
(tundamental	leader, agreement, expectations.	performing a test were found. The
aspects)		tundamental aspects largly comply with the
		test plan components found in the literature
		and can be incorporated there.

Table 9 A summary of the results of the interviews related to the reference framework

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When reviewing Table 9, one will notice that most aspects found in the literature comply with what is found in practice. For example, the objective of innovating is closely related to the definition of innovating, the development phases found are also closely related and the components of a test plan found are quite similar. However, the components mentioned in the interviews were more specific. Concrete items such as demands, risks and monitoring were mentioned. Also, stakeholders and their involvement in testing play an important role. Throughout the barriers and fundamental aspects mentioned in the interviews stakeholders, or more generally individuals, involved in the test process can have a definite influence on the trajectory of the test.

What is interesting to notice is that the providers and clients are far more in agreement over the fundamental aspects of testing, than over the barriers during testing. It seems there is some sort of gap where the providers experience far more barriers than clients when testing. This could be because of the discrepancy of the roles of providers developing innovations and clients facilitating development. However, the fact that there is agreement on the fundamentals of testing shows that both groups know what is important to test an innovation. Most interesting is the fact that in both the barriers and fundamentals of testing risks, stakeholders and location were mentioned. These three aspects are become increasingly more important moving towards testing in an operational environment, but apparently can appear to become a barrier to perform the desired tests.

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4 Design test plan V0

After reviewing the data gathered from the literature and the analysis of the interviews a first design for a differentiated test plan was developed. Rather than designing a test protocol, which describes every step necessary to perform a test, a plan was created to document planning the test. This was chosen based on the responses of the interviewees for the contents of a test plan.

4.1 Structure of test plan V0

Based on the findings in the literature and the findings in the interviews test plan V0 was designed. The structure of the test plan is based on the strategy for planning tests defined by Kukulies, Falk, & Schmitt (2016): (1) General development method, (2) test activities, (3) test demand, (4) test effort (Figure 5). Within this structure the test plan components and phases are included. Lastly, the barriers found in the interviews have been addressed in the test plan by taking them into account in the various components. An overview of the structure and parts of the test plan is given in Figure 7. The figure shows that one starts with defining the testing phase, after which the demand and effort are defined.



Figure 7 Overview of the structure of test plan VO

4.1.1 Test plan differentiation

The objective of this research is to design a test plan which can be differentiated over diverse situations. The differentiation is determined over the three test phases distinguished when developing innovations the railway sector, rather than over the types of innovations and the type of providers. Here it should be noticed that the test plan is thus a part of the overall development process and does not specifically stand on its own. Within the interviews it was mentioned that it would be possible to develop one strategy which could be applicable to all situations while, at the same time, adjusting this strategy to the innovation to be tested. Now when reviewing the literature, it was found that the components for a test plan are always largely the same. Furthermore, derived from the definition of a test, the steps taken in a test can always be the same. Thus, it was decided to develop one test plan in which all components are taken into account. Depending on the providers, innovation and phase of testing the components can be given context to the specific tests to be performed.

Three different phases have been distinguished in the railway sector: testing in-house, in a controlled environment and in a real-life operational environment. In addition, by both client and provider TRL are used to determine the development level of the innovation. Also, within ProRail TRLs are starting to be used: for example, to decide what sort of test should be performed. The TRLs give structure by assigning a specific state of readiness during the development of the innovation. Nine TRLs are distinguished: level one can be regarded as a functional idea and level nine is a working system at the end of the development process. These nine levels can be grouped in three phases, from 1-3 (research), 4-6 (development), 7-8 (fine-tuning) and 9 (life cycle management) (de Boer, 2018).

Table 10 the different phases are presented with the matching scale of testing and test environment. For the test plan only the first three TRL phases are acknowledged, as in phase 9 development is already ended and the innovation operates in a working system.



Table 10 Test phases with the matching technological readiness levels, test scale, environment and related barriers (U.S. Department of Energy Office of Environmental Management, 2010).

Phase	1	2	3
TRL	1-3	4-6	7-8
Test scale	Laboratory	Pilot/Engineering	Full
Environment	Laboratory	Controlled/non-operational	Full operational environment
		environment	

4.1.2 Test plan components

The components which are integrated into the test plan are displayed in Table 11. In this table, the components are divided between test demand and test effort. Test demand focusses on the (stakeholder) requirements and risks which are tested (Kukulies, Falk, & Schmitt, 2016). In the interviews, it was mentioned that risks and requirements determine which tests are to be performed. For this reason, test demand in this research characterises what needs to be known before the test are determined. Test effort describes which factors need to be considered to perform the test such as preparation, procedures and completion (Vivenzio & Vivenzio, 2013). It can be seen that more components have been added as a result of the interviews than found in the literature, as the interviews represent what happens in practice. The components added as a result of the interviews seem to be more related to planning tests then executing tests This matches the description of what a test plan is as found in the interviews, namely: a tool used to plan tests rather than how to execute tests. There are certain barriers found in the interviews which are not addressed by integrating them as specific components in the test plan. These barriers are: transparency, money, time, lack of information, processes, moving from controlled phase to the operational phase. They are addressed as:

• Transparency: is addressed in various components. By defining a clear goal for the test with all the important stakeholders involved and specifying how the goal is reached transparency is improved;

- Money: is not addressed in terms of the costs of every test, but the part each stakeholder has invested in the test;
- Time: Time is addressed by adding a planning for the test. Showing the lead time of the test;
- Lack of information: This barrier is linked to transparency. By specifying the approach, goal and test phase, etc; the stakeholders should identify what is needed to test in the railway;
- Processes: This aspect is addressed by specifying the demands and risks making it possible to identify which actions should be taken to prove or mitigate these, and thus knowing which processes should be followed;
- Moving from controlled to operational environment: this barrier is addressed by the go/ no go moment. By specifying, to the extent that is possible, what is necessary for go or no go one can specify which benchmark needs to be met to move to the next phase.

Test demand		Test effort		
Component	Source	Component	Source	
Function innovation	Interviews	Tests	Interviews	
Test goal	Interviews, literature	Location	Interviews, literature	
Test phase	Interviews	Approach	Interviews, literature	
Scope	Interviews, literature	Expected results	Interviews, literature	
Stakeholders	Interviews	Evaluation	Literature	
Go/ No Go	Interviews, literature	Planning	Literature	
Demands and risks	Interviews, literature			

Table 11	Components	of the	test plan	and	their	source
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4.2 Test plan V0

The set-up of the test plan and a description of its components are given in Figure 8 and Figure 9. The test plan is built up out of a general part introducing the innovation, after which the components of the test plan are divided in test demand and test effort, as seen in Table 11. In Figure 8 and Figure 9 from left to right, first the components of the test plan are given with the objective of this component, after which the procedure of filling in the component is given and by whom. Lastly the output of the component is given per phase.

4.3 Conclusion

Concluding the test plan can be differentiated over three phases, representing the phases found in the interviews. Each phase gives a distinction of the environment in which is tested and the scale of the test. The components of the test plan represent what is perceived necessary to plan a test in practice by the providers and clients and literature. These aspects have then been structured to prepare a test. Showing on which requirements the test should be based (test demand) and what is needed to perform the test (test effort).

Pro*R*ail

Components – Test plan VC	Procedure		Ouput	
Project background		Phase 1	Phase 2	Phase 3
Background project Informing stakeholders project 	Action: describe the development project until current stage.	Background information about the project up until this test stage.	Background information about the project up until this test stage.	Background information about the project up until this test stage.
Background innovation • Inform stakeholders project	Action: describe information about the innovation to be tested.	 Stage of development Function innovation in railway system Added value innovation 	 Stage of development Function innovation in railway system Added value innovation 	 Stage of development Function innovation in railway system Added value innovation
 Test phase Provides setting for test activities, scope, stakeholders and demands of test 	Action: description of the phase in which the test is performed.	 Phase 1 Lab environment TRL levels 1-3 	Phase 2 Controlled environment TRL levels 4-6.	Phase 3 Operational environment TRL levels 7-8
Test domend				
Goal • Determining the goal of the test for all involved stakeholders.	Action: Make sure the goal to be obtained by this test is clear. At the end of this test →	 End goal of development End goal for testing phase (e.g. learning) 	 End goal of development End goal for testing phase (e.g TvG) 	 End goal of development End goal for testing phase(e.g Implement)
 Scope Defines what has, and has not been, tested. 	Action: In line with the goal and test phase define what has and has not been tested to reach the goal.	 The extent of testing in lab environment. Level to which tests are performed. 	 The extent of testing in the railway. Level to which tests are performed. 	 The extent of testing in the railway. Level to which tests are performed. Sofaty loval test
		• Salety level test.	• Salety level test.	• Safety level test.
Stakeholders • Who takes part and who does not.	Action: Based on the scope and the test goal determine which stakeholders are needed to perform the test.	 Organisation + individual Role organisation Relation to test individual Invested worth organisation. 	 Organisation + individual Role organisation Relation to test individual Invested worth organisation. 	 Organisation + individual Role organisation Relation to test individual Invested worth organisation.
Go/ No go • Specifies in which situation testing is stalled or resumed.	Action: In agreement with stakeholders specify criteria for go/no go.	List of known criteria for stopping or continuing testing.	 List of known criteria for stopping or continuing testing. 	 List of known criteria for stopping or continuing testing
Demands and risks • Show which tests need to be performed in this phase.	Action: Determine which demands and risks are to be tested based on the end goal of this phase. →	 List of demands to be tested or questions to be answered. List of risks to be mitigated. 	 List of demands to be tested or questions to be answered. List of risks to be mitigated. 	 List of demands to be tested or questions to be answered. List of risks to be mitigated.
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Figure 8 Main concept of test plan V0.

Pro*R*ail

Component—test plan V0	Procedure	Ouput			
Test effort		Phase 1	Phase 2	Phase 3	
Tests • Defines which tests need to be performed	Action: Describe tests based on demands, risks and evaluation questions.	Describe test(s) Linked to demand, risks or question.	Describe test(s) Linked to demand, risks or question.	Describe test(s) Linked to demand, risks or question.	
Environment • Represents demands and risks to be tested	Action: Based on the demands and risks a test environment is chosen with the involved stakeholders.	 Environment which represents demands, risks and questions to be tested. Stakeholders related to environment. 	 Environment which represents demands, risks and questions to be tested. Stakeholders related to environment. 	 Environment which represents function of the innovation and tests. Stakeholders related to environment. 	
Approach • Gives context to how the test will be performed.	Action: Describe how the test is performed and which roles the stakeholders have when testing.	 Risks during testing Tasks and responsibilities Rules and regulations for testing Set-up Method of monitoring 	 Risks during testing Tasks and responsibilities Rules and regulations for testing Set-up Method of monitoring 	 Risks during testing Tasks and responsibilities Rules and regulations for testing Method of implementation operational environment Method of monitoring 	
Expected results • States which results are expected from the tests.	Action: Based on the demands and risks it is described which results the test is expected to have.	 Margins within which the innovation is expected to perform based on the demand or risk. 	 Margins within which the innovation is expected to perform based on the demand or risk. 	 Margins within which the innovation is expected to perform based on the demand or risk. 	
Evaluation • Evaluates how the test was conducted, which results are yielded and what the next steps are.	Action: Based on the output of the test an evaluation is done of the test with the involved stakeholders.	An evaluation report stating what the results of the test were, what method was used and how testing is resumed.	An evaluation report stating what the results of the test were, what method was used and how testing is resumed.	An evaluation report stating what the results of the test were, what method was used and how testing is resumed.	
Planning • States how long the test will take.	 Action: With the stakeholders, a planning is made of the test and its activities over the length of the test phase. 	A planning describing the trajectory of the whole test phase.	 A planning describing the trajectory of the whole test phase. 	 A planning describing the trajectory of the whole test phase. 	
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Figure 9 Main concept of test plan V0.

ProRail

5 Analysis case study Happy Railing Schaarfence

This chapter discusses the results from the case study of an innovation tested and released into the railway. One case is analysed in this research. The case is not the main source of data, but supplements the information already found in the interviews and provides a different angle to study the test process. For the reason that one case is studied a representative case is chosen to achieve the objective of this analysis, which is twofold: first to determine if the information from the literature and the interviews complies with a test performed in practice and secondly, the information from the case will provide more in-depth information on how the components of test plan V0 are used during testing in different phases. The result of the case study analysis will be an iteration from test plan V0 to test plan V1, based on the information found.

5.1 Method of analysing the case study

In order to choose a representative case various test processes were reviewed based on defined criteria. First it was decided if a test plan had been used. Secondly, if the innovation was provided by a market party. Thirdly, if the innovation falls within a category of which more tests are usually performed. Lastly, in order to ensure that the whole test process could be reviewed, the development and testing of the innovation was ended.

The data in this case was mainly collected through an independent analysis of documents that are readily available, such as reports. This does not offer as much control as interviews or observation but offers already recorded data from the performed test (Runeson & Höst, 2009). Furthermore, supporting unstructured interviews with the involved parties in the case were held to clarify and supplement the information. The data was collected following the structure of test plan V0. Thus, it was sought if the three tests phases were distinguished in the case and if the different components could be found in order to perform the test.

5.2 Description Happy Railing Schaarfence

Within the law and regulations on safety lengthy disruptions of the infrastructure are currently needed when inspecting the railway. In these situations, larger parts of infrastructure are closed than is necessary. When inspecting or maintaining the railway fences are used to function as physical barriers, such that workers are prevented from falling onto the neighbouring railway. However, observations show that, when in use, these fences often have limitations as they block the clearance area for special freight trains.

A solution to this problem is the Happy Railing Schaarfence (HRS), or ARBO safety guard, was developed by BAM Rail to solve this problem. The HRS is a foldable physical partition which can be implemented as a safety measure in the railway. In Figure 10 the HRS is shown in use. The HRS was developed to reduce the disruption of the railway traffic. The barrier can be left in the railway, because in its folded situation the fencing proves to be no obstacle for passing traffic and neighbouring railway can stay operational when in use. As the problem of the disruption already exists there was a certain need for this type of safety innovation. It improves the mobility of the trains and improves work safety. The rules and regulations around work safety often change, thus many innovations are developed in this category.



Figure 10 Happy Railing Schaarfence in use in the railway (Bam Rail, 2016)

The test process of the HRS has taken a total of three years,

which was considered as a lengthy time span for an arguably simple innovation. A timeline of the development of the HRS is given in Figure 11. The three phases defined within this research can also be found within this case. In the first phase of testing the provider of the innovation tested and developed the product on their own initiative and costs. In the second phase the product was tested by a certified body and in the last phase the product was evaluated by BAM again, ProRail having an assessing role. In this last phase, phase 3, the innovation was to be evaluated in the winter. In this case when there was a chance of malfunctioning of the product the HRS could be tested. In the overall process the provider of the innovation had already performed multiple tests by their selves and contact with the regional department of ProRail. It was quite late in the process that the head office of ProRail



got involved. One of the reasons found for this development was that the regional department was not aware of how to the innovation process could be started with ProRail Central.





5.2.1 Roles of the organisations involved in the case

Four parties were involved in the development and testing the HRS. These are ProRail, BAM Infra Rail and Aboma Rail.

ProRail:	ProRail's role in the test process was to give authorisation for the use and release of the HRS on the track, such that it could be used in the railway infrastructure. There are different departments
	which were involved in the test process. However, they will be taken as one for the examination
	of the test process.
RailAlert:	RailAlert is an institute whose goal is to facilitate occupational safety with the implementation
	and maintenance of rail infrastructure. They try to achieve this goal in the rail infra branch by
	supplying an effective and efficient certifying system within occupational safety (RailAlert, 2012).
	In the test process, they are the certifying body for the innovation to be used in the railway.
BAM Infra Rail:	BAM Rail is the provider of the innovation and the developer of the Happy Railing. Within this
	process they have developed the product from an idea to a functional product.
Aboma Rail:	Aboma Rail certifies materials and various equipment for in the railway. In the test process, they
	tested the HRS before the permission of use in the railway infrastructure (Toestemming voor
	gebruik (TvG)).

5.3 Results case study

Here the results of the case study are presented. The results are reviewed based on the test phases conducted and the identified components of the test. The phases researched are phase 2 (controlled environment) and phase 3 (operational environment), as these are the test phases were formal testing was conducted.

5.3.1 Identified test phases

In this case two test phases in which formal testing was conducted are distinguished, where ProRail got involved in the test process. The first phase was before the TvG in the railway and the second for the release of the product. Relating these two phases to the phases distinguished in test plan V0 the test before the TvG was granted in a controlled environment and the test for release was performed in an operational environment. A TvG is required when a realisation project wants to use a product in the railway, which has not yet been fully developed for use in the railway. A TvG is temporarily for the purpose of testing the product and has a maximum duration of a year. Releasing a product allows for other parties to use the product in the railway according to the demands and specifications for the product. Here there is a dependency for the developer of the innovation on another organisation to prove that the innovation works and to further develop it in the next phase. In both phases, the documentation for performing the test was scattered. A concrete plan for the test was not available and two completely different test plans were found. Furthermore, there was a significant difference in the method of testing and the specifications for the planning of the test.

In the first phase testing was performed by a certified body and tests were characterised by demands that required proof for certification of the product by RailAlert. The test was performed in a controlled environment with no operational trains by one person from Aboma who tested the HRS and recorded his findings. The other stakeholders were not involved in testing as they were not needed to execute the test and the results of ABOMA contributed for the approval of the TvG. The test in this phase of development went smoothly. BAM Rail was the

ProRail

client of this test and delivered a prototype fence to be tested by ABOMA. The demands for the test were derived from a NEN-EN norm for safety fencing and the test plan was made by ABOMA. NEN-EN norms are agreements which market parties have made voluntary over the quality and safety of their products (Stichting Nederlands Normalisatie-instituut, 2018). In this phase, these demands were tested and the results monitored. It was then decided if the results met the demands from the NEN-EN norm. Through this test it was proven that the innovation met these demands and was allowed in an operational environment. It was found that the goal of the test was clearly stated based on the NEN-EN norm for safety fencing.

In the second phase of testing, in the operational environment, the added value and potential was proven through usage of the innovation. The second phase was characterised by an evaluation of the product, based on questions and certain risks, rather than demands. Thus, the test was executed using an evaluation plan in which questions were stated, rather than demands. The evaluation was executed by BAM themselves while ProRail had a facilitating and supervising role. In this plan questions were stated focussed on the RAMSHE (Reliability, Availability, Maintainability, Safety, Health and Environment) criteria, the installation and the effectiveness of the innovation. The demands for the installation of the innovation were characterised by the profile of clearance such that the innovation would not be an obstruction for trains. This plan also stated how to evaluate the results and who was responsible for every evaluation.

In this phase, the time for testing was extended as the innovation was not able to prove its functioning in the first period due to the lack malfunctions of the railway, and thus the lack of usage of the innovation. It was not found if this extra period of testing could have been prevented. The innovation was eventually evaluated well enough to be released into the railway. Further, barriers found for testing were insufficient communication, no project leader, many risks and numerous parties involved. The barriers mentioned are not new and are also found in the previous parts of this research and seem to be organisational barriers rather than test execution barriers. The fact that many risks should be mitigated, related in some way to the many individuals present at the test. This could be a reason that the time to prove the innovation was extended.

5.3.2 Identified test components

In this section, the components of test plan V0 are evaluated against the tests performed in the case. It is found that per phase the various components were present, however, the information that was provided for each component was very different. The biggest changes were found in:

- the test plan used: In phase 2 a definite test plan and in phase 3 more of an evaluation plan;
- **the description of the location:** In phase 2 just the location was given, in phase 3 the location of the innovation was marked on a plan, motivation for the location was given and specifically chosen;
- the number of stakeholders: only few stakeholders involved in phase 2 and many in phase 3;
- **scope:** in phase 2 this was not specifically defined, in phase 3 it was defined where and how the innovation would be placed in the overall system and which interfaces it interacted with;
- **the demands and risks:** in phase 2 clear demands were stated, in phase 3 more or less evaluation questions were stated based on the RAMSHE and installation.
- **Tests:** In phase 2 tests were performed based on the demands, in phase 3 tests were performed based on the usage of the innovation and the evaluation questions.

There are big changes between phase 2 and 3. In general the test in phase 3 seems to be more complex, because considerably more information was needed to specify the test. This could be due to the involvement of the stakeholders and the fact that testing was performed in an operational environment. Tests in phase 2 were quicker and more structurally performed than in phase 3. Although the test in phase 2 was much smaller and fewer stakeholders were involved, it was very clear what should be tested based on the known demands. Furthermore, the goal was very clear for all stakeholders involved in this phase, with as result a test plan which specified clearly what was to be tested. This case shows that per phase the tests can be planned in a very different manner. It is also shown that, even though no clear test plan was used in phase 3, an innovation can still be implemented in the railway. This can possibly be explained by the structured test and gaining of the certification for use in the railway in the second test phase. Proving that the innovation was safe to use in the railway and could be safely evaluated in the railway. The provider furthermore mentioned that extensive testing was performed by themselves before testing by ABOMA.

The components of both phases are compared in Table 12. Here the components of test plan V0 is stated on the left, after which it is indicated, per phase, if the component was found and what it included.

FIGRAII	P	Y	C	R	a	i 1
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Component test plan V0	Phase (2) TvG	Phase (3) release
Test plan	Yes, based on the demands of the NEN-	Yes, evaluation plan based on questions
	EN norm.	related to RAMSHE and installation of
		product.
Phase	Technical/controlled on a storage yard.	Operational in the railway.
Function of the	Yes, were provided when the innovation	Yes, were provided when the innovation
innovation	was suggested at ProRail.	was suggested at ProRail.
Goal	Yes, stated in test document. Proving the	Yes, test at different switches in the
	demands set by RailAlert.	autumn/winter period, such that
		and the innervation used
Scope	Not defined. The demands of Rail Alert	Yes defined as installing using and
Scope	needed to be met	maintaining the HRS next to the railway
	needed to be met.	out of the profile of clearance. Interfaces
		with other systems were also defined.
Stakeholders	Yes, BAM, ABOMA and Rail Alert.	Many were involved, however not
		specifically stated. It was found BAM
		executed the test and ProRail
		supervised.
Go/ No Go	Not specifically mentioned. It was given	Not specifically, however, testing phase
	that because of the positive test results	was extended because functionality of
	no iterations were needed for acquiring	the innovation was not shown in first
	the TvG.	phase.
Demands and risks	Yes – clearly based on the NEN-EN	More risk based than demand based.
Tosts	Norm.	Based on questions.
16515	res, based on the demands set.	questions and use of the innovation than
		testing demands and specific risks.
Location	Yes, in a non-operational environment.	Yes, test yard in Breda. It was
	With low risks.	specifically mentioned at which switch it
		would be tested and why. Furthermore,
		a drawing of the location in the overall
		system and a cross section next to the
		railway was supplied.
Risks during test	Not found. Risks of using the innovation	Yes, it was asked how testing would be
	in the railway were not tested.	secured and what would happen in the
		case of failure. Furthermore, the
		during use
Test regime	Not found	Sort of the innovation was only to be
restregime	i vot iouna.	used by instructed personnel
		Furthermore, a local workspace safety
		instruction was given for the use of the
		HRS.
Monitoring	It was not mentioned how monitoring	Not specific. Results were gathered
	was performed.	through regular use during
		maintenance.
Expected results	No, the demands mentioned a certain	Yes, a document was given of the
	margin tor tailure. The results were	expected reduction of disruptions.
Dianning	recorded as found.	Not experific The length of the T-C is
		normally a year

Table 12 The com	nonents of	test plan V() compared to	the case study
	ponents of	icsi piùn ve	, comparca to	the cuse study

ProRail

The fact that two different test plans were used can possibly be explained by the fact that one test was performed by ABOMA rail and the other by BAM, in the case of the last the test plan was set up by ProRail. The greatest difference was the structure of the test plan and the requirements on which the tests were based. This might be since in phase 2 a certified test organisation performed the test and in phase 3 ProRail and BAM performed the test/evaluation together. The extension of the test time in phase 3 could possibly have been prevented if a structured test plan was used in which it was clearly stated which stakeholder should or should not be involved in the test. Subsequently, the test plan could have been used as communication tool between the involved stakeholders, stating what and how the test should be performed. Possibly a different location could have been chosen which was better suited for the test.

5.4 Conclusion

The case shows that most items identified in test plan V0 can also be found in practise. However, instead of being stated in one test plan the information which in this research is perceived to be present in one test plan was now scattered throughout various folders. The test plans used being documents only describing the core aspects to be tested. It must be noted that the test plans did not represent a test protocol, as defined in this research, where every step of the test is explained, but rather a document describing the demands which should be verified and validated. The fact that both test plans were different in both phases of the test process shows that there is a different perception of what a test plan can be. It furthermore shows that very different tests can be performed within the same development process.

When focussing on the contents of the components it was found that per phase the contents, location and the type of tests performed can be very different. In the operational phase these aspects were described in more detail. The case also shows that per testing phase the roles of the stakeholders differ. In phase 2 BAM was dependent on the results of ABOMA to move to the next phase. ABOMA being the testing organisation and BAM the client which wanted the demands for the use of the innovation proven. In phase 3 BAM was dependent on ProRail to release the innovation in the railway. BAM being the evaluator of the innovation and ProRail the supervisor and assessor for this test. This is something that can be accommodated by the test plan V1 by specifying who is responsible for delivering information for the different parts of the test and stating their roles within the test process. The case study is described more in-depth in appendix E.

Lastly the case is compared to the reference framework. Comparing the findings in the case to the findings in the literature and the interviews, this is done in Table 13.

Items	Case study analysis	Clarification findings to literature + interviews (test plan V0)
Innovation objective	Release of the innovation in the railway.	The objective to innovate was the same as found in the literature and in the interviews: to implement the innovation in the rail system and
		be able to drive business with it.
Test phases in development	Controlled environment and operational environment	Two of the three development phases were distinguished in which ProRail and the Provider were present.
Barriers	Many risks, numerous parties involved, individuals with many questions, no project leader, communication was tedious.	Most barriers found resemble in a certain way the barriers found in the interviews. Remarkable is that a project (or test) leader was missing in this case, whereas it was mentioned as one of the fundamental aspects in the interviews.
Testing definition	-	No definite test definition was found. A definite test objective was found.

Table 13 Finding of the case study compared to the reference framework

ProRail

Goal testing	Objective: permission for use and	Permission for use was done via verification	
	evaluation functions product for release.	and validation and evaluation was carried out	
		predominantly via validation. This objective of	
		testing also complies with objectives found in	
		the literature and the interviews.	
Test plan	A plan to verify and validate the product	The test plan in both phases resembled the	
definition	and a plan to evaluate the product.	aspects which needed to be tested but not much	
		more. The plan met the objective of testing,	
		however was different from the definitions	
		found in the literature and the interviews.	
Test plan	See Table 12.	The components considered in test plan V0	
components		were found in the test phases, however, they	
		were not included in the test plan.	
Planning	Based on the demands, the RAMSHE	The most interesting part is that the RAMSHE	
strategy	critiera and further risks and location.	criteria were used to determine demands and	
		risks which needed to be tested. This was not	
		found in the literature and the inteviews and	
		can be taken into account for the next iteration	
		of the test plan.	

ProRail

6 Design test plan V1

Test plan V1 is based on the information found in literature, interviews and the case study. V0 was designed based on the first two aspects test plan. The information gathered in the case study will form the next iteration of the test plan.

6.1 Structure of test plan V1

The overall structure of the test plan will remain the same. This means the test plan will stay differentiated over the three phases identified in the literature and the interviews. The case study showed that different test plans were used in different phases. By using one format for different phases test plan V1 accommodates structure throughout the whole development process, making it possible to evaluate previous phases and consider future phases. A slight difference is made in the introduction of the test plan. The chapter explaining the phase in which the test will be performed will become a separate chapter. This allows for a clearer distinction of the differentiation of the test plan and the test activities, as displayed in Figure 12. Here one sees that first a distinction is made of the phase of development. Secondly, the testing activities within the phase are described and lastly the test demand and test effort are described, as explained in test plan V0.



Figure 12 Structure of test plan V1

6.2 Adjustments test plan V1

The most relevant insights of the case are that there is a distinct division of roles per test phase. The concrete changes in test plan V1 will be:

- Per component of the test plan a certain role division will be advised to give an indication who should fill out the various parts of the test plan;
- The component "approach" has been split into risks during tests, test regime, implementation and monitoring. Specifying better what should be taken into account for the test, especially when testing becomes more complex. This way the test plan can be used as a communication tool;
- The stakeholders involved in the test will be specified better, making it clear who should be involved when testing and why.
- Test phase, goal and scope will be separate in the test plan making it clear which test activities are to be performed. A different goal per test phase translates to very different tests and meaning of the test components.

6.3 Test plan V1

The modifications are presented in Figure 14 and Figure 13 can be compared to Figure 8 and Figure 9. The specifically changed components are highlighted by a red border.

ProRail

Components – Test plan V1 Procedure		Ouput		
Project background		Phase 1	Phase 2	Phase 3
Background project Informing stakeholders project 	Who: Project manager Action: describe the development project until current stage.	Background information about the project up until this test stage.	Background information about the project up until this test stage.	Background information about the project up until this test stage.
Background innovation • Inform stakeholders project	Who: Project manager Action: describe information about the innovation to be tested.	 Stage of development Function innovation in railway system Added value innovation 	 Stage of development Function innovation in railway system Added value innovation 	 Stage of development Function innovation in railway system Added value innovation
Testing activities				
Test phase • Provides setting for test activities, scope, stakeholders and demands of test	Who: Project manager Action: description of the phase in which the test is to be performed.	Phase 1 Lab environment TRL levels 1-3	Phase 2 Controlled environment TRL levels 4-6.	 Phase 3 Operational environment TRL levels 7-8
Goal • Aligning the goal of the test for all involved stakeholders.	Who: Provider and ProRail Action: Make sure the goal to be obtained by this test is clear and can be communicated between stakeholders. →	 End goal of development End goal for testing phase (e.g. learning) 	 End goal of development End goal for testing phase (e.g. TvG) 	 End goal of development End goal for testing phase(e.g Implement)
Scope • Defines what is, and is not, tested.	Who: Provider and ProRail Action: In line with the goal and test phase define what is and is not tested to reach the goal.	 The extent of testing in lab environment. Level to which tests are performed. Safety level test. 	 The extent of testing in the railway. Level to which tests are performed. Safety level test. 	 The extent of testing in the railway. Interfaces with other systems. Safety level test.
Test demand Stakeholders • Who takes part and who does not.	Who: Project manager Action: Based on the scope and the test goal determine which stakeholders are needed to perform the test.	 Organisation + individual Role individual Relation to test individual Invested worth organisation. 	 Organisation + individual Role individual Relation to test individual Invested worth organisation. 	 Organisation + individual Role individual Relation to test individual Invested worth organisation.
Go/ No go • Specifies in which situation testing is stalled or resumed.	Who: Provider and ProRail Action: In agreement with stakeholders specify criteria for go/no go.	 List of known criteria for stopping or continuing testing. 	 List of known criteria for stopping or continuing testing. 	 List of known criteria for stopping or continuing testing
Demands and risks • Show which tests need to be performed in this phase.	Who: ProRail Action: ProRail determines initial demands and risks from existing rules and regulations and RAMSHE criteria.	 List of demands to be tested or questions to be answered. List of risks to be mitigated. 	 List of demands to be tested or questions to be answered. List of risks to be mitigated. 	 List of demands to be tested or questions to be answered. List of risks to be mitigated.
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Figure 14 Main concept of test plan V1 (page 33).

Figure 13 Main concept of test plan V1 (page 32).

Pro*R*ail

Components – test plan V1 Procedure		Ouput		
Test effort		Phase 1	Phase 2	Phase 3
Tests • Defines which tests need to be performed	Who: Provider, ProRail checks and adds. Action: Describe tests based on demands, risks and evaluation questions.	 Described test(s) Linked to demand, risks or question. 	 Described test(s) Linked to demand, risks or question. 	 Described test(s) Linked to demand, risks or question.
Location • Represents demands and risks to be tested	Who: Involved stakeholders Action: Based on the demands and risks a test location is chosen with the involved stakeholders.	Nothing to specify	 Description and motivation of location chosen Stakeholders in test environment. 	 Location which represents function of the innovation and tests. Visual presentation of location. Stakeholders in test environment.
Risks during testing • Informs all stakeholders of the expected risks during testing	Who: Provider Action: Risk analysis of expected risks that occur during usages of innovation.	Risks during test and mitigation only if deemed needed.	 Expected risks handling innovation. Mitigation possible if risks are severe. Manual innovation possible. 	 Expected risks of using innovation. Mitigation method if risks occur and responsible party Manual innovation
Test regime • Informs stakeholders of rules and regulations to perform test.	Who: Provider, ProRail and testing party Action: Based on the area and the type of test that is performed it is stated how the test is safely performed.	No test regime is needed.	When there are no interfaces with an operational environment a test regime is not needed.	Documentation of which rules and regulations are followed during the test. These can be specifically for the test.
Implementation • Specifies implementation innovation in system	Who: Provider Action: Description of set-up innovation and installation on test location.	Simple description of test set-up.	Simple description of test set-up.	 Description and visual representation of innovation set-up. Description installation in railway svstem
Monitoring • Determines what is measured and how.	Who: Provider and ProRail. Action: Description of how monitoring is performed and who will monitor the test.	What is measured? Who measures? How is measured? Documentation of measurements.	What is measured? Who measures? How is measured? Documentation of measurements.	What is measured? Who measures? How is measured? Documentation of measurements.
Expected results • States which results are expected from the tests.	Who: Provider and ProRail Action: Based on the demands and risks it is described which results the test is expected to have.	 Margins within which the innovation is expected to perform based on the demand, risk, questions. 	Margins within which the innovation is expected to perform based on the demand, risk, questions.	 Margins within which the innovation is expected to perform based on the demand, risk, questions.
Evaluation • Evaluates how the test was conducted, which results are yielded and what the next steps are.	Who: Provider and ProRail Action: Based on the output of the test an evaluation is done of the test with the involved stakeholders.	An evaluation report stating what the results of the test were, what method was used and how testing is resumed.	• An evaluation report stating what the results of the test were, what method was used and how testing is resumed.	An evaluation report stating what the results of the test were, what method was used and how testing is resumed.
Planning • States how long the test will take.	Who: All stakeholders testing Action: A planning is made of the test and its activities with the stakeholders over the length of the test phase.	• A planning describing the trajectory of the whole test phase.	A planning describing the trajectory of the whole test phase.	 A planning describing the trajectory of the whole test phase.



6.4 Conclusion test plan V1

Based on the iterations, the role division made will guide the stakeholders involved into which information is expected from them to perform the test. Furthermore, by elaboration on the different components of the test plan it makes it possible to communicate efficiently about what is needed and expected from the test. The use of these components differentiated over the test phases will allow one test plan structure to be used throughout development minimizing the discussion over what a test plan should be or contain. Lastly, from the case it was seen that per test phase the test changes dramatically, by differentiating the formulated components change in the different tests can be planned throughout development.

ProRail

7 Evaluation test plan V1

As it is the objective to improve the test process between ProRail and providers, it is sought to evaluate the test plan with both parties. Evaluating the test plan while performing an actual test does not fit within the time frame of this research. For this reason, it was decided to evaluate the test plan in a workshop in which both the market parties and ProRail will discuss the use and effect of the test plan.

The objective of the workshop was twofold:

- 1. The first objective was to validate the components of the test plan, based on the experience of the participants on tests performed and planned in practice.
- 2. The second objective was to validate that the test plan is usable and to determine which effect it would have when used in planning and executing tests.

7.1 Method of evaluation

The workshop was held with various market parties and ProRail. It was ensured that from these two groups the participants had been involved in planning, executing or guiding tests. In total eleven participants were present. From this group six participant were from ProRail, with the backgrounds asset, innovation and infrastructure manager. The other five participants were market parties, with the backgrounds contractor, supplier and testing organisation.

The workshop was split into two parts, matching with the objective of the workshop.

- **Part one** In the first part of the workshop all participants were asked to participate together. Here the different components of the test plan were rated as to their relevance in belonging in a test plan.
- **Part two** In the second part of the workshop the participants were split into two groups. Here the usability of the test plan was evaluated based on the experience of the participants. The participants took into consideration a test case which they had been involved in. The applicability of the test plan in this situation and how the test plan would be applied over various phases was discussed.

7.2 Results validation of the test plan components

In the first part of the workshop the components of the test plan were discussed. It must be noted that there were eleven participants at the workshop but none of the test plan components was scored eleven times. Thus, the results are based on the scores that were applied.

Overall the various components in the test plan were scored well. The first part of the test plan (test demand) scored better than the second part (test effort). In the part concerning test effort the components test regime and expected results were scored the least well. Within the time of the workshop these two components were discussed. Furthermore, the participants were asked about the role division of filling in every component.

7.2.1 Test regime

From the interviews, it was derived that the test regime secures the safety of testing and states which rules and regulations are leading to perform a test, as it was found that for the execution of tests in the railway no regulations are present.

The participants discussed that the test should, among others, be established based on a test regime. Thus, this part should not be established in a test plan but be considered when setting up a test plan. The fact that there are operational trains in the railway is more of a demand than a condition when executing tests in the railway. For testing in the railway various safety and health plans exist. Subsequently, for fire tests protocols already exist to perform such a test. Thus, existing rules and regulations should be incorporated in setting up a test plan, instead of establishing a test regime when setting up a test plan. One obstruction that was found was the rules and regulations regarding the timetables of trains when testing in the railway, as it prevents quick iteration.

7.2.2 Expected results of testing

It was argued that expected results for a test should not be taken into account in a test plan. From this component, a discussion was started between innovation development and testing. It was suggested that there are no expected results to be conceived from a test, only objective results. In the workshop expected results related to finding out if one's expectation for the performance of the innovation are correct. However, this was argued to be dangerous as

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one could set-up a test to obtain the expected result, possible achieving biased results. Expected results should be taken into account when developing the innovation. A test should then be performed on the function or demand that should be tested. The result obtained from this test is then objective and can be in line with the expectations or not. One has to be open minded when performing a test. For this reason, the way the test is performed, monitored and how the results are recorded should be correct, such that the results of the test can be objectively assessed.

7.2.3 Role division when setting up a test plan

No certain distinction was made between who should fill out the different components of the test plan. It was agreed that a test plan should be established in accordance with the different stakeholders involved in the test. It was perceived as more important that the roles and responsibilities during the test should be accurately stated. Such that it is known who carries certain risks and a common goal for the test is agreed upon.

7.2.4 Additional components suggested by the participants

In addition to rating the existing components the participants also suggested components that were not considered in the test plan. It must be mentioned that most of these components came from an infrastructure manager, who is responsible for the availability of the railway in his area and are related to phase 3 testing. The following components were missing, and were found to be important in later stages of testing:

- **Malfunctioning:** the innovation might malfunction in the railway. This would create operational problems which could lead to increased costs. If this happens how will it be handled?
- **Maintenance:** If the innovation is implemented in the railway, or during a long test period, it must be evaluated how the innovation is to be maintained. This is also relevant for future use.
- **Costs:** There are many costs involved in testing, it should be evident who is responsible for which costs when testing or who must pay when things go wrong.
- **Removal of innovation:** When the innovation has been tested, it should then be removed, and the railway brought back to its original situation. Thus, it must be taken into account how the innovation is removed.
- Contract: Specifies the different responsibilities and agreements of the various parties.

Once more this shows that in the last phase of testing many more aspects are involved, indicating that this phase is more complex.

7.3 Effect and usability of the test plan

It was established that the test plan can be used in most situations when planning tests in practice. However, it was perceived that the test plan is extensive and that, filling out all the components, would diminish the motivation to perform and plan a test. Meaning that at the first phases of testing the test plan can be less elaborate then in later phases, to allow freedom to test different aspects of the innovation. Here testing is characterised rather as exploring, led by research questions. Yet, it was also found that, unconsciously, most aspects of the test plan are already considered by the participants when planning a test. Subsequently, the workshop showed that in later testing stages the test plan should become more elaborate as the context of the different components becomes larger, here testing is characterised by verification and validation. Especially stakeholders were deemed important when testing. In earlier phases stakeholders would be more technically involved focussed on development. In later phases of testing stakeholders would be involved to also promote and support the innovation. However, it still important to include stakeholders which contribute to achieving the goal of the test, having to many stakeholders involved in testing can form a barrier.

7.4 Conclusion of the evaluation

The first objective of the workshop was to validate the components of the test plan and to see if they were relevant to the test plan. In this session the components in test demand did a lot better than the components in test effort, this could be because test demand includes components which decides which test are to be performed and how they are performed. Where test effort includes components for the execution of the test. Within test effort it was discussed that test regime and expected results were components which should not be explicitly included in the test plan. The discussion furthermore showed that to accommodate testing in the last phase (in the operational environment) still some components needed to be added. Aspects relating to malfunctioning and removal of the innovation were not yet in the test plan and were argued to be important to test for later usage of the innovation.

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The second objective of the workshop was to validate the usability of the test plan by seeing if the test plan would be usable in the different phases distinguished in the development process. In the discussion it was mentioned that per phase the test can be completely different. It is expected that using a differentiated test plan will accommodate the change in tests that are performed in different stages of development. However, the participants mentioned that if the plan is too extensive the motivation to perform a test will diminish and the test plan could become a barrier when it is obligatory to fill in all components when this is not possible. Especially in the earlier phases, where testing is rather characterised by experiments and technical iterations this could become a barrier to perform tests. Thus, through the differentiation of the test plan it should be taken into account which components are used to plan a test, and to which extent these components are used. It was evident that throughout development the tests need to be more elaborately planned the closer one gets to the operational testing phase. Here more aspects need to be regarded while testing, such as risks, stakeholders and interaction with the railway system. Especially stakeholders seemed to have an important impact on the trajectory of the test and their importance can differ per phase.

The conclusion gives changes which shall be taken into account in the next iteration of the test plan. Hence the components for test plan V1 were validated but the components for test plan V2 could still be checked in the future. The analysis of the evaluation of test plan V1 is compared to the reference framework, presented in Table 14. Here it is indicated what the most important in relation to the rest of the research. The specific details of the evaluation are given in appendix F.

Items	Evaluation analysis	Clarification findings to test plan V1
Innovation	-	The definition or objective of innovating was
definition		not discussed in the workshop
Test phases	In-house, controlled environment, operational	All the phases were distinguished and agreed
in	environment.	upon. It was however found that testing in
development		the railway is most complex and here the test
		should be planned more elaborately.
Barriers	No specific barriers were mentioned or	It was found that when planning a test, it
	addressed.	should be well defined what is needed and
		what is not to plan a test. Having to specify
		aspects of which the answer is not known or
		which are not needed can have an inhibitory
		effect.
Testing	-	The definition or objective of testing was not
definition		specified.
Goal testing	All agreed that this was an important aspect.	A specific test goal was not mentioned, as it
		can differ per test. It was however mentioned
		that the joint goal of the involved
		stakeholders should be clear, before staring a
		test.
Test plan	Various definitions were found of what a test	It should be clear what is meant by a test plan
definition	plan should be.	as there are various ways of setting one up.
Test plan	Added: removal, malfunctioning and	It was found that most of the components are
components	maintenance. Removed: Test regime and	unconsciously used when planning a test.
	expected results.	Aspects found missing were removal,
		malfunctioning and maintenance. As they are
		found to be part of the test process. Based on
		the argumentation of the expected results it
		has been chosen to take this out of the test
		plan.
Planning	Dialogue between the involved parties is	It was found that many aspects are stated in
strategy	important.	the test plan and this could have an inhibitory
		effect on testing. Thus, it is important to have
		dialogue about how the test will be
		conducted.

Table 14 Conclusion of the evaluation, evaluated against the reference framework

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8 Design test plan V2

Test plan V2 is based on test plan V1 which has been modified using the findings from the evaluation. The structure of the test plan remains the same, as displayed in Figure 12. Meaning the three phases will stay incorporated and the test demand and test effort will remain the same.

8.1 Adjustments test plan V2

The evaluation showed that the difference in the test phases and adding + removing certain components were the most prominent changes to the test plan. The changes made based on these two aspects are discussed in this chapter.

Removed components

It was found by all participants that there should be no expectations from the results of a test. It was argued that this is part of the overall development process. This component was mentioned in the interviews and related to the expectations of the results of the test. However, in the workshop it was mentioned that this was related to innovation development rather than testing itself. This can be underpinned by the definition of testing found in the literature that, when testing, results are only observed and recorded, and an evaluation is made (Radatz, Geraci, & Katki, 1990). Thus, the method of testing is important to yield objective results, such that a good evaluation can be made. For this reason, the component expected results is removed from the test plan.

Concerning test regime, it was mentioned that there are already a lot of rules and regulations describing how to perform certain tests (for example, fire tests) and how to work safely in the railway. It was agreed upon that testing safely in the railway should still be ensured. The existing rules and regulations should be used to plan a test and set up a test plan. In the interviews it was mentioned that specifically for the performance of a test no rules and regulations are present to facilitate testing. Only in a possession it is possible to perform a test. This is the reason the component was added. Based on both input it is chosen to address the existing rules and regulations in the risks that can occur during a test. Here it can be stated which rules and regulations are active to safely perform a test.

Added components

The components malfunctioning, removal and maintenance will be added to the test plan. In the output of the test phases defined it will be addressed to which extent these components should be taken into account in the test process. The aspect of malfunctioning will be added under the risks during testing. Here it is noted that one should ensure, that when a malfunction occurs, the problem is secured. The aspect of maintenance will be added to the aspect testing. Via the RAMSHE criteria it can be assessed that maintenance should be tested. The aspect removal is added as a separate aspect, as this completes the final test cycle (Figure 6).

The aspect contract will not be added. During the interview or in the literature it was not found that a contract is part of testing. Costs also will not be specifically added, as it is not found in any other sources of this research that this is part of the test process. Costs are part of the overall development process relating to the choice whether or not to execute a certain test. If deemed needed each stakeholder in the test process can address their invested worth in the test.

Usage of test plan

The most important outcome of the usage of the test plan is that it is different per phase which components are used or what their input is per phase. Dependent on, for instance, the goal of the specific test phase and the test environment certain components are or are not used. This can be very different per innovation or provider. Extra notifications will be given per component to consider the importance and effectiveness during the test. Finally, the case study showed that there is a certain role division for filling in the test plan. However, in the evaluation it was found that the test plan should be established together and not by separate parties. One individual could set-up the test plan, which is also an aspect which was missing in the case and mentioned as fundamental in the interviews. This individual could set up the tests plan based on test to be performed, creating a coherent test process, as there would be one individual coordinating the tests. For this reason, the role division per test component will be removed and it is suggested that one individual fills in the test plan, the manager of that test.

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8.2 Test plan V2

It has been chosen to still design one test plan which can be used over the different phases of testing. This will provide consistent planning of tests through development. Slight changes have been made to the aspect testing activities, here only the test phase is now stated and not the goal and scope of the test. The components goal and scope are found to be part of test demand and determine which tests are to be performed, rather than the test activities as they set boundaries within which the test is performed. Furthermore, the aspect time planning is moved to be a separate aspect of the test plan, this way after the test demand and effort has been determined a clear planning can be made. Again a red boarder is given to indicate the changes to the test plan. The main concept of Test plan V2 is presented in Figure 15 and Figure 16, and can be compared with Figure 14 and Figure 13.

8.3 Conclusion for test plan V2

Test plan V2 is a complete test plan, in every different test situation, one is able to take into account the various individuals into the test process and testing activities. There is a differentiation per phase of what needs to be tested, depending on the goal, stakeholders and activities that are set for the specific phase. This is accommodated by the components and the differentiation and by having one person guide and plan the test the information needed for the test and manage the stakeholders involved in the test.

The expected effect of using a differentiated test plan with similar goals in contrast to currently performed tests is that, firstly the plan was deemed to be to elaborate to test freely. However, participants of the workshop mentioned that they consider most components when testing anyway. Testing is part of the overall development process, thus a lot of information to plan a test should already be available. However, making the test plan less extensive in the earlier phases of development should prevent that using the test plan becomes a barrier in order to perform tests. Using a complete test plan helps to take into account the information which might otherwise be missing. Subsequently, making it possible to use the test plan as a communication tool between the stakeholders involved in testing.

In appendix B the document test plan V2 has been added. This document follows the same set-up as the main concept which is given in Figure 15 and Figure 16. In the this plan all components will be displayed, just as in the figures. Per component it will then be addressed what should be done and what the output of the action should be, just as given in the main concept of this thesis.

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Components - Test plan V2	Procedure	Ouput		
Project background		Phase 1	Phase 2	Phase 3
Background project Informing stakeholders project 	 Who: Manager of the test Action: describe the development project until current stage. 	Background information about the project up until this test stage.	Background information about the project up until this test stage.	Background information about the project up until this test stage.
Background innovation Inform stakeholders <pre>project</pre> 	Who: Manager of the test Action: describe information about the innovation to be tested supplied by provider	 Stage of development Function innovation in railway system Added value innovation 	 Stage of development Function innovation in railway system Added value innovation 	 Stage of development Function innovation in railway system Added value innovation
★ Testing activities				
Test phase • Provides setting for test activities, scope, stakeholders and demands of test	Who: Manager of the test Action: description of the phase in which the test is to be performed.	Phase 1 Lab environment TRL levels 1-3 "Lab" tests	Phase 2 Controlled TRL levels 4-6. Pilot tests	Phase 3 Operational TRL levels 7-8 Full scale tests
Test demand Goal • Aligning the goal of the test for all involved stakeholders.	 Who: Manager of the test Action: Make sure the goal to be obtained by this test is clear and can be communicated between the involved stakeholders. 	Clear goal for testing phase (e.g. learning)	 Clear goal for testing phase (e.g TvG) 	 Clear goal for testing phase(e.g Implement)
Scope • Defines what is, and is not, tested.	Who: Manager of the test Action: In line with the goal and test phase define what is and is not tested to reach the goal with provider and client.	 Level to which tests are performed. A scope linked to the TRL of testing. 	 The extent of testing in the railway. TRL to which tests are performed. (Safety level test) 	 The extent of testing in the railway. Interfaces with other other systems. Safety level test.
Stakeholders • Who takes part and who does not.	 Who: Manager of the test Action: Based on the scope and the test goal determine which stakeholders are needed to perform the test. 	 Organisation + individual Role individual Relation to test individual Invested worth organisation. 	 Organisation + individual Role individual Relation to test individual Invested worth organisation. 	 Organisation + individual Role individual Relation to test individual Invested worth organisation.
Go/ No go • Specifies in which situation testing is stalled or resumed.	Who: Manager of the test Action: In agreement with stakeholders specify criteria for go/no go moment to start the test and based on results test	Agreements for go/no go moment Unexpected reasons might occur.	 Agreements for go/no go moment Unexpected reasons might occur. 	 Agreements for go/no go moment Unexpected reasons might occur.
Demands and risks • Show which tests need to be performed in this phase.	Who: Manager of the test Action: ProRail determines initial demands and risks from existing rules and regulations and RAMSHE criteria.	 List of demands to be tested or questions to be answered. List of risks to be mitigated. 	 List of demands to be tested or questions to be answered. List of risks to be mitigated. 	 List of demands to be tested or questions to be answered. List of risks to be mitigated.
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Figure 16 Main concept of test plan V2 (page 41).

Figure 15 Main concept of test plan V2 (page 40).

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Components – Test plan V2 Procedure		Ouput		
Test effort		Phase 1	Phase 2	Phase 3
Tests • Defines which tests need to be performed	Who: Manager of the test Action: Describe which tests are to be performed together with the testing party and an expert of the product.	 Described test(s) Linked to demand, risks or questions. 	 Described test(s) Linked to demand, risks or questions. 	Described test(s) Linked to demand, risks or questions. Consider RAMSHE criteria
Location • Represents demands and risks to be tested	Who: Manager of the test Action: Based on the demands and risks a test location is chosen with the involved stakeholders.	Nothing to specify	 Description and motivation of location chosen Stakeholders in test location. 	 Location which represents function of the innovation and tests. Visual presentation of location. Stakeholders in test location.
Risks during testing • Informs all stakeholders of the expected risks during testing	Who: Manager of the test Action: Risk analysis of expected risks that occur during usages of innovation. Use information provided by provider innovation if available.	Risks during test and mitigation only if deemed needed.	 Expected risks handling innovation. Mitigation possible if risks are severe. Manual innovation possible. 	 Expected risks of using innovation. Mitigation method of risks with responsible party (e.g. malfunctioning innovation) Manual innovation
Implementation • Specifies implementation innovation in system	Who: Manager of the test Action: Describe set-up innovation and installation on test location together with testing party.	Simple description of test set-up.	Simple description of test set-up.	 Description and visual representation of innovation set-up. Description installation in railway system
Monitoring • Determines what is measured and how.	Who: Manager of the test Action: Describe how monitoring is performed and who will monitor the test together with testing party.	 What is measured? Who measures? How is it measured? Documentation method of measurements. 	 What is measured? Who measures? How is it measured? Documentation method of measurements. 	 What is measured? Who measures? How is it measured? Documentation method of measurements.
Removal • Determines how the innovation is removed after testing	Who: Manager of the test Action: Together with the stakeholders of the test and location it is determined when and how the innovation is removed after the test.	No specification needed.	No specification needed.	Description in case of removal of the innovation after testing. With responsible party.
Evaluation • Evaluates how the test was conducted, which results are yielded and what the next steps are.	Who: Manager of the test Action: Based on the output of the test an evaluation is done of the test with the involved stakeholders.	 An evaluation report stating what the results of the test were, what method was used (and how testing is resumed). 	 An evaluation report stating what the results of the test were, what method was used and how testing is resumed. 	 An evaluation report stating what the results of the test were, what method was used and how testing is resumed.
Time Planning Planning • States how long the test(s) will take.	 Who: Manager of the test Action: With the stakeholders a planning is made of the test and its activities over the length of the test phase. 	Planning is optional for longer tests	Planning is optional for longer tests	 A planning describing the trajectory of the whole test phase.



9 Conclusion and discussion

This chapter gives the conclusions and discussion of the research.

9.1 Conclusion of the research

This master thesis research has been performed on testing innovations in which both ProRail and providers (public and private) are involved in the test process. A first analysis showed that providers, collaborations, goal alignment, type of innovation, verification and validation and processes and procedures influence the test process. The effect being that ProRail and providers experience difficulties in preparing tests which leads to an unclear test process. In order to solve this situation in this research the following question is answered: *'What does a differentiated test plan look like to test potential innovations between ProRail and providers such that the test process can be improved*?

For the first development of the test plan the theory showed that in order to perform a good test a mere description of the test is not sufficient. A test plan is needed which acts as a blueprint for the test and can be used as a communication tool for the stakeholders involved. In accordance with the interviews the theory showed that there are different phases in which testing occurs within the overall development process. For the railway infrastructure three phases are distinguished, namely: laboratory testing, controlled environment testing and operational environment testing. These phases showed to be a recurring factor in innovation development and the test plan is differentiated over these phases. The objective to perform a test can be different per test that is performed, however the objective of the innovation development stays the same throughout development. The three most important objectives to perform a test are verification and validation of the demands and risks, determining through testing what is to be verified and validated and gaining value from a test. Setting a clear objective determines which tests are to be performed. Lastly based on what is seen as important components of a test plan are defined and are divided by test demand and test effort. The components of the test plan address the barriers and the fundamental aspects for testing which are perceived by both clients and providers.

The case study showed that the same components to plan a test, as identified in the literature and the interviews, were used in order to conduct a test. Subsequently, the difference per testing phase can be quite large, including different test methods, goal and test plan used. This indicated that there is not one vision on what a test plan should be. However, there are base aspects such as location, demands, risks and stakeholders which were found present in both test phases. This was despite of the difference in the testing method and test plan. Furthermore, in the case the involved stakeholders got different roles in the identified testing phases. The provider of the innovation became client of the test in the second phase and developer and executer of the test in the third phase. This shows that a stakeholder can be otherwise involved based on the nature of the test. Barriers experienced to smoothly test the innovation were found to be poor communication, many risks presented, possible unnecessary stakeholders within the scope of the test process were further specified within the test plan to make it clear if the stakeholders should or should not be involved in the test process. Furthermore, test phase, goal and scope of the test were more prominently specified such that the change per test phase can be better defined, making it clearer what testing activities are to be performed.

The evaluation with market parties and ProRail showed that the components of the designed test plan can be used in the three test phases distinguished. However, the test plan could become a barrier if it becomes mandatory to fill in all the components, if they cannot be filled in because they are not used in the test. Especially in early phases where testing was characterized as experimenting. In later phases tests would become more complex and the test plan becomes more extensive. The evaluation showed that especially when testing in the operational environment extra attention in the test plan was needed towards malfunctioning, maintenance and removal of the innovation during a test. By addressing these aspects in the components of the test plan the test plan better accommodates testing in an operational environment. Furthermore, by using the differentiation to distinguish which components can or cannot be used when testing in different phases the barrier of using the test plan is lowered.

In conclusion the differentiated test plan is differentiated over the three phases, namely: laboratory, controlled environment and operational environment testing, within the overall innovation development process. For each phase it is then specified what is demanded and which effort is needed to execute the test, by filling in the different components of the test plan. The depth and comprehensiveness of the plan increases the further one gets into development of the innovation. Per phase one structure is provided based on the fundamental aspects distinguished for testing by providers, clients and the literature, regardless of the type of innovation or provider.

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The clarity of what needs to be tested is improved by the components of the test plan which make it possible to have a uniform structure of planning a test throughout development, making it clear what should be specified to execute the test. The fact that stakeholders and a common goal is defined makes it possible to use the test plan to communicate how the test should be executed to achieve the defined goal. The differentiation accommodates change throughout development making it possible to be more specific for every new test initiated.

9.2 Discussion

In this section the conclusion of this research will be discussed. First, the results that have been obtained in this research will be further discussed on the insights they have provided. Secondly, the validity of the research methods and their use in the research are discussed. Thirdly, the limitations and shortcomings of the research are discussed. Fourthly, based on the discussion of the result and limits of the research future research suggestions are made and lastly recommendations are given for further improvement of the test process.

9.2.1 New insights thesis scientific relevance

At the start of this research a literature study was performed to investigate what is known about innovation development and testing between private and public organisations in the railway sector. Literature on performing tests was found to be limited and mostly focussed on innovation development in general or software testing. Specific literature on performing and preparing tests between public and private organisations, let alone testing in the railway sector between public and private organisations, was also found to be scarce. This research adds knowledge about planning and executing tests between private and public organisations, the role of testing in the product development process and the difference with software testing.

Testing between public and private organisations

The importance of proving the innovation is important in the public sector. People live, work and recreate around public structures, and safety is an important issue. Clients then often have a high risk when implementing an innovation which has not proven itself in practice (Arnoldussen, Groot, Halman, & Zwet, 2017). This research acknowledges the importance of testing to show that an innovation works in practice. It shows that testing is an important medium to verify and validate that the innovation can be used in the operating system. Furthermore, as risks can be extensive and high because of the interaction with people, it shows testing is an important method in mitigating these risks.

The literature provides information on differences on innovating between both private and public organisations, as shown in section 2.2.3. The research builds on this knowledge by providing insights into the position of public and private organisations when testing, as a sub part of developing innovations. It does this by showing what both public and private organisations experience as barriers and as fundamental aspects of testing. Giving insights into where they agree and what their differences are. Lastly, the research shows that successful testing also depends on the stakeholders and their roles in the test process, their cooperation and coordination. Their role and influence on the test process was especially interesting as this was not found in the literature on performing tests.

Testing in the innovation development process

Various innovation development processes were identified in the literature which recognize testing at a certain point to validate and verify the product that is being developed. Furthermore, the literature gives examples of different tests executed throughout this process (Alsem, et al., 2013; Baskoro, 2006; Boehm, 1988; Cooper, 1990; National Aeronautics and Space Administration, 2007; Unger & Eppinger, 2009; Veryzer, 1998). However, none indicated how testing in such a process should be performed or even planned. This research shows what different goals are of performing tests; how testing in different phases can have a different purpose in developing the innovation; that there is a definite difference per phase that should be taken into account when planning a test throughout product development. The differentiation of the test plan over the development stages shows that the research underpins that testing is a part of innovation development.

Product testing compared to software testing

Much of the literature describes the test process and the contents of a test plan in the context of software testing. However, as Cooper (2014) mentions physical product development is much different from software development. As software development is almost infinitely divisible. In a code of many lines multiple increments might be made at the same time in one development cycle. This is not possible in product development as the product cannot be incrementalized in this way. This research shows that for the development of products in the railway a more linear process is followed were development is lead through various stages in which, depending on the stage of

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development, certain tests are performed. Especially in later stages of development often the whole product is tested in relation to the system in which it must function, rather than loose components. Subsequently, the environment in which products are tested add multiple variables to take into account.

9.2.2 Validity research methods

In this section the validity of the results gained from this research are discussed. It is discussed how the interviews, case study and workshop were used and how this affected gathering the results.

The interviews

The interviews in this research were used to get a broad range of information about testing by various providers. The data that was gained was recorded to ensure the correct documentation. Furthermore, the documentation was sent back to the interviewees to validate that the information was correct. For the population interviewed it was than validated that the population was correct. By interviewing clients in other infrastructure sectors and selecting a diverse group of providers, the designed test plan is generalizable to certain extent. The test plan is usable for more than just one group of providers and can possible be used in other infrastructure sectors to plan tests. Lastly the interviews were held semi-structured meaning that, although the same questions were asked in every interview, not all the data gained from the interviews is the same. Through the questions used and the interpretation of the answers by the researcher it is possible that different results could have been found for this research which could have contributed to different results.

The case study

One case was studied in this research, in order to ensure that the case would yield the desired information the choice of the case was made using predefined criteria to ensure that data which was sought after to answer the research question would be found. However, there was limited time to study the full contents of the case study. This has affected output from the case as only a selection was study which was deemed most important for the research was studied. One main source of information was studied in the case study, this was documentation. It is possible more data could have been collected if a different method of data gathering would have been used next to the documentation analysis. However, unstructured interviews were held in order to get a better understanding of the documentation if deemed needed.

Workshop

In order to evaluate the designed test plan a workshop was held. To ensure that the correct data was obtained a script was made to conduct the workshop. Through this script and the methods, the research was able to measure the data intended. The workshop was interactive, thus it was possible to discuss the answers from the participants. This reduced the chance of misinterpretation of the information. In the workshop it was ensured that a variety of participants was chosen to participate. The participants were both from ProRail and from the market parties, because of the confidentiality of the interviews conducted the participants were openly asked to participate in the workshop. This meant that the researcher had less influence on selecting which participants would attend the workshop. This could have affected the results which are gained and the results which were intended to be obtained. However, the variety in the participants makes the results of the workshop generalizable beyond a specific group.

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9.2.3 Limitations

In this section the limitations and shortcomings of the research are discussed based on the research methods used and the scope of the research.

Limitation of not using the test plan

Within this research a differentiated test plan has been designed based on theoretical and empirical findings. A workshop was held to validate the design of the test plan based on the opinions of both ProRail and market parties. However, it was not possible to evaluate the use of the differentiated test plan in a real test process, as developing innovations and preparing tests can take a longer period then was scheduled for this research. This means that there are still possible improvements to be made within the design of the test plan, based on how it is used when a test is performed with both ProRail and a provider.

Limitations of the interviews

First of all, within the research a select group of stakeholders were interviewed. Although a diverse group of stakeholders was chosen for the interviews and the interviews were validated, there are many providers of innovations in the railway sector. Thus, there might be many other market parties which can be interviewed to improve the test process. Subsequently, the interviews were held with providers of innovation in the railway sector and clients of other infrastructures. Informal interviews were held within ProRail which have influenced the design of the test plan, however, concrete interviews were not conducted. This is a limitation of the information gained to design the test plan. However, this has been compensated by conducting a case chosen within ProRail.

Limitations of the case study

Secondly, only one case was studied to compare the data found in the interviews and to get a better understanding of a test process, because one test process is not the same as the next, studying more cases would have possible yielded a better picture of the course of a test. Two polar cases could have been studied to compare a test which was performed in a "bad" way and compare this to a test which was performed "good", in order to distinguish what would have made the difference in the course of the test.

Limitations of the scope

Thirdly, within the scope of this research only the test process and the test plan have been researched. Firstly, it might have proven fruitful to focus on other parts of improving the test process then just through planning. Although in this research organisational aspects seemed most important, technical aspects (execution) influence testing as well. Furthermore, a lot of information gathered on testing is also linked to the innovation development process, as they are both part of one process. Thus, the scope of the research might have been too narrow by just focussing on the test process and not the relation between testing and innovating.

9.2.4 Future research

As a last part of this discussion suggestions are given for future research on testing, but also on the innovation process in general. Suggestions one and two are closest related to the research performed and cover research on the test process. Suggestions three and four are related to research on the innovation process in general.

1. The use of technological readiness levels

In this research TRL's have been used to give more structure to the various test phases within the innovation process. The researcher believes the TRLs can improve communication between stakeholders for executing tests, help guide complex innovation development and distinguish testing activities. The TRL have been used to clarify the test phases found within the research in the test plan. However, no concrete research has been performed on the TRL's in this thesis, because within ProRail research is already being performed on the subject. It is advised that, once this research is matured, the findings are used to further optimize the test process.

2. Connection between ProRail central and ProRail regional

Within the interviews it was mentioned that there is a gap in communication and interests when performing tests between ProRail Central (Utrecht) and the regional departments of ProRail. Furthermore, the case showed that the infrastructure manager found it hard to initiate tests through ProRail central. Both are important to test innovations in the railway and it should be researched what this gap is and how this gap can be closed.

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3. The relation between innovation and testing and how this affects testing

The research has been focussed on only the test process. Throughout the literature, interviews and the workshop, it was found that testing is a part of the innovation development process, and barriers and fundamental aspects mentioned often overlap between these innovation and testing. Barriers such as money and time are considered to be more related to innovation development then the test itself. For instance, the time to test could be relatively short and the time in between tests were decisions need to be made can be relatively long. There is a relation where the innovation process influences the test process. Thus, future research could be performed to determine the relation between these two and how it affects testing.

4. Agile product development

From the literature, and an organisation interviewed, it was found that agile development is used to develop products in short sprints. This type of development can decrease development time, however, ProRail as a large organisation was not deemed ready for this method yet. Thus, future research can be performed on what agile product development is exactly and, if proven to have potential, examined as a possible way of testing innovations quicker.

9.3 Recommendations for ProRail

In this section recommendations are formulated which are derived from the conclusion and results of the research. A separation is made between long-term and short-term recommendations. For long-term and short-term recommendations first the most important recommendations are presented.

Short-term recommendations

The short-term recommendations focus on the use and the implementation of the test plan for the development of innovations.

1. Use and evaluate the test plan in a test and appoint one individual, per test, to guide this process

Based on the output of the workshop extra components were added to the test plan and feedback was given on the expected usability. It is therefore recommended that, within ProRail, the test plan is used in order to determine the further usability of the plan by having both ProRail and the provider set up the test plan. By walking through the test plan from top to bottom it can be determined what the output per component should be. By doing this with the stakeholders involved in the test, it can be assessed if all information can be gathered to plan the test. After testing feedback from the test plan if needed. The guiding text within the test plan and the flow chart in Figure 16 and Figure 15 provides an overview of the actions per component and output per test phase.

When using the test plan it is then recommended that one individual experienced in testing from ProRail is assigned per test(phase) to guide this process at first. This individual sets up the test plan together with the provider of the innovation and knows which expert and other stakeholders should be involved to execute the test. Throughout the research there has been discussion over who should fill in the various parts of the test plan. It showed that one individual should coordinate planning and guiding the test process as this will provide a contact point and project coordinator for the execution of test. This individual can communicate between the stakeholders involved to assess which information is needed to perform the test and has a general overview of the test plan is used as communication tool. By using the test plan to communicate over the planning of the test everybody involved can agree on its contents and thus how the test should be executed. This is important as the way the test is performed will also affect the results of the test.

Thus, three main points are recommended:

- Use the test plan in a test to evaluate the usability of the plan and ensure feedback is received to further alter the test plan if deemed needed based on the feedback received;
- While using the test plan assign one individual, experienced in testing, to plan and guide the whole test;
- Have this individual use the test plan as a communication tool over how the test should be planned and performed, between the stakeholders involved in the test.

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2. Implementation of the test plan in an existing innovation process

After the first use and evaluation of the test plan it is recommended that the test plan is implemented in an existing innovation development process. This way - regardless of where or with whom a test is initiated - the same structure can be used. This provides uniformity to the planning of tests and prevents individuals reinventing the test plan every time a test is started. The literature and empirical analysis showed that testing is part of the overall development process, thus once one comes to a point that a test should be performed one has a test plan ready to perform the test. The information up until the point of testing can then be used to plan the test. If the next steps in the development process are known a definite goal can be stated for the test. Standard formats for listing risks, demands and other aspects of testing can then be used to determine which information is needed to perform the test. Furthermore, if an innovation is provided of which a similar test has already been performed, it is possible to evaluate a previous test on how it was planned and executed based on the structure of the test plan. This gives the opportunity to accelerate new tests as there is information available on planning previous tests. The department of quality within asset management describes a process for product development were a test plan has not yet been defined. Thus, there is potential to implement a test plan for structured testing of innovations. However, this would also be possible in other development processes defined.

Long-term recommendations

The long-term recommendations focus on aspects to further improve the execution of tests, but are not directly linked to the design of the test plan

1. Provide guidance for parties who are new to testing in the railway

There are various providers of innovations. In the interviews a distinction was made between experienced and new providers. Although the test plan should have the same contents regardless of the experience of the providers, the new providers mentioned that they were surprised by the procedures of testing in the railway and the rules and regulations. They were unaware of how testing in the railway can be performed. For this reason, during the intake of the provider and the innovation it should be assessed how well acquainted the provider is with working in the railway. Might the provider be new to working in the railway an expert on the topic of the innovation is needed to guide the new parties when performing tests in the railway. This person needs to know which rules and regulations apply for the development of the specific innovation and can determine what are possible obstructions.

2. Making testing in the operational environment (the railway) more accessible

Testing in the operational railway system is considered the most representable to test the properties of the innovation out of the three phases distinguished. It is experienced by providers that, outside of a possession, there is no situation in which testing can be accommodated in the railway. It is often suggested that a separate railway should be built which simulates an operational environment. However, it can be argued if this would really simulate the real-life environment and market parties mentioned that they wouldn't test on such a track due to confidentiality of exposing the innovation. Furthermore, building a track is expensive. The test plan designed gives insight into all three phases of testing until the end of product development. By identifying the end goal of the test and the barriers and risks that could occur at this last phase one can assess if these barriers and risks can be mitigated in earlier testing phases. This way tests could more easily be performed in the operational environment, because by knowing which risks and barriers are mitigated in earlier phases, one can take this into account when planning future tests.

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10 Reflection

During my master thesis I have experienced a great learning curve in managing this project and creating a product. In this last chapter I will reflect on how I conducted this research and what went right or could be changed in the future. I will do this by reflecting on the desk study, used research methods and the outcome of this research.

The literature was gathered at the start of this research has only partly been used to conduct the research. Looking at the literature found a lot was focussed on innovation in general rather than testing. Which was needed to understand how testing relates to innovation but did not further contribute to the empirical part of the research. The most relevant insights were gained from the understanding of testing in the innovation development process and what testing and the planning of testing encompasses. These theories offered a substantial foundation to perform the empirical part of this research. Further research towards performing tests between public and private parties and in the railway sector would have strengthened the foundation to perform this research even more. Thus, I think some different literature could have been reviewed.

In order to answer the main research question, I have used three research methods: interviews, a case study and a workshop. The interviews and the workshop were an effective method to reach the target group of providers for this research, because they were cooperative when conducting both these research methods. Furthermore, the response from both these methods (especially the interviews) contributed greatly to the design of the test plan. The case study was used to compare the data found in the literature and the interviews to an executed test process and give more depth into how a real-life test is performed. This data was gathered via a document analysis. I think the case yielded interesting findings, however, more information could have been gained from the case if a different method would have been used then only a document analysis. The documentation in the case study was scattered and unstructured for somebody who was not involved in the test process. A different method to evaluate the case could have been used.

In order to improve the overall empirical analysis, I could have sought more guidance from both the company and the university in questioning if the research methods were correct for the goal which was to be achieved with these methods. Additionally, by putting more thought into the feedback on my research methods and consulting if different methods would be more appropriate. This could have improved the quality of the research by yielding more interesting results. By scheduling more frequent and consistent appointments and incorporating the readers in advance this feedback could have improved the research throughout my project. By scheduling deadlines in advance, I could have managed the planning of my research better and make iterations to change research methods.

I think the results of the research have yielded sufficient insights to recommend what should be done to further improve the test process and implement the test plan. The differentiation made over the test phases is not what I expected at the start of this research, were I expected to differentiate over a type of innovation or a type of provider. This shows that a lot of knowledge was gained from the research on how testing is performed in the Dutch railway sector. Looking at the research a lot of results and information was gained through the used research methods. However, this information could have been utilized more if I would have asked myself more frequently why certain results were found. In the research I was more focussed on how the results could be used to design a differentiated test plan.



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12 Appendices

- I. Appendix A Summary findings of the research
 - a. Summary of information from empirical analysis related to the reference framework.
- II. Appendix B Test plan V2
- III. Appendix C Literature study
- IV. Appendix D Empirical analysis interviews
- V. Appendix E Case study Happy Railing Schaarfence
- VI. Appendix F Evaluation test plan V1

Pro*R*ail

12.1 Appendix A

Items	Theory	Interview analysis	Case study analysis	Evaluation analysis
Innovation	The development and implementation of	Objective: To implement and apply the	Objective: Release of the innovation in the	-
definition	new ideas, products, processes or services	innovation in the railway and drive	railway.	
	(Van de Ven, 1986)	business with it and having an added		
		value.		
	In-house testing, beta testing, field	In-house testing, technical environment	Controlled environment and operational	In-house, controlled environment,
Development	(Cooper 2014)	and operational environment.	environment	operational environment.
Barriers	Risk & Safety, Rules & Regulations, Social	Lack of information, processes, rules and	A lot of risks, a lot of parties involved.	No specific barriers were mentioned or
	& Political, Equal treatment, Collaboration	regulations, existing specifications, decision	individuals with many questions, no	addressed.
		making, money, time to market,	project leader, transparency,	
		transparency, fear, controlled to	communication was tedious.	
		operational environment, scope,		
		location/placing, individuals.		
Testing	Operating a system or component under	Objective: Verification and validation,	-	-
definition	specified conditions, observing or	defining demands, gaining value.		
	recording the results, and making an			
	evaluation of some aspect of the system or			
	component (Radatz, Geraci, & Katki, 1990).			
Goal testing	Verification and validation, learning,	Verification and validation, defining what	Objective: permission for use and	All agreed that this was an important
	demonstration and certification (Tahera,	to verify or validate and gaining value.	evaluation of the functions of the	aspect. Was not specified what the goal
	2014).		innovation for release.	was.
Test plan	A blueprint for the test, describes how you	Test plan is a communication tool. It	A plan to verify and validate the product	Various definitions were found during the
definition	will go about testing the innovation. Serves	describes how the test is planned and gives	and a plan to evaluate the product.	workshop of a test plan.
	as a communication tool between	attention to all attributes needed to perform		
Test plan	Stakenolders.	a test.	See Table 12	Added; removal malfunctioning and
rest plan	test and not to test approach, pass/fail	runctions to test, execution of test, end	See Table 12.	maintenance Removed: Test regime and
components	criteria suspension criteria resumption	stakeholders role assignment testing		expected results
	requirements deliverables tasks	phase risks during tests specifications		expected results.
	environmental needs responsibilities	Go/no go_risks innovation_monitoring		
	staffing and training needs, schedule, risks			
	and contingencies, approvals.			
Planning	Figure 5, covers general decisions regarding	Demands, risks, stakeholders, experts,	Based on the demands, the RAMSHE	Continuous dialogue between the involved
strategy	test criteria and test methods in order to	location, Structure/work method, project	critiera and further risks and location.	parties is important.
(fundamental	derive and prioritize test activities during	leader, agreement, expectations.		- ·
aspects)	product development (Kukulies, Falk, &			
	Schmitt, 2016)			

